3rd World Irrigation Forum

1-7 September 2019, Bali, Indonesia

Full Papers of WIF3
and
International Workshops

Development for
Water, Food and Nutrition Security in a Competitive Environment

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INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE

COMMISSION INTERNATIONALE DES IRRIGATIONS ET DU DRAINAGE

3rd WIF 2019

Theme:
Development for Water, Food and Nutrition Security in a Competitive Environment

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Organized by:

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Ministry of Public Works and Housing
Directorate General of Water Resources
SDA Buiding, 8th Floor,Jalan Pattimura No. 20
Kebayoran Baru, Jakarta Selatan 12110
Republic of Indonesia

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The International Commission on Irrigation and Drainage (ICID), established in 1950 is the leading scientific, technical and not-for-profit Non-Governmental Organization (NGO). ICID, through its network of professionals spread across more than a hundred countries, has facilitated sharing of experiences and transfer of water management technology for over half-a-century. ICID supports capacity development, stimulates research and innovation and strives to promote policies and programs to enhance sustainable development of irrigated agriculture through a comprehensive water management framework.

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THIRD WORLD IRRIGATION FORUM

1-7 September 2019, Bali, Indonesia

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WELCOME

Dear Friends,

On behalf of the Indonesian National Committee of International Commission on Irrigation and Drainage (INACID), I would like to welcome all the members and distinguished participants of the 3rd World Irrigation Forum (WIF3), which will be followed by the 70th International Executive Council (IEC) Meeting to Bali, Indonesia. Indonesia has the distinguished honor of being a founder member country when ICID was established in the year 1950. We sincerely welcome you all again, for the 3rd time, after the 49th IEC at Sanur- Bali in 1998 and 61st IEC and 6th Asian Regional conference at Yogyakarta in 2010.

Indonesia is the largest archipelago in the world, consisting of about 17,541 islands. The territory of Indonesia is 5,2 million km2 with 1,9 million km2 of which is the mainland. However, “food security” remains a challenge for the burgeoning population of Indonesia. Given above, the Forum has come to Indonesia at right time to look for solutions to alleviate the food security. The main theme of the WIF3 “Development for water, food and nutrition security in a competitive environment” is very appropriate for exploring new innovative ways for better food security.

The venue of the event “Bali” is known for its picturesque landscape of paddy fields and rice terraces. The integrated rice-field irrigation system of Bali, Indonesia, called “Subak” has been known to the world for centuries. Bali possesses an important cultural historical heritage, including Subak Landscape of the Pakerisan watershed and the royal temple of the Taman Ayun that have been determined as the world cultural and natural heritage. There are also a vast number of Balinese performing art featured throughout the province including the classical Kecak dance, gamelan music and popular fire dance, not to mention the Endek Bali, a traditional heritage dress with unique pattern.

I believe that through this important event, we will be able to show you the whole set of our experiences in implementing the country’s development particularly in irrigation and drainage fields, and the water resources development in general. Therefore, it is a great honor for us to host this important Forum and welcome you to Bali. We shall render every effort to make the most of these events meaningful, enjoyable and memorable to the participants and their accompanying persons.

In closing, may I inform you that the people of Bali are looking forward to welcoming and embracing you and your family as part of our family, not only during the Forum, but also for the subsequent holiday enjoyments now and in the years to come.

Ir. Adang Saf Ahmad
President, INACID

FOREWORD

Dear Colleagues,

The current world population of 7.6 billion is expected to reach 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100, according to a new united nations report (2017). Most of the addition will be in developing countries, and the exponential growth in population would require doubling the current food production. Regionally, the population in Asia will nearly double to over 4 billion (47%) people in 2025. This has led the world, especially the Asian continent, face some serious challenges in water, food, and energy sector due to incessant growth of population, leading to environmental degradation and numerous other global issues which are simultaneously affecting our water resources development and management. Sustainable development as envisaged under ICID

Vision 2030, under limiting natural resources, calls for recognizing the interlinkages between various sectors. Given above, the main theme of the 3rd World Irrigation Forum (WIF3) is chosen as “Development for water, food and nutrition security in a competitive environment”, which is further divided into three subthemes.

A clear understanding of interlinkages such as nexus between water, food and energy (Sub theme 1 of the Forum) requires greater interaction between stakeholders from all the sectors (Sub theme 2 of the Forum) and generate a better understanding and coordination mechanisms among different disciplines. Such an approach can only improve the water and energy productivity in agriculture to ensure rural transformation (Sub theme 3 of the Forum). The third Forum will provide an opportunity for the actors in these sectors to come together and develop pathways to sustainable development.

The pre-Forum proceedings provide background papers on these Sub themes and abstracts of papers with an electronic version (USB) containing all full length papers. I am confident that this volume will help you in your active participation in various technical sessions of the Forum. Apart from the technical sessions, there would be fourteen Supporting Events organized by various international partners, a Ministerial and Senior Officers’ Roundtable and Farmers Roundtable, Six International workshops and Young professional training sessions. The International Exhibition along with the WIF3 is sure to provide a rich experience providing multi-disciplinary perspective.

We wish you all a successful Third World Irrigation Forum.

Eng. Felix B Reinders
President, ICID

PREFACE

Dear Colleagues,

The triennial World Irrigation Forum (WIF) aims to bring together all the stakeholders involved in agricultural water management at all levels, including the policy makers, experts, research institutions, non-governmental organizations and farmers. It provides a platform for the world irrigation community to find solutions to problems plaguing the irrigated agriculture, in time of depleting freshwater resources as a result of global warming and climate change.

Accordingly, WIF3, hosted by Indonesian National Committee of ICID (INACID) in cooperation with ICID is being organized in partnership with ADB, FAO, IWMI, World bank and many other International Partners during 1-7 September 2019 at Bali, Indonesia. The main theme of WIF3 is “Development for water, food and nutrition security in a competitive environment” with three Sub-themes as : 1. Enabling policy environment for water, food and energy; 2. Role of civil society and NGOs with focus on farmers and extension facilities; and 3. Improving agricultural water productivity with focus on rural transformation are part of this publication. Background papers were prepared by experts representing various stakeholders with a view to present the global perspectives on the above three sub-themes. My special thanks are due to Mr. Jelle Beekma (ADB), Dr. Olcay Unver (Vice-Chair, UN-Water, FAO) and Mr. IJsbrand H. de Jong (World Bank) and their teams for preparing these knowledge rich background papers. More than 300 abstracts were received on various sub-themes, which were reviewed and finally 191 papers have been incorporated in the Forum proceeding. These papers will be presented during the Forum in several parallel sessions and poster sessions and the issues emerging from the sub-themes would be discussed in the plenary session and presented as Forum statement during closing session of WIF3.

In order to facilitate the discussions during the various Forum sessions, this pre-Forum proceeding has been placed in your hands which includes the abstracts of all accepted papers/posters and a USB containing all the full length papers including the Background Papers of the sub-themes. Many other experts / professionals offered their valuable time at the request of the International Technical Advisory Committee (ITAC) to act as International Reviewers of more than 300 abstract received. My profuse thanks are due to each member of the International Review committee for their time and efforts in reviewing the abstracts/papers.

Besides deliberating on the technical papers presented, the Forum provides opportunity for participation of policy makers, planners, famers, youth and the industry. Accordingly the Forum includes a Ministerial and Senior Officers’ Roundtable and a Farmers’ Roundtable, YP Training, Supporting Events and International Exhibition.

Last but not the least, my special appreciation to the Central Office team consisting of Dr. Vijay K. Labhsetwar, as a Mentor, Er. B. A. Chivate Director (Tech), Mr. Madhu Mohanan, Communication Officer and Mr. Keshav Dev Tanwar, Assistant IT Officer and other supporting staff for their dedication in bringing this volume to you on time. My special thanks are also due to Dr. T. B. S. Rajput, an external expert, engaged in supporting the review process.

Er. A. B. Pandya
Secretary General, ICID

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World Irrigation Forum: A Platform for Stakeholders

The triennial World Irrigation Forum (WIF) aims to bring together all the stakeholders involved in irrigation of multi-disciplinary and all scales, including the policy makers, experts, research institutions, non-governmental organizations and farmers. It provide a platform for the world irrigation community and interested development professionals to find solutions to problems plaguing the irrigated agriculture, in time of depleting freshwater resources as a result of global warming and climate change. ICID provides a unique platform for multi-stakeholder in World Irrigation Forum (WIF) for sharing and learning by engaging in issues of interest at global level. WIF also gathers a wide range of experts from various fields to discuss important issues highlighted. The World Irrigation Forum stimulates and promotes multi- disciplinary discussions towards sustainable solution to water management in agriculture through:

- Exchange of latest irrigation and drainage policies, practices, innovations and technologies;
- Exploring and formulating concrete inter-disciplinary proposals;
- Development of liaison/ collaboration among various national / international institutions/ organizations/ private sector working for irrigated agriculture; and
- Advocacy for political commitments.

The First World Irrigation Forum (WIF1) took place in September 2013 at Mardin, Turkey on the theme “Irrigation and Drainage in a Changing World: Challenges and Opportunities for Global Food Security” and was attended by over 700 participants drawn from different disciplines including young scholars, farmers, academicians, researchers, international scientific community, engineers, industry and the irrigation managers.

The Second World Irrigation Forum (WIF2) was held from 6 to 8 November 2016 in Chiang Mai, Thailand. The theme of the Forum was “Water Management in a Changing World: Role of Irrigation for Sustainable Food Production”. The Forum was organized by the International Commission of Irrigation and Drainage (ICID) and the Thailand National ICID Committee (THAICID) in cooperation with a number of International and National Partners that brought together representatives of various stakeholders involved in irrigation of all types at all scales. About 1200 participants from 71 countries drawn from different disciplines including young scholars, farmers, academicians, researchers, international scientific community, engineers, industry and the irrigation managers. Summary Reports and other details are available at **https://www.icid.org/conf_wif.html**

THIRD WORLD IRRIGATION FORUM (WIF3)

Theme: Development for Water, Food and Nutrition Security in a Competitive Environment

Climate change and rapidly changing diet patterns are adversely affecting the water-energy-food (WEF) nexus and the natural resources that keep this nexus in a balanced state. Quantitative and qualitative uncertainties associated with precipitation further compound the problem and challenge both human intellect and resilience. The complete picture of climate change is yet to play out and this ambiguity is becoming a cause for serious concern in human communities. Global issues that have been discussed in scientific circles so far are now being reported in popular media almost on a daily basis, creating an anxiety in the masses. It seems it is not climate, but the rate of change that threatens the biological evolution. These issues need to be addressed with a higher level of commitment by all the stakeholders of the WEF framework.

Most experts believe that the global food demand will increase 50% from the current levels by 2030, while the land and water availability will either remain constant or may even dip. The situation is much more alarming in the densely-populated developing countries that rely heavily on rural livelihoods for employment generation and food security. Under such circumstances, the logical course of action would definitely begin with a multi-stakeholder communication, consultation and collaboration that can assess the possible future scenarios and potential options in various sectors, and then suggest a way forward for streamlining of policy, technology and financial linkages within the WEF framework.

Obviously, the role of policy making is central to all this as it would pave the way forward to financing of technology adoption by the players of production value chains. As the problem becomes more complex due to limited supply of natural resources, greater knowledge inputs at various stages of the value chain are necessary to make up for the reduced material inputs. “Produce More with Less” sums it up. Higher knowledge inputs require human capacity building at an unprecedented scale across the entire value chain. In this regard, the efforts of government agencies and the private sector need to be supplemented by civil society organizations and NGOs as they work closely with the workforce of any sector. Capacity building should not be limited to unskilled rural workers and farmers only, but at all levels starting from policy makers through their sensitization and awareness generation on global concerns to continuing education of research and extension workers for technology transfer from laboratories to the fields and regular training of skilled workers in various links of the value chain to ensure an all-round science uptake by the society and greater resilience against destructive forces of nature.

Following policy formulation, the next important aspect in this struggle would be technology development that focuses on productivity improvements for greater food and nutrition security. Agriculture sector is sometimes wrongly accused to be a water guzzler and it is time that this sector leads the way for other sectors by demonstrating how to fight climate change or to put it more positively how to befriend it. Many promising technologies for water conservation are available at various levels of implementation; however, their rural adoption may need creation of new business models. Affordability is key issue here. New techniques such as drip and sprinkler irrigation are showing good results with most crops in most countries, and are becoming more affordable with government support. Further research and development are still needed to mainstream such techniques for wider adoption at field level.

Last, but not the least, the financing mechanisms needed for policy translation into action and technology facilitation at the last mile cannot be ignored. Public-Private-People (PPP) partnerships based on a solid foundation of transparent and fair-for-all understanding will potentially lead to realization of larger objectives of global food and nutritional security.

Considering the above, it is hoped that WIF3 deliberations will lead to a clear understanding of the burning issues as well as practical action on the ground. Role of various stakeholders of the production value chains will also be better understood.

Given above, papers were invited and discussed under the following Sub-themes:

Sub-Theme 1. Enabling Policy Environment for Water, Food and Energy Security

Topics

1.1 Sustainable water Resources management policy; integration of surface water and groundwater to ensure water sustainability for environment and ecosystem, to support water, food, and energy security.

1.2 Sustainable development of small and large scale irrigation system, lowland development and management for food security policy within the framework of global climate change, land consolidation management, and land conversion protection.

1.3 Improvement of irrigation water productivity policy including efficient and effective water use, financing aspect, incentive and disincentive system, capacity building including non-state actors, Utilize SMART irrigation management.

Sub-Theme 2. Role of Civil Society and Non-State Actors with Focus on Farmers and Extension Facilities

Topics

2.1 Performance of public irrigation extension services in strengthening the irrigation management institutions

2.2 The potential roles of non-government organizations, including private sector (NGOs) and civil societies in irrigated agriculture extension and advisory services including improvement of farmers livelihood (i.e. agricultural input, post-harvest technology, market chain, agro-based industry)

2.3 Promoting public-private-partnership and participation of WUA in the irrigation development and management for irrigation sustainability (i.e. to improve water efficiency and to reduce water conflict).

Sub-Theme 3. Improving Agricultural Water Productivity with Focus on Rural Transformation

Topics

3.1 Utilizing Information Communication Technology (ICT) and innovations for Improving water productivity and maximizing agriculture production including smallholder farmers and indigenous people;

3.2 Optimizing value of water through integrated farming and market driven agriculture (i.e. labour per m^3, revenue per m^3, nutrition per m^3 etc), enhancing value chain of irrigation water to promote social economic community transformation (i.e. multifunction use of irrigation water, etc.).

3.3 Financial scheme and access development for improving agricultural water productivity in alleviating poverty in rural area.

BACKGROUND PAPERS

SUB-THEME 1
Enabling Policy Environment for Water, Food and Energy Security

Jelle Beekma (Philippines), Jeremy Bird (UK), Adey Nigatu Mershaihe (The Netherlands), Stijn Reinhard (The Netherlands), Sanmugam A. Prathapar (Phillipines), Golam Rasul (Nepal), Jeffrey Richey (USA), Jouke Van Campen (The Netherlands), Raqab Ragab,(UK), Chris Perry (UK), Rabi Mohtar (Lebanon), Laurie Tollefson (Canada), and Fuqiang Tian (China)

SUB-THEME 2

Role of Civil Society and Non-State Actors with Focus on Farmers and Extension Facilities

Olcay Unver (FAO), Melvyn Kay (UK), Konda Chavva (FAO), and Amali Abraham Amali (Germany)

SUB-THEME 3

Improving Agricultural Water Productivity with Focus on Rural Transformation

IJsbrand H de Jong (World Bank), Eman Ragab Nofal (Egypt), Klaus Röttcher (Germany), Narges Zohrabi (Iran), Patel Neelam (India), Sigit Supadmo Arif (Indonesia), K Yella Reddy (India), Paavan Kumar Reddy Gollapalli (India)

Background Paper – Sub-Theme 1

ENABLING POLICY ENVIRONMENT FOR WATER, FOOD AND ENERGY SECURITY

ABSTRACT

This paper focuses on sub-theme one: An Enabling Policy Environment for Water, Food and Energy Security. It discusses water food and energy (WFE) security and their interrelations as the background for policy discourse and introduces the WFE nexus and its quantification by modelling as one of the tools for developing a broader approach to resources management.

The complexity of water, food and energy security is analysed mainly from the perspective of (i) water and food and (ii) water and energy and their interconnectivity. We focus ultimately on water as a primary input into processes and analysis since this is the entry point for participants of the Third World Irrigation Forum. Other interrelations will also be touched upon but not analysed in-depth.

The paper first provides a general overview of trends in water, food and energy security, then highlights the inter connectivity between the various elements. This is followed by the introduction of the WFE nexus as a potential analysis tool for improving productivity per unit of resource (water as well as energy) and a basis for improving sector policies including avoiding unintended consequences on other sectors. Invariably, if one of element of the nexus is optimized, there will be trade-offs in the other elements; the challenge is to find combinations of measures that have a net positive outcome. In order to quantify security in the three elements and the trade-offs between them, emerging modelling approaches for the nexus are discussed.

Sub-themes two and three of the irrigation forum are closely connected with the nexus. In our paper we firstly discuss the various technology interventions focusing on agricultural water use which has potential to also improve other nexus outcomes. This is directly related to sub-theme three. Stakeholder interaction, the focus of sub theme two, is essential to contextualise the trade-offs and provide guidance for policy development. The combination of modelling, technology innovations and stakeholder participation should ideally lead to better understanding of linkages and more robust policies for water, food and energy security. Challenges and success and failure of various policies for WFE security are analysed and reviewed and subsequently used to derive recommendations for an enabling policy environment.

1. WATER, FOOD AND ENERGY (WFE) SECURITY – THE BASIS OF LIFE AND SOCIO-ECONOMIC DEVELOPMENT

Food and water are essential elements for human existence and, together with energy, are important for economic growth, poverty reduction and social development. Adequate access to these resources and their sustainable management through preserving the ecosystems that support them are the basis for human well-being, socio-economic development, all in a climate of peace and political stability, (UN Water, 2013). The world is facing an increasing challenge of water, food and energy security both for those currently with limited or no access, as well as those yet to be born. There is already an imbalance between demand and availability leaving millions of people with shortages of one or more of these vital resources (FAO/IFAD/UNICEF/WFP/WHO, 2017).

The interrelations between water, food and energy are many. In order to systematically frame discussions in the sub-theme, the most recent definitions for food, water and energy security are used and a compound definition for all three is proposed for guidance of the forum discussions.

For food security, we use the definition as part of sustainable development goal (SDG) 2: zero hunger which reads: ensure that everyone everywhere has enough good-quality food to lead a healthy life (UN, 2015). Water security is defined by Grey at al. (2013) as: the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable and tolerable level of water-related risks to people. For energy security the definition of IEA (2019) is used: the uninterrupted availability of energy sources at an affordable price[1].

Using these individual definitions, the proposed compound definition for water, food and energy security is: everyone, everywhere has enough good quality food, access to sufficient water of acceptable quality for health, livelihoods, production and ecosystems while having uninterrupted availability of energy sources at an affordable price coupled with acceptable level of water risk and energy failures.

1.1 Consequences of growth on food, water and energy security

Against these aspirations, the demand for water, food and energy is continually increasing due to rapid population and economic growth in combination with accelerated urbanization and changing lifestyles. It is estimated that by 2030 the global population will need at least 40 percent more water, 35 percent more food and 50 percent more energy (UN, 2014). The world's population is projected to continue growing with approximately 83 million more people being added annually (Gerland et al., 2014; United Nations, 2015) leading to a global population of nearly 10 billion people by 2050.

1.2 Food security

By 2050, the Food and Agricultural Organization (FAO) predicts an increase of global food demand of 70 percent (FAOstat, 2009; World Bank, 2007).Meeting the demand for food in a sufficient quantity and acceptable nutritious quality underlines the importance of greater efficiencies in agricultural production systems globally. The number of hungry people has been growing during the last three years despite an earlier steady decreasing trend and now amounts to more than 800 million people back to levels of almost a decade ago. This demonstrates the severity of the challenge(FAO, IFAD, UNICEF, WFP and WHO. 2018). These are not just theoretical concepts. The UN sustainable development goals report (UN, 2018) showed food insecurity is on the rise with the proportion of under nourished people worldwide increased from 10.6 per cent in 2015 to 11.0 per cent in 2016. The rise is attributed to conflicts however it also indicates the fragile status of food security. In 2017, 151 million children under age 5 suffered from stunting (low height for their age), while 51 million suffered from wasting (low weight for height), and 38 million were overweight.

Further pressures on food systems will arise from an overall increase in incomes globally with past trends showing changes in dietary habits requiring higher quality food and increased reliance on animal protein (FAOstat, 2009). The rapid rise in milk production in India and meat production in China demonstrate this trend and led to significant increases in agricultural water demand (Thakur et al., 2018, Zhou et al., 2016). In contrast, there is an emerging awareness of the consequences of high meat-based diets on resource use and the environment more generally, but at present and without major changes in perceptions on diet, this is not yet at a scale needed to offset increased resource demand.

1 https://www.iea.org/topics/energysecurity/whatisenergysecurity/

1.3 Water security

Global water demand, in terms of fresh water withdrawals, is predicted to grow by about 55 percent by 2050 (United Nations, 2016).In 2025, over 40 percent of the global population is projected to be prone to severe water stress. The number of people affected by water shortages has increased over time (Kummu et al., 2010) and, under current development paradigms, this situation can be expected to increase in future due to population pressure, higher welfare, and increasing climate variability (Gosling and Arnell, 2016,United Nations, 2016).

According to the sustainable development goals report 2018 (UN, 2018) water insecurity remains high and accelerated progress is needed to meet the SDG targets for SDG 6.1, water supply and sanitation, for SDG 6.4 on water use efficiency and for SDG 6.5 on water resources management. For example, 30% of people lack safe water supply (844 million people lack basic water supply facilities and 1.5 billion people have only basic water supply), and only 39% of the 84 countries monitored in 2015, had safe sanitation facilities, 29% had basic facilities and 2.3 billion people lacked even basic facilities. In the least developed countries, only 27% have basic hand washing facilities. In 2014 water stress was above 70% in 22 countries in Northern Africa, Western Asia and Central and Southern Asia. In 2017 progress in water resources management on average over 157 countries was 48%, ranging from 10% to 100%. The difference in progress was not clearly related to the region or level of development. In the future variability in water supply and risks of drought and floods are expected to increase while at the same time overall competition for water will increase.

1.4 Energy security

Global energy demand is projected to rise by 25% until 2040 (IEA, 2019). Although considerable progress has been made in electrification, still just under 1 billion people are without electricity. The provision of total clean energy lags far behind. For example, the SDG goals report of 2018 indicates that in 2016, around 2.8 billion people still used solid fuels with inefficient stoves, leading to high levels of household air pollution. It also states that if current trends continue, 2.3 billion people will continue to use highly polluting traditional cooking methods in 2030 with negative health consequences. Energy insecurity is likely to continue to constrain human development and local economic development in many locations.

1.5 Recognizing interconnectivity

In assessing water use and availability, particularly across sectors, it is important to distinguish between consumption and withdrawals as they are not the same. Consumption is defined as the conversion of water from its liquid state to a vapor[2] state, either by agriculture through crop evapotranspiration, evaporation from water and land surfaces, incorporated into products or crops, or consumed directly by humans or livestock (USGS, 2014). Whereas a significant fraction of withdrawn water is generally returned to storage in water bodies or aquifers. For example, in Pakistan the total withdrawal in the Indus Basin Irrigation System is 136 billion cubic meter (BCM), but only 82 BCM of this amount is consumed (World Bank, 2019). The quality of the returned water is affected by its use and recycling for safe re-use downstream can require special attention and incur treatment costs.

Water for food. Over 70% of global freshwater withdrawals is used for food production (Hoekstra and Mekonnen, 2012, D'Odorico et al 2019). Water for food production, including crops and

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2 For simplicity, here we assume that the water converted to vapor by evapo-transpiration is "lost" to the atmosphere. Within greenhouses this water can be recycled, (see section 4).

livestock, accounts for about 92% of the total societal water 'consumption' (Hoekstra and Mekonnen, 2012). The importance of water in agriculture is apparent as irrigation contributes to about 40 percent of the world's food production from approximately 20 percent of all agricultural land (FAO, 2018).

Water for energy. Water is needed for the main processes in the energy sector, from energy extraction, electricity generation, refining and processing. Currently, energy withdrawals amount about 10% of the total water withdrawals globally (IEA, 2016), while the global water consumption for energy is 4.7% (Hoekstra and Mekonnen, 2012). Water withdrawals for energy production in some parts of the world can be much higher and account for up to 49 percent of all water withdrawals (Kearney at al. 2014). Based on estimates in 2010, approximately 75 percent of the total industrial water withdrawals are used for energy production (WWAP, 2014)..

The picture on water consumption and withdrawal for energy is mixed. In some cases, it is expected that withdrawals for energy will increase much less than consumption because of a switch to more sophisticated cooling technologies that withdraw less but consume more water.The future water needs for energy production and conversion are likely to increase further because of increased use of unconventional energy generation, such as shale gas, shale oil and oil sands, these require greater amounts of water (Rosa et al., 2018). Similarly, demand will increase through the wider uptake of biofuel energy production as alternatives to existing fossil fuels. In contrast, the expansion of solar and wind power will demand less water. Overall, it is projected that by 2035, water withdrawals by the energy sector could rise by 2 percent to 400 BCM and consumption by 60 percent to 75 BCM(EIA, 2018). Even where water use in energy is non-consumptive, there is modification of return flows, higher temperatures in case of cooling water and changes in river hydrology, water quality and ecosystems for hydropower. Uncertainty of water availability for the energy sector is already evident in some places. For instance, a coal-fired power plant was shut down in India due to water shortage (IEA, 2015) and in California electricity generators needed to negotiate a reduction in domestic water supply to maintain adequate availability of cooling water (Keulertz et al. 2018).

Water for energy and food. Hydropower generation is a clear energy-water-food-environment connectivity case. Many hydropower projects have multiple uses including irrigation and flood management leading to tensions in operating rules of the reservoirs due to different priorities. But even single purpose hydropower projects have cross-sectoral implications. For example, evaporation from hydropower reservoirs have a global water consumption of 5.41 m^3/ MWh (Mannan et al. 2018). They can influence the pattern of downstream flows having consequences for both food production, for example in Central Asia where hydropower peak demand is in the winter, while irrigation needs are in the summer, and impact the environment both locally and beyond due to changes in river flows, habitat change and blockage of fish migration routes. Another such case is reported by Rosa et al. (2018) where in south Texas, shale oil and gas extraction, using hydraulic fracturing, have to compete for water with agriculture.

Agriculture and land for energy and water: Agriculture has a dual role as an energy user and as an energy supplier in the form of bioenergy. Over 1% of crops produced is utilised within the bioenergy sector (Garcia, 2016). Sustainable agricultural practices can also save energy, for example, by reducing the use of energy-intensive fertilizers. Agriculture and food production have a further impact on the water sector through their effects on land condition, runoff, groundwater discharge, water quality, and availability of water and land for other purposes, such as natural habitat (Alauddin and Quiggin 2008). Climate policies, globally, can lead to an increased demand of biofuel (Mercure et al., 2019). The biofuels industry is rapidly expanding leading to the increasing diversion of crop supply towards the production of bioethanol and biodiesel, mainly maize in the United States, sugarcane in Brazil, rapeseed in Europe, and oil palm in Indonesia and Malaysia, (e.g., Rulli et al., 2016). Since the demand for energy can be partially met by biofuels, if this approach expands significantly, energy and food production will increasingly compete for water, challenging our ability to produce sufficient food and fibre on limited land and with diminishing mineral nutrients and water. Water use for fuel extraction from, for example, corn ethanol is 25.8 m^3/MWh which is more than 50 times higher than for the least efficient conventional source, coal (Mannan et al. 2018).

Agriculture, water and the environment: Over-abstraction from surface water affects the minimum environmental /ecological flow that is required to maintain ecosystem services, water quality, fish communities and leisure. The use of agrochemicals such as fertilizers, herbicides and pesticides affect the environment including water quality. Vörösmarty et al., (2010) found that 65% of global river discharge, and the aquatic habitat supported by this water, is under moderate to high threat. All these dimensions come together in the Aral Sea basin where the Lake Aral recession has largely been due to unsustainable expansion of irrigation abstractions to achieve national production targets of cotton and wheat, much of it pumped to considerable heights using subsidized electricity, (Micklin, 2010, Bhaduri et al., 2015). Although full restoration of the Aral Sea is no longer considered feasible due to the high volumes of water needed and consequences this would have on economies and rural communities (Micklin, 2014)considerable improvements are thought possible as shown by Djumaboev et al. (2019) who found that by better irrigation scheduling alone, more than 575 million cubic meter and 259 KWh can be saved.

Energy for food and water: Energy is required for food production, transportation, processing, packaging, and for water supply, including extraction, purification, and distribution of water (Nonhebel 2005; Bazilian etal.2011). The global food system is dependent on fertilizer production, for example half of the energy used for nonorganic bread production in the UK is used for the production of nitrogen-based fertilizer inputs (Mannan et al, 2018). Agriculture production is increasingly dependent on energy, principally on oil and natural gas, due to ever increasing mechanization, intensification and increasing reliance on agro-chemicals. Groundwater irrigation is more energy intensive than surface water irrigation and about 8% of all energy generated is utilised for the pumping and treatment of water (Hoff, 2011). Demand of energy for transporting, processing and refining water, particularly in desalinization and wastewater treatment, is very high. The food production and supply chain alone accounts for over 30 percent of total global energy consumption, mainly depending on fossil fuels as its source currently (FAO, 2011). Given the fluctuating energy prices, unreliability of fossil fuel supply, and increasing concern on greenhouse gas (GHG) emissions, there is concern on the ability of the food sector in its current state to meet global demands while minimizing adverse environmental impacts, (FAO, 2011).

According to Lillie (2015) and Mannan et al. (2018), about 10% of the United States of America (USA)energy consumption or 2,283 Gigawatt-hour (GWh), is used in agriculture. Of this energy use, 21% or 479.4 GWh is used for crop cultivation, including fertilizer and pesticide production, and fuel for field preparation and harvesting, another 14% (319.6 GWh) is used for transportation of the produce, 11-16% for food processing and 50% for food handling, such as packaging, services and sales.

Energy used in irrigation depends strongly on the local conditions and irrigation method. For example, Daccache et al (2014) show that that Spain ranks highest in the Mediterranean region in terms of energy demand for irrigation (>774 GWh) followed by Turkey (570 GWh) and Syria (529 GWh), even though irrigation water demand in Spain is 8 BCM, compared with more than 10 BCM in Turkey and Syria with more than 10 BCM.

Energy for water supply and sanitation: Pumping of water from the source and for distribution in water supply networks is needed. Energy is also needed for treatment of raw water to potable standard and the treatment of wastewater. The entire process is energy intensive, for example the USA consumes about 4% of the total energy production in water supply and sanitation (Copeland and Carter, 2017 in Mamman et al. 2018).For countries dependent to some degree on desalinising seawater for their water supply, energy requirements are much higher, for example in the Persian/Arabian Gulf countries (Keulertz et al. 2018).

Increasing stress on water resources and the multiple and complex interrelations between food, water and energy security are summarised in the previous paragraphs. Climate change adds to uncertainty and further complicates resource management and allocation. Limited guidance exists on how to potentially plan for the climate uncertainty although some examples are emerging, e.g. the recent National Water Initiative of Australia (2017) and the Netherlands Delta programme (2019).

The linkages outlined above demonstrate the need for effective management tools such as data and information, policies, and institutions that are able to recognize and systematically address competing pressures on the resource.

2. CONTEXT: WATER, FOOD AND ENERGY SECURITY WITHIN THE BROADER DEVELOPMENT AGENDA – ADOPTING A NEXUS PERSPECTIVE?

2.1 Need for a broader perspective

Meeting each of the sectoral SDG[3] goals for water, food and energy is already a major challenge in many countries. Lack of an integrating resource management framework, exacerbates this challenge through the risk of inefficient use of resources. The prevailing sectoral approach to planning of energy, food and water often takes place in the absence of meaningful consideration across sectors. For years, sector analysts have emphasized the need to increase productivity, boost production and reduce waste as solutions to meet pressing global challenges of increased demand. However, it is increasingly recognized that the challenges are far more complex than simply producing more food or energy because of increasing resource constraints and interconnectivity of sectors, the levels of stress on environment and ecosystems, and the consequences of carbon emissions.

These inter-sectoral considerations are very evident at a local scale and are recognized by researchers and practitioners supporting the delivery of development services at community level. Ostrom (2010) found multiple cases where local resource users had successfully self-organised resources management. Based upon her findings she elaborated attributes of the Social-Ecological Systems (SES) that determine the success of self-organisation: e.g. the number of users, the size and predictability of the resource system. Hence, the Ostrom (2010) model explains what seems evident at community scale, appears to get lost and subdivided when one moves up to district, provincial and state levels of administration.

Ideally, greater competition for water will stimulate more economically efficient use of water and facilitate allocation towards the most appropriate use (though as Ostrom's insights on the tragedy of the commons reveals, this "efficient" reallocation of the scarce resource requires both constraints to access and mechanisms to facilitate reallocation). Such institutional, regulatory and physical systems however take time to develop and respond to increased scarcity. Short term perspectives that protect the status quo often prevail due to political expedience: limiting

[3] SDGs 2, 6, 7, 11 and 13 explicitly link to the Nexus and consequences of decisions made will influence Goals 14 and 15.

access to existing water users, for example, does not win many votes. Political decisions can also have unintended consequences, for example in India and Pakistan where energy is subsidised as part of their rural income policies. Ringler et al., 2013, show that the poor benefit least from energy subsidies and they lead to over-extraction of groundwater, excessive water use, and a misallocation of water. In 1988, the Gujarat Electricity Board changed from metered to flat tariffs, making the marginal cost of electricity for tube-well owners zero. Farmers overused energy and water, leading to lowering groundwater tables and over-usage of the power grid, leading to unreliable supply of electricity both on the farms, but also in villages and for rural industry (Shah and Verma, 2008; Shah et al., 2008).

More recent subsidies for solar irrigation systems as part of government carbon mitigation programs are expected to exacerbate over-pumping of groundwater because the marginal cost of pumping will essentially be zero (Shah 2018). This demonstrates how subsidies designed to address problems in one sector can have unintended consequences in other sectors—in this case, aggravating environmental degradation. In Egypt, the Government increased its food subsidy allocation by 20% in May 2016 to mitigate the impact of the rising inflation due to the devaluation of the currency. Currently, 67 million citizens (out of a total population of 92 million) benefit from the food subsidy system. Such subsidies may be important politically, but do not encourage efficiency of resource use (Reinhard et al., 2017).

The ways that water is consumed by society have rarely been shaped by awareness of their scarcity or their value (Allan et al., 2015). Water governance and water pricing are ideally deployed to ensure productive and efficient water use and equitable water distribution. Competition inevitably increases from water users that generate more welfare (e.g. income) with their water use (Scott et al., 2015; Hellegers et al., 2008); e.g. people in municipalities are able to pay far more for the use of water than subsistence farmers can.

The challenge, therefore, remains how to achieve a balance between using the water resource to meet growing and competing demands of food, water and energy security, meeting a nation's development aspirations and while at the same time ensuring the integrity of ecosystems and tackling the challenges of climate change and increased variability.

2.2 Introducing the Food, Water and Energy Nexus

Recognizing the urgent need for efficient use of the existing limited or declining natural resources base to achieve sustainable development goals, the global community has turned its attention to the concept of the water, food and energy nexus. A number of international forums have been promoting a comprehensive approach to food, water, and energy security, the major ones being the World Economic Forum and the Bonn Nexus Conference, both in 2011. These have been followed by coverage of nexus thinking in several regional conferences, research programs as well as knowledge products of practitioners, for example the analysis of water use in the energy sector by BP (Williams and Simmons, 2010) and of interconnectivity between water and energy in China by the Asian Development Bank (Perera and Zhong, 2017). One representation of the WFE nexus is given in Figure 1 by Rasul (2014).

The nexus approach is based on a system-wide thinking for the sustainable use and management of interlinking resources and processes within water food and energy systems. It is aimed at providing tools to assess the use of a broader set of resources than conventionally has been the case as well as managing the inevitable trade-offs and exploring synergies for planning of sustainable adaptation responses (Bazilian et al., 2011; Hermann et al., 2012; Prasad, Stone, Hughes, & Stewart, 2012; Rasul & Sharma, 2016).

Policy recommendations from the Bonn 2011 conference assessed implications for all sectors including agricultural and irrigation, by emphasizing the need to enhance policy coherence, produce more with less, promote natural infrastructure and increase stakeholder participation. Focussing[6] on the nexus aims to provide an evidence base of approaches and solutions to meet the challenge of a future with limited natural resources. In agricultural water management it places the challenge on improving (crop) water productivity across levels from field level to river basin incorporating energy implications and exploring the multi-functionality of irrigation systems.

By comprehending the complexity of the interconnections among dimensions of the WFE nexus and addressing the trade-offs, a long-term, concerted and sustained strategy can be developed and applied to address issues associated with resource security (Rasul and Sharma, 2015; Al-Saidi and Elagib, 2017; D'Odorico et al., 2019). The nexus can also stimulate innovation and use of new technologies as discussed in section 4.

Achieving synergies and win-wins is not easy and most cases involve trade-offs between sectors. Adopting good practice in one sector can though lead to benefits in others. For example, well-established improvements in agronomic, land management and water management practices can lead to reductions in both water use and energy consumption. These include land preparation techniques, soil conservation practices and pressurized irrigation systems. The question though remains as to whether there are sufficient incentives, including price signals, for farmers to adopt such practices.

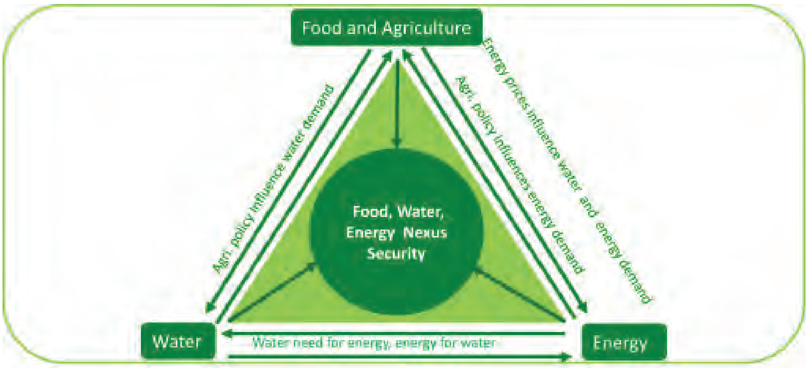

Figure 1. Dynamic relationship among food, water and energy security

2.3 Challenges inherent in adopting an integrated approach

A word of caution about 'integrated' and 'nexus' approaches is also needed to avoid the impression that there is a panacea out there that can solve the world's water, food and energy security challenges by adopting a different approach. There is a risk that 'the nexus' becomes an end in itself rather than a means to recognise these critical challenges. Perry argues that water, food security and energy are three separate policy areas that interact with each other in unpredictable ways and require differing approaches to address their differing challenges (perscomm, 2019). In the case of water, if governments fail to restrict currently excessive demand through an orderly, managed process, the unavoidable outcome will be "chaotic disallocation" of water from irrigated agriculture as aquifers become unusable and rivers run dry. Failure by governments to manage water most commonly involves either allowing farmers to access water at the expense of unacceptable environmental damage (which is commonly the case for surface water) or failing to regulate access (which is commonly the case with

[4] https://www.water-energy-food.org/fileadmin/user_upload/files/documents/bonn2011_policyrecommendations.pdf

groundwater). Severe depletion of aquifers leads to irreversible changes to the quality of water in the aquifer and the capacity of the aquifer to accept recharge due to subsidence. There are high risks of salinization due to upcoming of saline water and there is a risk that wells will go dry, or will become too deep for economic exploitation; downstream users from rivers, including for domestic and commercial use will increasingly frequently find the river is dry or too saline for use. This ‘disallocation’ of water first affects the environment and then irrigated agriculture. These processes will not be orderly, or prioritised. There is no way to predict whether the most or least productive farmers will suffer—but all farmers will grow more risk-averse and less willing to invest in highly productive agriculture as uncertainty begins to dominate their access to water.

This perspective demonstrates the complexities of overcoming a lack of institutional commitment to address issues of over-abstraction and at the same time reinforces the need for a different approach, where solutions in one sector do not exacerbate insecurity in another and where the trade-offs discussions look for synergies. In cases where resources are not constrained, then single sector solutions may suffice, although still cost-savings may be apparent by taking a broader perspective.

2.4 Competition for water as a scarce good

Scarcity by definition refers to conditions when demand for water is higher than that of supply. IWMI highlighted the global distribution of water scarcity and distinguished between physical scarcity, economic scarcity and institutional scarcity in their comprehensive assessment of water management in agriculture (Molden, 2007). Globally, there is no clear evidence to suggest an absolute scarcity of land-water-energy (LWE) resources. The impacts from LWE bottlenecks, however, vary significantly spatially and temporally. Therefore, the main issue is having the resources at the right time in the right place (OECD 2017), which is a major component of water security. The Asian Water Development Outlook (ADB, 2016) provides a periodic water security assessment in five dimensions, rural, economic, urban, environmental and disaster risk and resilience for 49 countries in Asia and the Pacific as a tool to track water security over time.

As an indication of the scale of the problem, Wada and Bierkens (2014) identified regions where current water use is not sustainable and thus future water security is compromised, because the rate of ground water abstraction exceeds replenishment (see Figure 2b).

The World Resources Institute (WRI) indicated the regions with increased water scarcity in the future based upon the Aqueduct database (Gassert et al., 2014), see Legend: Projected change in water stress (Change from baseline to 2040 business as usual).

Figure 3 in the regions with increased future water scarcity current levels of water use will have to be reduced by more efficient water management practices.

2.5 Linkage to the ICID discourse

The International Commission on Irrigation and Drainage (ICID) is working collectively towards a common goal of realizing a more integrated and holistic approach to water resources management. Among the number of existing WFE nexus frameworks, the ICID strategy for implementing the Vision for Water for Food considers the approach from FAO (2014) as appropriate to harness the food, water, energy systems in the agricultural sector (ICID, 2017). This framework describes nexus interactions as how we use and manage resource systems as well as explore interdependencies, trade-offs and synergies pertaining to water, energy and food. It mainly focuses on the biophysical and socio-economic resources base on which we rely to sustain life and achieve socio-economic development goals.

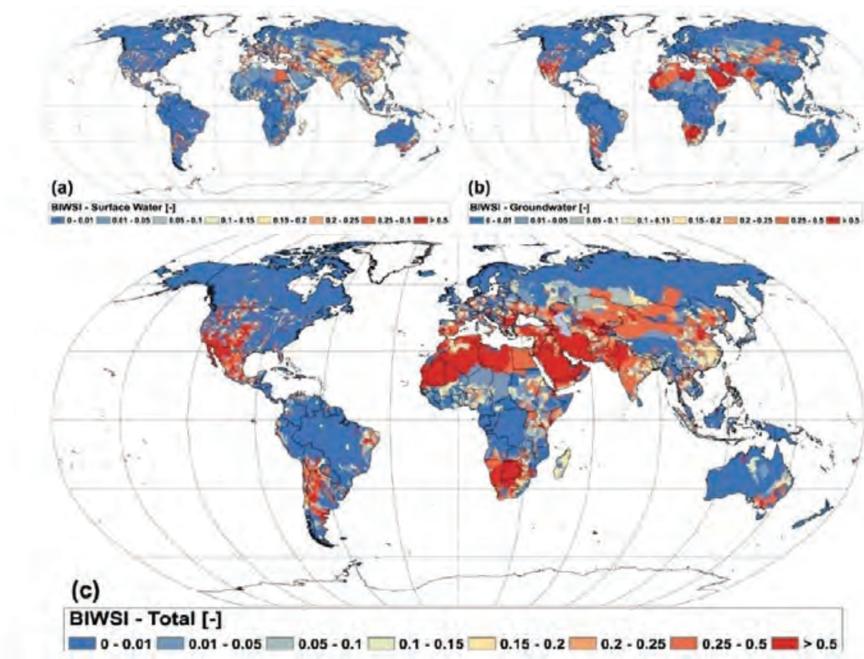

Figure 2. Global maps of historical blue water sustainability indicator (BlWSI) (dimensionless) for (a) surface water, (b) groundwater, and (c) the total at a sub-basin scale (except the Antarctica and Greenland) (1960–2010). The sub-basin dataset was obtained from the FAO AQUASTAT database (www.fao.org/nr/water/aquastat/main/index.stm) that used the HydroSHEDS (http://worldwildlife.org/pages/hydrosheds) to derive the sub-basins. (source Wada and Bierkens, 2014)

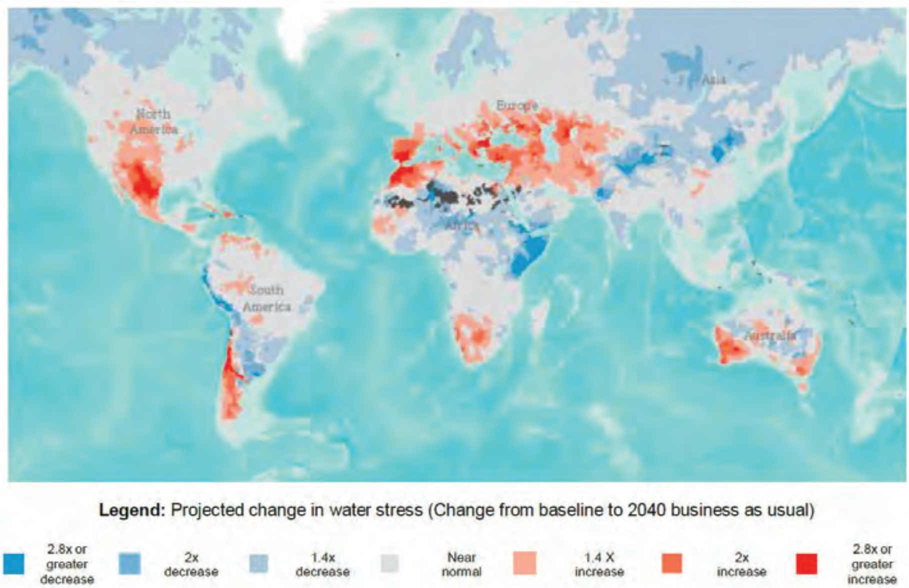

Figure 3. Future areas of increased water stress (Source: WRI 2015)

Submitted papers for sub-theme 1 of the Forum include those dealing with innovations for improving irrigation and agricultural productivity, including smart and high technology approaches, and aspects of the circular economy and sustainability focusing on re-use and reductions in impacts on water quality. Beyond this sector focus, there are a number of papers dealing with modelling the broader nexus dimensions and monitoring nexus outcomes.

3. UNLOCKING THE NEXUS – FRAMING OF AN ANALYTIC APPROACH

3.1 Call for a frame work within which alternative development decisions can be evaluated

The Nexus approach to decision making encourages decisions on one sector to take into account other sectors or internalize the externalities to the extent possible. Decisions on water would then require the inclusion of effects on food and energy – are they positive, negative or neutral? The decision-space would then expand depending on the level of cross-sectoral influence and the search for trade-offs. Beyond that, more creative thinking is encouraged to move towards 'nexus-positive' outcomes where actions in one sector have a mutually beneficial outcome in other sectors.

The task of finding win-win solutions is complicated though by quite different and separate institutional frameworks and planning processes in the main water, food and energy sectors. For example, the agricultural sector is dominated by rural politics in areas and the need to keep basic food products within the affordability of both urban and rural communities. Energy security is national commitment central to economic and industrial growth, but often follows quite different planning processes and timescales to food and water. In many cases, it is a regulated private sector arrangement where developers respond to market signals for the provision of a new power station. Private sector processes make it more complex to factor in planning considerations for other predominately public sector services and has to be done through regulatory signals and in the upstream framing of projects.

Such an integrated approach is neither new, even for the nexus topics of water, food and energy, nor are they restricted to these in a narrow sense, (Woltjer et al, 2019). Burnett et al. (2018) distinguish three types of dependencies between them: (i) direct dependencies, (ii) direct competition, and (iii) externalities. Direct dependencies and direct competition gain most attention in nexus research, mainly when analysed from a physical perspective. Externalities are often difficult to physically quantify, and even more difficult to monetize (Burnett et al., 2018).

The comparison of inter-linked outcomes across three or more different sectors becomes difficult to manage and although conventional cost-benefit analysis can provide an insight into the viability of any outcome, more nuanced indicators are needed to distinguish between them and the degree that overall development objectives are being met. The search for an all-embracing single 'nexus indicator is challenging due to the multiple dimensions involved and indeed it may not be possible to end up with a single measure. Some suggestions include a monetary measure or one that focuses on efficiency of resource use. So far, the authors are not aware of a satisfactory approach to nexus indicators. This challenge recently faced the Asian Development Bank which having embraced the concept of the nexus in its recent Strategy 2030[5],raised the question on how to measure the Bank's effectiveness in influencing outcomes.

[5] https://www.adb.org/sites/default/files/institutional-document/435391/strategy-2030-brochure.pdf

It is in general difficult to measure marginal external costs and assessing the effects of several domains in one integrated analysis would inevitably include uncertainties and ambiguities. Stirling (2015) warned that the power dynamics related to individual decisions might seek to understate complexity, neglect uncertainty, deny ambiguity and suppress dissent. Currently the research discussion is predominantly based on availability or scarcity of resources and projected costs and benefits in related sectors, but a reality test is also needed taking into account the practicalities of implementing potential solutions within prevailing institutional and governance systems. Many earlier attempts at greater integration across sectors have been successful at policy level only to fail in implementation (Giordano and Shah, 2014). Rasul et al. (2019) show that in many instances, there is a lack of policy coherence across sectors as well. For example, India has a policy to double agricultural production and thereby rural incomes by 2030 and provides subsidies on agricultural inputs including energy which leads to excessive pumping and use of groundwater, at the same time the water policy promotes water use efficiency and the energy policy emphasizes cost recovery and pricing as a demand management instruments. An important conclusion by Ostrom (2010) is that there is not a general governance system that can be applied to all situations.

Although most research has been devoted to quantifying the nexus (Keulertz et al. 2018) there are only limited examples of the results of such a quantification. In this paper we argue that due to the complexity of quantifying direct dependencies, direct competition and externalities, models are required to assess potential trade-offs at local scale. Such an approach could provide quantifiable indicators for progress monitoring, and also inform stakeholder engagement by focusing on localised solutions on the basis of physically quantifiable information and indicators. The SIM4NEXUS project aims to predict society-wide impacts of resource use and relevant policies on sectors such as agriculture, water, biodiversity and ecosystem services through a model-based analysis (e.g. serious gaming)[6].

3.2 Examples of potential decision support tools – using models to provide a window on the consequences and benefits of alternative actions

Despite the progress in recent years, there remain many challenges in scientific research on the WEF nexus, while implementation as a management tool is just beginning. The scientific challenges are primarily related to data, information and knowledge gaps in our understanding of the WEF inter-linkages (Liu et al. 2017).Furthermore, despite the nexus literature identifying some barriers to achieving coherence it does not clearly explain why the barriers are present, what influences them, and how they can be acted upon. These gaps disconnect the nexus literature from the governance processes it ultimately seeks to influence (Weitz et al. 2017).

3.2.1 Modelling approach

Enabling a robust policy environment for water, food and energy (WFE) security requires the capability of combining detailed knowledge of the physical and transactional dynamics within or between sectors with the requirements of multiple stakeholders. Brazilian et. al. (2011) suggest that robust analytical tools harnessing existing data, can advance scientific understanding in WFE systems and make an analytical resource accessible to a range of end-users, particularly in regions with limited data availability and computing resources. Communication and collaboration are key components for successfully managing shocks in the WFE nexus space by bridging the disconnect between knowledge producers and users (Buizeretal., 2012; Mohtar and Lawford, 2016) as well as the disconnect between communication of uncertainty and the risk at local, national, and international scales (Howarth

[6] www.simnexus.eu

and Monasterolo, 2016). Andrienko et al. (2007) highlight the need for new computational tools that can translate between the complex space-based resource management problems and the physical boundary spanning nature of human decision-making on resource problems. A cloud-based cyber infrastructure comprised of "modules" linking the water, food and energy water systems would provide such a decision-support toolset. The overall Nexus toolset is then represented by the coupling between the models.

The overarching concept of dynamic modelling for an effective decision information framework can be addressed with the specific models mentioned within this section or other modelling toolsets with equivalent capacity and functionality. To be effective, the processes and data required have to be of sufficient resolution to accurately and robustly address the problem. The lack of data and knowledge of cross-sector understanding have long been considered an impediment to the implementation of such models. But the advent of not only advanced informatics technology and data from multiple sources greatly increases the power of the nexus models. Information products that use remote sensing and advanced models to interpolate field observations provide invaluable input data. The challenge, though, is how to mobilize all that data into useful products across the nexus. Here we represent examples of contemporary models that combine to form the modules addressing nexus issues.

3.2.2 Individual components

Starting with water resources, as the central thread across all sectors, the responsibility of a water module includes overall water accounting and the water footprint by determining the mass of water entering and exiting the river network of the basin of interest. Different models available within the water module may have differing capabilities, e.g. capturing different hydrologic processes, servicing agriculture, performing additional processing, or producing different resolutions of output but all versions within the water module must provide the water mass output. The energy module relies on this to determine the supply of water available for hydro-power generation and the cropping model relies on this to determine water available for either rainfed or irrigated agricultural conditions. The water module needs to be represented by a spatially explicit model of sufficient resolution to capture basin processes relevant to the decision maker. Open-source, large scale hydrological modes can be used to quantify regional energy and water balances. For example, such models as VIC, CLM, NOAH, Water GAP and their brethren use the high-resolution climate forcing, soil and vegetation information that is now available.

Spatially explicit hydrology models do not usually represent human impacts from energy (i.e. hydropower) or agriculture explicitly, but instead couple to other offline models to simulate these impacts. This approach does not account for the dynamic interaction between the energy, agriculture, and water systems. For example, the energy model EAGERS (see below) provides such coupling to manage reservoir nodes based on a cost-optimization function. Most hydrology models do not explicitly represent groundwater, instead baseflow is produced through the bottom soil moisture layer. A model such as the Simple Groundwater Model (SIMGM) by Niu et al. (2007) is implemented in some hydrologic models to represent an unconfined aquifer layer at base of the soil column. While progress is being made to better represent groundwater in standard hydrology models, it currently remains best represented with separate groundwater models.

3.3.3 Linking models

A priority in capturing the coupled human/natural system dynamics is through quantification of explicit linkages between the basin agricultural practices and the hydrologic cycle (as represented by a hydrology model). The examples given in this section are not intended to be exhaustive, but rather provide a window on some of the current possibilities. A cropping systems model can serve as the corner stone of a high-fidelity food module. Such a model, for example the Cropyst model (Stockle et al., 2003), should be a multi-year model capable of simulating soil water budgets, nutrient budgets (e.g., nitrogen and phosphorus), carbon cycling, crop grow than yield, residue production, and soil erosion at a combination of hourly and daily time intervals.

The explicit linkages between the land use practices and the hydrologic systems have been well established by prior efforts coupling cropping and hydrology models, for example CropSyst with the Variable Infiltration Capacity (VIC) hydrology model, termed VIC-CropSyst (Maleketal.,2017b) or Saltmed (Raqab, 2015). The coupling uses the hydrology model to compute natural water availability in the form of soil moisture and precipitation, while the cropping model determines yield, biomass, transpiration, irrigation water demand, leaf area index, and plant water uptake by soil layer.

An energy sector module is needed to capture the energy consumption of buildings, industry, and transportation, while being sensitive to energy market prices at the regional boundary and direct or indirect linkages with the food and water sectors. The highest fidelity version of an energy module captures direct linkages with the food module through the energy consumption of industrial fertilizer production, refrigerated food storage, and retail food outlets. Indirect linkages to food arise through the electric demands of the irrigation and water storage infrastructure operations in support of crop production, a coupled dynamic captured within an integrated decision information framework combining modelling modules for food, energy, and water. An additional linkage with agriculture, relevant to particular basins, is the production of supplemental biofuel and biogas. Models are available for modelling transport costs of various options based on prevailing fuel costs. Electrification of the transport sector would be a major change, particularly in relation to air quality and carbon emissions

The EAGERS energy module is an example that captures the direct linkage of water runoff and baseflow from the hydrologic modelling as part of a larger simulation of the regional electric network (McLartyetal, inreview). EAGERS co-optimize the management of hydroelectric generators and water reservoirs by computing an hourly resolved receding horizon control solution for the energy generation and storage systems. In an unperturbed simulation this solution represents the optimal management strategy for the maximum economic output of the reservoir system for electricity production. Management practicalities are introduced through system-wide and reservoir specific constraints for flood control capacity, agricultural diversions, or treaty requirements. The constrained optimization efficiently computes the Pareto horizon of management decisions which illustrates the trade-off potential between different basin priorities.

Harou et al. studied how optimization could be an effective response to prolonged severe drought (2010). Using a hydro-economic model covering the entire water supply system of California, they minimized state-wide costs from water scarcity and water operations by allocating, storing and trading water throughout the network. This kind of model is useful to determine how much the water system could be able to cope with droughts and provide insights regarding institutional instruments and water policy management. Under the Future DAMS research project, modellers are using river basin simulation across multiple scenarios and metrics to explore the trade-offs involved in setting and revising reservoir operating rules The trade-offs of alternative development scenarios are presented through innovative visualisation of the results demonstrating the trends for downstream environmental flows, energy generated and financial benefits. It extends conventional planning modelling through its ability to represent many more dimensions of the river basin with energy generation models (Geressu and Harou, 2019).

As an example of applying more broadly defined models, Amjath- Babu et al. (2019) aimed to quantify the benefits of proposed water resource development projects in the Koshi basin, a transboundary subbasin of the Ganges basin (with 4 storage and 7 run-of-the-river hydropower dams) in terms of hydroelectric power generation, crop production and flood damage reduction. A hydro-economic model was constructed by soft coupling hydrological and crop growth simulation models to an economic optimization model. The model assessed the potential of the interventions to break the vicious cycle of poverty and water, food, and energy insecurity. Unlike previous studies, the model (a) incorporated the possibility of using hydropower to pump groundwater for irrigation as well as flood regulation and (b) quantified the resilience of the estimated benefits under future climate scenarios from downscaled general circulation models affecting both river flows and crop growth. The results showed significant potential economic benefits generated from electricity production, increased agricultural production, and flood damage control at the transboundary basin scale.

WEAP (Water Evaluation and Planning System) and LEAP (Long Range Alternatives Planning System) are also software packages developed by the Stockholm Environment Institute (SEI). These tools have been applied in different parts of the world for scenario based evaluation of policy measures for water resources and energy development. These models have been applied separately per their respective designed purpose, however, the models were integrated recently to become 'WEAP-LEAP.' The integrated WEAP-LEAP model can now be applied for water-energy related scenarios evaluation by alternating parameters resulting in different outputs, such as energy generated (hydropower) or water requirements for cooling (Dargin et al., 2019, SEI, 2013, SEI, 2014)

4. Improving the Productivity of The Resource: Examples of Technology, Policy and Governance Interventions

Given the focus of WIF3, in this chapter we focus on innovations in the agricultural production dimension of the nexus, in its broadest sense such as water and energy use for food crops, fodder, biomass, and aquaculture rather than the water supply or energy production dimensions.

4.1 Water productivity

Irrigation efficiency has for a long time been a measure used to help gauge the effectiveness of irrigation and is used to help define irrigation performance at various levels of the system (Ahadi et al 2013). Various definitions of irrigation efficiency have been developed and used (Israelsen 1944, Jensen 1967, Bos 1985, etc.). However, water productivity in kg/m3 or $/m3, depending on the prevailing development objective and degree of water scarcity, is preferred as this links the production (or benefits) to the water consumption. This is an indicator for the efficiency of actual water use as it links the consumption of water to the crop production or the economic returns. For pressurised systems and through fertilizer efficiency gains it also links to energy usage. It can be used for crop and location specific assessments, (Giordiano et al. 2017). The advent of more cheaply available satellite imagery with a higher resolution and wider spectral coverage, has led to remote sensing systems for assessing water productivity at field scale[7].

The productivity of water in irrigation increases with the adoption of precision technologies such as variable rate irrigation, lower energy irrigation, drip irrigation, irrigation scheduling, fertigation, and chemigation (Tollefson 2018). In Canada current research focuses on eefficiency measures along the entire agrifood chain to help save energy and water and

7 http://www.fao.org/in-action/remote-sensing-for-water-productivity/overview/about-the-programme/en/

motivate farmers to invest in their systems to ensure optimal returns from their investment, while also addressing environmental impacts of greenhouse gas emissions. Institutional approaches include the participatory approach, water pricing, training and educational opportunities.

4.2 Innovative technological applications for addressing WFE Nexus challenges

A whole range of technical and management interventions that have been characterized as ‘good practice’ or ‘sustainable water management’ are available, many of which will be featured at the Forum. These include technologies and management practices that are either well-established in some locations and are available to transfer elsewhere or have shown promising results in pilot testing. For example, improving water use productivity by using suitable and efficient irrigation systems, e.g. subsurface drip, low level sprayer sprinkler, using renewable energy for the required pressure (e.g. solar energy, wind energy or potential energy to pressurize drip and sprinkler systems in the form of reservoirs at a higher elevation, directly connected to the pressurized system).

4.2.1 Reducing field applications through improved water management in the root zone

More efficient application of water for irrigated crops requires energy to pressurise the water delivery system. Energy gains can be obtained through using alternative energy sources to build the pressure, or by reducing the water application. An estimate of water needs at different times of the season and crop growth is needed and conventionally water application has been based on current methods of calculating the crop irrigation water requirements based on equations fed by meteorological data. New technologies such as the Scintillo meters as well as the Eddy Covariance measure actual evaporation values that represent the real crop need for water. Results of Water4Crops project in Southern Europe[8], showed significant reduction of actual crop water requirement differences when compared with the present practice. On average, obtaining a better understanding of the actual crop water requirement based on the modern technologies could save at least 50% of irrigation water for this region (Ragab et al., 2017a).

Another new technology to determine the crop water requirement through real time continuous soil moisture content and deficit is the COSMOS. The method is based on the use of natural atmospheric cosmic rays, which are non-invasive, non-destructive, and can sense soil moisture for an area of 300 to 700 meters radius. It was tested in the Water4Crops project. The results (Ragab et al., 2017b) showed that soil moisture values obtained by COSMOS were comparable with measured values for the top 0-60 cm. The COSMOS technology provides continuous, integrated, area-based values and solves the problem of spatial variability and can be used to determine when and how much to irrigate to avoid harmful water stress.

These new technologies when accompanied by an efficient irrigation strategy such as Partial Root Drying Method, (PRD) and subsurface drip irrigation has the potential to save even more water, and importantly reduce energy use. The results of the application of only PRD on corn, potato and tomato were water saving with higher productivity and water use efficiency compared to surface drip and sprinkler systems alone without improved soil moisture measurement.

A word of caution is needed. There are limits to the increase of water productivity in open air. When all circumstances are close to ideal (e.g. rootzone nutrition, aeration and absence of pests), water consumption and productivity are almost linearly related and higher production

[8] www.water4crops.org,

leads to higher consumption. Limiting water supply to the exact crop need, or even belowit will, in the absence of sufficient precipitation, lead to salinization of the rootzone as the salts present in the irrigation water need to be leached and a rootzone salt balance maintained. The limiting of water supply in traditionally irrigated areas may also lead to falling water tables and drying of rivers due to reduced percolation. The basin or (sub)-catchment water balance needs to be considered in any move towards efficiency and productivity gains.

4.3 Greenhouse cultivation and optimizing circular use of inputs.

The emerging technology of greenhouse horticulture completely rethinks irrigated agriculture systems and has the potential to radically reduce crop water demand, particularly in arid countries. The reduction of water (irrigation) and energy (pumping) inputs to produce food is a clear nexus case, but potentially comes at a threat to water quality in drainage water released into surface water bodies or groundwater. This can partially be offset by better fertilization providing the exact amounts crops need and introducing recapturing systems for the used chemicals.

In open fields, sensors assist the farmers on when to irrigate and case studies have shown that the introduction of innovative technologies may raise water use efficiency by up to 60% while maintaining existing crop yields[9]. The use of fertilizers may be reduced by up to 30%, which reduces costs and limits high concentrations in the environment. Yields often increase due to the new water management system and growers might use this extra income for investment in new technologies.

WUR Greenhouse Horticulture has studied, developed, and made applicable numerous innovations in the field of energy conservation and novel energy conversion techniques. Proven examples are greenhouse covering materials that keep a good transparency while improving insulation and development of improved strategies for using thermal screens to save energy without the risk of problems with pests and diseases. New fossil fuel free greenhouse designs are made and tested for the future.

Internationally these topics were addressed in the EU project EUPHOROS[10] aimed at developing a sustainable greenhouse system that does not need any fossil energy and minimizes carbon footprint of equipment; has no waste of water nor emission of fertilizers and full recycling of the substrate; has a minimal need of plant protective chemicals yet has high productivity and resource use efficiency.

In research in Riyadh where the conventional water use for tomato production is around 300-400 liters per kilogram of tomato, this has been reduced to only 50 litres per kilogram using mid-level technology and only 4 liters per kilogram using high technology solutions

Seawater Greenhouses (Davies, P and C. Paton, 2005) can be used to desalinate seawater without external energy inputs. Seawater is also let into a greenhouse and subsequently evaporated by solar heating and condensed to produce fresh water. The remaining humidified air can be expelled from the greenhouse and used to improve growing conditions for outdoor plants orthe water could also be condensed and circulated for re-use.

In places where the available water is not fit for irrigation or human consumption because of salinity and/or other chemical pollutants, the application of SolarDew systems can be considered. SolarDew systems are a purely solar driven membrane distillation systems

9 https://www.wur.nl/nl/show/FlowAid-2.htm.

10 https://www.wur.nl/en/Research-Results/Projects-and-programmes/Euphoros.htm

consisting of a membrane unit in the form of a “plastic bag” in a housing. Such systems can be installed on the roof of a greenhouse for which they also serve as cooling unit. Of the source water that flows into the system, 10% - 20% flows out as brine and the remaining 80-90% is pure water fit for irrigation. The daily production, depending on the solar radiation, is around 8 litre of pure water/day/m² or 8 mm. Cost are between €0.01 and €0.02/litre mainly because of the costs of the membrane units that have to be replaced ever 3-4 years. (www.solardew.com)

Other promising initiatives are in the use of the potential energy of water in irrigation systems to electrify off-grid and remote villages. Techniques have been developed to develop easily installed portable turbines, adapted to variable flows, requiring limited head loss and with minimal interference with the flow systems in small canals. Such systems have been successfully applied to electrify remote villages and are a good example of a positive water, food and energy nexus[11] (www.heliosaltas.com/how-micro-hydro-can-aid-farmers-in-developing-countries)

Having dramatically increased food production potential since the 1970’s when the limits to growth dominated the development paradigm entirely new possibilities have risen. For example, in 2013 global deaths from obesity with 3 million were three times higher than deaths from hunger (Lancet, 18 December in Harari 2016). The above examples of further improving productivity of water, recycling water and nutrients in greenhouses, desalinizing water using solar energy (due to the conservative nature of salts like NaCl, such salts tend to accumulate during the re-use cycle of circular use) and using potential energy of water in a much wider range than reservoirs for generating power, are all elements of a more circular economy. Circular economy and its underlying principles form a new paradigm in our strive for development and sustainability, get rapidly more attention and provide new positive challenges for further development and progress (e.g. Raworth, 2017, Vanham et al. 2017).

4.4 Policy Instruments for managing WFE Nexus challenges

Using the nexus approach to improve trade-offs requires a major shift in the decision-making process towards taking a holistic view and integrated approach, as well as developing institutional mechanisms to coordinate the actions of diverse actors and strengthen complementarities and synergies among the three sectors. Both regulatory and market-based instruments need to be aligned to incentivize nexus-positive activities. Below a policy framework is introduced following Figure 4.

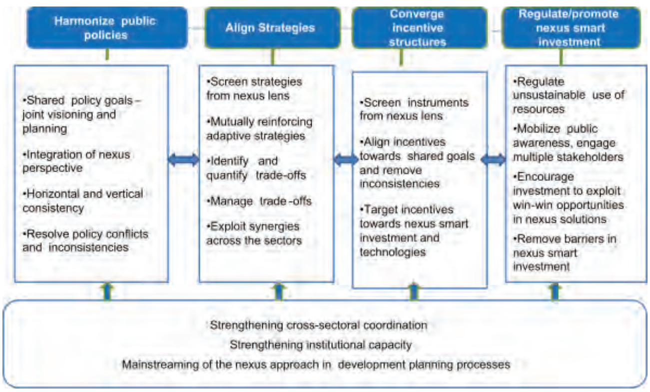

Figure 4. Policy framework for managing the WFE nexus (after Ghulam Rasul, 2018)

8 https://www.heliosaltas.com/how-micro-hydro-can-aid-farmers-in-developing-countries/

4.4.1 Regulatory measures.

Monitoring groundwater use using remote sensing chips. Groundwater is over extracted in many areas of the world (Shah et al., 2003, Feng et al., 2008), for instance, parts of India, where the government has recently initiated an innovative approach to monitor and measure extraction of groundwater through remote sensor chips installed in new solar water pumps (Gupta, 2019). Installing level sensor in pumps, which automatically stops pumping water when the water levels drops below a certain limit, or implementing policies where farmers have to pay for groundwater extracted by the unit, would be helpful in managing ground water over extraction (Gupta, 2019).

4.4.2 Market based instrument.

Given the limitation of regulatory measures, many market-based innovations are introduced to manage water-agriculture-energy nexus.

Water buybacks. Water withdrawal has been increasing for consumptive uses, and with it, so has the demand to conserve water for maintaining environmental flows. Market based instruments are used in several developed countries where water rights are purchased (buyback) to meet the environmental demands. Water buyback is practiced in Australia's Murray–Darling Basin (MDB), Klamath Basin of southern Oregon and northern California, USA, and the Murcia Plateau, in the south-eastern Segura basin of Spain (Garrick et al., 2009). The Murcia Plateau suffers severe overdraft of the aquifer and Spanish water authorities have implemented buyback of groundwater rights to reduce groundwater abstraction (Calatrava & Martínez-Granados, 2018). Though costly, potential benefits of this market-based approach are considerable in addressing environmental purposes.

Electricity pricing and metering: Subsidized and unmetered tariff of electricity supply to agriculture has led to an excessive energy and ground water use in many countries, but a better quality of power supply and metering in combination with increased unit pricing, can conserve groundwater (Bassi, 2014; Kumar, 2016). In the 1980s in the Barind region of Bangladesh, farmers with few resources were only able to grow a single crop and had no access to groundwater. Technological advances have opened possibilities for conjunctive use of water, even for those without their own wells. A pre-paid meter with Smart Cards and installation of underground plastic pipes has changed irrigated agriculture. Introduction of pre-paid meters and Smart Cards has reduced the disparity among the farmers within the irrigation schemes and encouraged timely water supplies and timely repairs. Command area increased by 22%.(Zaman, 2013).Comparable practices are now widely adapted in new irrigation projects funded by the Asian Development Bank in the Eastern Gangetic Basin. The State government of West Bengal in India has initiated tariff reform in agriculture by installing meters on all its new electric irrigation pump-sets and changed from a flat tariff per user to a consumption-based tariff.

Solar pumping program. As ground water irrigation has become crucial for ensuring food production in many parts of the word, particularly in South Asia, supplying energy for pumping ground water has become an integral component of food-energy-water nexus. Solar-based power options, have been tried in different parts of the world as an alternative mechanism for supplying water for irrigation. In India, solar pumping was stimulated by subsidizing part of capital cost to farmers. Studies indicate that solar pumps have led to increased crop productivity in some areas and reduced electricity and diesel consumption, however, it has also increased the extraction of ground water in some areas (Gupta, 2019). Inspired by the success of solar pump irrigation, the state government of Maharashtra adopted a new approach – the Solar Agricultural Feeder, under which farmers can export surplus electricity generated by solar pump to the State electricity grid, which is expected to contribute further in meeting electricity needs of Indian agriculture. Similar arrangements have been trialled in Gujarat involving cooperatives of solar producing farmers as an intermediary institution. The resulting incentive framework has had impressive results in curbing water use and providing an additional source of income for farmers while maintaining agricultural production levels (Shah et al. 2017). However, these findings are challenged and Sahasranaman et al (2018), argue rather the opposite. They state that on the basis of empirical data that solar photo voltaic systems for well irrigation are economically unviable, and that high subsidies for such systems combined with higher feed-in-tariff for the electricity produced than the market price would distort energy markets and incentivise farmers to pump excess groundwater that might be used for water-inefficient crops or sell the excess water for a profit.

4.5 Policy interventions- incentives to address the competing environment

Best results in the complex food water energy trade-offs require us to abandon silo thinking and vested interests (Ringler et al., 2013). At the same time, the dominance of sector based planning systems is likely to continue and so a compromise is needed where strengthening resilience of the water sector means better coordination and integration with other sectors' activities and plans, including the agriculture, energy, urban and trade sectors, each of which depends on and/or affects water resources. Hence all water measures need to be aligned to the extent possible with other sectoral plans, strategies, policies and measures (Reinhard et al., 2017). The main issues in the nexus are not so much 'technical'; they are largely institutional. It is necessary to take into account political and market forces in the form of subsidies, profit seeking and state agendas (Allen and Matthews, 2016; p87). An important institutional pre-condition to make nexus solutions work is the political will in the respective country to coordinate and cooperate across sectors, ministries and authorities (ACCWaM,2017). The nexus is useful framing within which to develop policies, strategies and investments to exploit synergies and mitigate trade-offs among development goals, with interactive participation by and among governmental agencies, the private sector, academia and civil society (Dodds and Bartram, 2016). Below some suggestions are given for using a nexus perspective to inform policy development.

4.5.1 Invest strategically for managing water, food and energy security.

It is necessary to make investments in strategic areas which can contribute to a combination of food, water and energy (Pardoe et al., 2018). Development of multi-purpose dams is a nexus example and can generate hydropower, provide water for irrigation, flood management, domestic and other competitive uses (Pardoe et al., 2018; Rasul et al., 2019). For instance, the Durance–Verdon Rivers multipurpose program, besides generating 6.5 billion kWh hydropower per year, also supplies water for drinking, agriculture, industry and provides tourism services around the reservoirs, which contributes to the region's business activities and attractiveness. Flexibility in operation is needed as the importance and priority of different reservoir uses has changed over time. (Branche, 2016).

4.5.2 Internalise external effects

The water, energy and food nexus is dominated by market mechanisms and supply value chains that are not yet equipped to expose the environmental and social risks associated with the otherwise rather effective market systems that produce and provide foods and services. (Allan et al, 2015). Market signals and the reporting and accounting systems that track them are dangerously partial and blind to the values of water and they do not capture the costs of mismanaging them (Allan et al., 2015). It is necessary to quantify external effects, make them transparent and develop policies such as water pricing to internalise external effects. It is primarily the role of governments to ensure that the price mechanism works properly and to correct distortions in the pricing systems regarding freshwater, climate change and natural resource depletion (van Meijl et al., 2017). The farmer or farm household is the decision maker at lower spatial level and decisions are based on the resources at the farm taking into account the trade-offs and synergies. The farmer (entrepreneur) makes integrated decisions if he receives the correct (price)signals.

4.5.3 Create incentives

Given that agriculture and nature will be competing more for water resources in the future, policy interventions should align to this development (Ringler et al., 2013). Shifting taxation to natural resources to reflect the scarcity value and to emissions in order to promote sustainability is one approach. This would strengthen implementation of the 'polluter pays' principle within the market mechanism, creating suitable incentives to substitute resources and induce innovation. Policy interventions can similarly aim to create incentives for firms to increase and steer their innovation capacity towards developments that have positive, or at least neutral, nexus outcomes.

4.5.5 Promote a circular economy

Increasing efficiency and re-use of water for irrigation has considerable potential as discussed in section 4.3. Extending that concept to the re-use and recycling of waste for energy or for use as an organic fertilizer offers similar positive nexus outcomes such as reduced pollution of natural resources and need for expensive treatment costs, the foregone energy and water costs of producing energy and fertilizer that is displaced by reusing waste products, and reduced energy and emissions embedded in transport. A recent review of more than 150 business cases for nutrient, energy and water re-use demonstrates the significant potential that can be harnessed providing there is an openness for cross-sectoral cooperation from early stages of planning (Otoo and Drechsel, 2018).

4.5.5 Stimulate development of an overarching research framework

Discussion of the WFE nexus in practical terms is still in its infancy and there is a need to stimulate further understanding of the nature and extent of interactions. Research is needed to further develop the modelling tools and indicators necessary to describe the trade-offs between socio-economic outcomes and resource sustainability. More insights into system interactions at different spatial levels and the likely responses of agents to market and policy incentives are necessary for coherent policy analysis. Ultimately, this understanding will help (i) reduce trade-offs, (ii) build synergies and (iii) improve governance across sectors. Dealing with increasing complexity comes at a cost and there is therefore a need for careful cost–benefit assessment of the right strategy to design capacity development for the nexus in relation to its effectiveness and efficiency at improving outcomes (Bhaduri et al., 2015).

5. CONCLUSIONS AND FUTURE OUTLOOK

5.1 Concerted effort is required within each sector to address the intensifying challenges of water of water, food and energy security

Meeting the needs of the hundreds of million people who are already water, food and energy insecure as well as the rapidly increasing demands of an increasing global population with higher expectations for their standard of living, remains a key challenge. Recent progress on implementing the Sustainable Development Goals demonstrates the depth and breadth of the challenge and it is not yet clear that the necessary levels of priority have been assigned to deliver on these goals by 2030. Limits of resource availability in many parts of the world are being reached, stressing ecosystems beyond the point of providing healthy water resources. This in turn has negative consequences for the poor, who cannot afford alternative sources of supply, for the environment where degradation can take decades to recover, and for the economy due to lost opportunities for growth and the cost of water treatment and new source development. There is however room for optimism in terms of innovations available. Policy-makers will need to take a longer-term horizon to benefit from such sustainable solutions.

5.2 There is a growing body of promising innovations to address insecurity

This background paper and related submissions under this sub-theme of the Forum highlight some of the technological and management innovations that are addressing the scarcity challenge. The WFE security challenge fosters creativity and opens opportunities that were earlier not thought possible. Consider for example the advances in crop breeding decades ago by Norman Borlaug that led to the green revolution. Similarly, a range of agronomic and water management innovations possible now in laboratory and pilot trials that promote resource efficiency, adopt concepts of a more circular economy, and reduce externalities, are likely to be available for more widespread adoption in the coming years. The pace of change and underlying investments needs to keep up with the scale of new demand.

5.3 There is growing awareness of the inter-connectivity between sector interventions and trade-offs for resource management

International focus on the WFE Nexus as well as the expected consequences of climate change has brought inter connectivity into sharper focus. Policy incoherence between sectors or between larger national objectives of food security and poverty reduction and sector policies aiming at sustainability can have negative impacts. As water resources come under greater pressure, the nexus is useful for raising awareness of a broader approach to seeking solutions, focussing on synergistic outcomes with multiple benefits (nexus positive outcomes) and minimizing perverse interventions that can have unintended and adverse consequences for another sector (nexus negative outcomes). Trade-offs are inevitable in resource-constrained situations and a new set of support tools and monitoring metrics are required to simulate the consequence of alternative developments choices across a wider set of variables.

5.4 New modelling approaches are being developed to simulate cross-sectoral consequences of alternative development choices in support of decision-making

Existing modelling approaches focus and optimize sectoral interests, whether it be the water balance of a river basin, the provision of food to meet national food security targets or the least cost supply of energy. A new set of modelling tools is being developed that combines elements from the sectoral models and permits a far higher number of development options to be investigated. They aim to produce information on the consequences of a particular development intervention across the WFE nexus space. Their application maysupport decisions to improve coherence of policies and lead to informed and locally appropriate decisions by the prevailing governance structures responsible for individual sectors.

5.5 From research frameworks to improved policy direction and incentives for change

Currently nexus analysis is still largely confined to the academic community. Progress needs to be made to involve planning and finance ministries by demonstrating the resource implications of a more joined-up approach. The nexus is a tool for helping to define an overall development trajectory and understanding the implicit trade-offs within which individual sectors can then develop sectoral policy interventions and incentivize sustainable behaviour. If the right policy and regulatory conditions exist for valuing natural resources and ecosystems, then market mechanisms and supply value chains may play an important role in increasing the efficiency of resources use.

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Background Paper — Sub-Theme 2

ROLE OF CIVIL SOCIETY AND NON-STATE ACTORS WITH FOCUS ON FARMERS AND EXTENSION FACILITIES

1. INTRODUCTION

Coping with food insecurity from crop failures brought about by droughts and disease has long been a challenge for mankind. So too has the tradition of providing relevant and useful information services to help farmers deal with the problems. Various sources of information and advice are available in most countries but for various reasons there is still a dearth of support for many millions of impoverished smallholder farmers in many developing countries who struggle with poor literacy and lack technological know-how to improve their livelihoods. Over the coming decades, significant changes are anticipated that will no doubt increase the challenges facing smallholders. Climate change and the uncertainties of seasonal rainfall on which many smallholders rely for producing food, rapidly growing populations in developing countries, and increasing pollution – too little to too dirty' – all add the risks of both water and food security (Box 1). This is happening at a time when water resources management is shifting away from government planning and control to a more adaptive and flexible model involving many more stakeholders. Concerns about food security, once expressed only in the national and international media, are now commonplace in local media and serve to create anxiety among impoverished rural communities.

Box 1. After A Decade of Steady Decline, Hunger Is on The Rise Again

The number of undernourished people has increased to nearly 821 million in 2017, from 804 million in 2016 (FAO, 2018a). Most live in rural communities in water scarce regions where a lack of water availability for agriculture can slow down the achievement of SDG 2 (of the United Nation's 2030 Agenda for Sustainable Development) that aims to end hunger, achieve food security and improve nutrition, and promote sustainable agriculture. Water scarcity and food insecurity go hand in hand.

Agriculture already accounts for almost 70% of all freshwater withdrawals and is seen as one of the key areas for future water-saving to bring future water demands into balance with available water resources. Much potential exists for improving water-use efficiency and water productivity in irrigated agriculture (Boutraa, 2010; IWMI, 2017; Unver et al, 2017).

Many governments continue to look to their smallholder farmers to increase food production and to find ways to "produce more with less". Doing this requires not only boosting production but also improving nutritional productivity of water from planning irrigation systems and assessing their performance to extending advice to farmers (Lundqvist and Unver, 2018). Farmers will need incentives to produce more but they will also need to increase their capacity to cope with the changes taking place at a time when governments are seeking ways of reducing public spending and traditional state-funded agricultural support services are in decline. Smallholders will inevitably need to take more personal responsibility for developing their capacity. This is still about life-long learning – transferring good science from the laboratory to the field, putting innovative technologies into practice to increase their productivity, and developing the skills to engage with the commercial food value chains that link farmers to the

[1] Countries are considered water-stressed if they withdraw more than 25% of their renewable freshwater resources. They approach physical water scarcity when more than 60% is withdrawn and face severe physical water scarcity when more than 75% is withdrawn (FAO, 2016).

markets and consumers. But farmers will need to find new ways of learning and rely more on their own resources, on the private sector, and on support from civil society organisations (CSOs) and non-governmental organisations (NGOs).

This background paper examines the changing nature of farmer support services, particularly the increasing importance of agricultural water management and irrigation as water becomes the limiting resource for food production, how food markets are growing and can incentivise smallholders to produce more, and critically, how farmers are finding new ways of acquiring the knowledge and expertise they need to do this.

2. THE ADVENT OF FARMER SUPPORT (EXTENSION)

Advice to farmers on how best to use limited water resources to grow food has a long and chequered history highlighted by archaeologists who uncovered clay tablets used in Mesopotamia and inscribed with advice on watering crops. Extension services as we know them today emerged in northern Europe in the 1900s following major crop failures, droughts, and famine. Across Africa and Asia, farmer extension services emerged during colonial times as fledgling government departments of agriculture began to introduce agricultural education in schools, and missionaries brought agricultural advice along-side religious work.

Thus, began the formal structures for agricultural extension, organised predominantly by central and local governments, with support from agricultural colleges, research centres, and various farmer organisations. Government-run services matured as funding increased and staff were better trained and more professional. But the services also grew and changed. The demand increased from focusing on crop production alone to include specialist advisory services like irrigation water management, marketing, and sustaining rural livelihoods, and more recently advice on protecting the aquatic environments on which smallholder livelihoods depended. Services thus became more complex, costly to run, and inevitably more bureaucratic with distinct ‘top-heavy’ and ‘top-down’ hierarchical administrations.

Agricultural extension is still widely recognised as an essential mechanism for delivering information and advice to the many millions of smallholders, men and women, who still subsist on farms less than one hectare and struggle to produce enough food for their families. They do not always have access to improved seeds, fertilisers, irrigation, and finance and have little resilience to the natural elements such as floods, droughts, pests, and diseases, and to volatile market prices. Low motivation, poor literacy levels, a lack of technological know-how, and the high risks of failure, all conspire to constrain smallholders from entering the cash economy.

The demand for extension continues but governments, looking for ways to reduce public spending, can often find themselves unable to afford to fund. Let alone services that farmers have come to rely on. Many developed country governments have found it attractive to pass on the responsibility to farmers and to the private and voluntary sectors. Commercial farmers, profiting from advice are increasingly expected to pay for it.

These trends are beginning to take hold to some extent in the developing world as well. However, the case is much weaker in countries where farming still dominates national economies and where the priority for many millions of smallholder farmers is to increase food production both for their own needs and to support national food security. UNDP (2012) reported that poor rural infrastructure, weak institutions, poor research and access to innovative technologies, low productivity, reduced government investment and official development assistance, as well as limited engagement with the private sector, all hinder the process of commercialising agriculture.

2.1 Irrigation advisory services

Irrigation advisory services have grown alongside the traditional agricultural extension services as water resources can limit production. In 2002 Smith and Munoz classified irrigation advisory services promoted since the 1970s according to the different objectives and type of advice, target groups, service provider, and the different tools and communication methods used to reach irrigating farmers (Table 1). These are wide ranging services from specialist crop water scheduling to planning and design, and advisory services for on-farm irrigation practices for both large schemes involving many smallholders and individual smallholder farms.

Table 1. Irrigation extension services

Service	Details
Crop water management/ scheduling services	Advise farmers on when and how to irrigate. Different devices and tools are promoted to provide farmers with guidelines and instructions on how to determine the correct time and application depth of the irrigation. This is the type of advisory service most widely introduced in many developed countries.
Irrigation performance analysis services	The analysis of irrigation system performance. This is carried out by a specialized field survey team who measure in the field a number of key indicators to assess the efficiency and performance of an irrigation system.
Design and installation services	Advice on the investment and installation of irrigation equipment is of direct interest to the provider and a range of services are available from the private sector to provide information and advice on design and installation as well use and maintenance of the irrigation equipment. Two basic services may be distinguished, namely, irrigation equipment providers and irrigation system designers.
Environment and water quality services	Concern about the environmental degradation linked to irrigated agriculture has resulted in strict regulations and legislation in many countries. To advise farmers on environmental hazards and to have them to comply with the regulations, advisory services are set up to monitor chemical and biological water composition, groundwater depth and water quality, water logging and salinity conditions, health hazards related to water borne diseases
Irrigation management support services	Many governments have adopted policies to transfer the management of irrigation systems to the beneficiaries and farmers, as government agencies have proved unable to maintain the irrigation systems in a sustainable manner. A process of irrigation management transfer (IMT) was initiated plus the formation of Water Users Associations (WUA) as the local organisation to take over responsibility for operation and maintenance of the irrigation system. Participatory irrigation management (PIM) is the guiding principle with appropriate legislation put in place to facilitate the transfer process.
Agricultural advisory services	Although not directly to be classified under irrigation advisory services, agricultural services are nevertheless closely linked and need to be integrated in the package of advisory services to be provided to irrigation farmers.
Target group	
Large scale farmers	Predominant in developed countries. Individual approach possible as their resources and technical know-how are well advanced. Moreover, they will be able to pay for services offered, which provides opportunities for the private sector and makes the financial sustainability of such services much more achievable.
Small holders	Predominant in developing countries. The individual farmer is more difficult to reach and often he is unable to pay for such services. The agricultural extension service is in most cases the appropriate agency, which can effectively provide advice to farmers. However, knowledge and experience of the extension service in irrigation is very limited and technical messages need to be simple and adapted to knowledge level. In addition, farmers can be reached through radio, television and local meetings. Extension leaflets and posters are common tools for information dissemination.

Service	Details
Water user associations and farmer groups	Farmers groups and water users' associations managing a common water resource for irrigation require support and advice on the management of the irrigation system. Although their financial resources may initially be weak, they may be able to pay for advisory and consultancy services through water fee collection. Groups of individual farmers interested in advice on irrigation practices may be easier and more effectively reached as groups rather than as individuals. Farmer field schools and farmers field days are typical opportunities to introduce irrigation advice to individual farmers. Reference is made in this to the FAO Participatory training and extension approach, which is oriented towards the group approach.
Commercial estates	Commercial estates will have a strong financial management and are best able to appreciate advisory services and be willing to pay for them. In some cases, they will establish a dedicated unit for irrigation management within their own organisation
Support service providers	
Irrigation agencies	The irrigation agency will typically have the national mandate for the development, management and monitoring of water resources for irrigation and drainage. In many countries emphasis has been traditionally on the planning and design of irrigation development and the responsibility for the management of the larger state operated irrigation systems. With the IMT devolution process initiated in many countries and resources for new development strongly limited, the role of the irrigation agency is changing into a more service-oriented agency in particular to support the water users associations in managing their irrigation systems. Many agencies are not yet well prepared for their new role, nor motivated and they have little capacity and means for this new role. There is a need to strengthen their ability as services providers through a process of training and capacity building.
Agricultural agencies	Although the agricultural agency provides by tradition an extensive extension service reaching all farmers including smallholders, their knowledge and skills in irrigation techniques are very limited.
Irrigation extension services	In a limited number of countries, a dedicated service has been established for irrigation in order to advise farmers in all aspects of irrigation, including the formation of water users associations. The financial resources to establish and maintain such services may however not be sustainable without financial support.
Irrigation equipment suppliers	The growth in modern irrigation equipment such as sprinkler and drip irrigation systems have resulted in a quite extensive and growing irrigation industry, which is interested in an effective information stream to potential clients. Their role in promoting relevant information often in close cooperation with regional irrigation agencies and irrigation research and extension services has become increasingly important in particular in developed countries.
Non-governmental organisations (NGOs)	Several non-profit organisations with special aims directed to social development or environmental concerns can play a role in providing relevant advice to individual farmers and farmers groups. The introduction of the treadle pump for irrigation in Asia and Africa is a good example of the role of the international NGOs in demonstrating the technique and in establishing the local manufacturing and service capacity.
Private consultants	Where farmers are able to pay private consultants can play a highly successful role in irrigation advisory services. They have proved successful in providing irrigation scheduling services and field evaluation assessments.

Smith and Munoz identified several constraints that have limited the effectiveness of services:

(a) Irrigation scheduling developed by research institutes are not user-friendly

(b) Irrigation management advice defined by irrigation experts who do not always respond to the needs and priorities of farmers, thus low acceptance rates

(c) Complexities of good irrigation management not easily translated into simple operational guidelines for farmers

(d) Irrigation advisory services linked to development projects with limited time duration and thus not sustainable beyond the project life

(e) State training and advisory services have low priority and limited funding

(f) Services have limited reach because of a lack of staff and communication facilities.

The authors overall assessment was that although some farmers had profited from the services and were actively adopting new technologies, generally experiences were mixed. They also commented that in many cases the demand for irrigation advice was based on the desire of planners, water resources developers, and irrigation experts to see that less water was withdrawn for irrigation.

Unver et al (2017) argue that water managers, regulators and those involved in broad management performance tend to use measures of efficiency, while farmers are more interested in productivity. As a result, irrigation management advice does not always respond to the real interests and priorities of farmers, and results in low acceptance rates.

3. TAKING RESPONSIBILITY -- WORKING TOGETHER

As public services have declined or were already weak, and in some fragile states, did not exist, the challenges facing farmers have not gone away. They continue to face a common set of challenges around water security – economic water scarcity, under-investment in infrastructure, and weak organisations and institutions. Common challenges can bring people together to collectively resolve problems and take responsibility for their livelihoods.

3.1 CSOs, CBOs, and FBOs

As water resources management shifts from “water government” to water governance, civil society organisations (CSOs) are closing the gaps left by inadequate ‘formal’ state services. They are playing integrative roles by bridging the current stream of ideas on the importance of good water governance with sustainable growth and the common interest of citizens (Wetlands International, 2017).

CSOs is a ‘catch-all’ term for a wide range of informal networks within communities that collectively provide benefits to their communities (Box 2). Community based organisations (CBOs) are a form of CSO that work specifically within and for the benefit of a community. In the more fragile states CSOs are usually the only institutional structures within communities, whereas in states with declining state services, CSOs usually complement or replace them.

Farmer-based organisations (FBOs) are another form of CSO and have grown out of a desire among smallholder farmers to work together for their mutual benefit. Examples of FBOs include Water User Associations (WUAs), farmers’ credit unions, and producer groups. Such groups are becoming increasingly important as they provide a mechanism for smallholder farmers to engage with the private sector.

3.2 NGOs

Some consider non-governmental organisations (NGOs) as CSOs. They are organisations that support farmer groups and have two main roles: service delivery and advocacy. They operate in most countries and range from small, local grass-roots organisations to large organisations that are almost indistinguishable from state and international institutions (Box 3). Their value comes from being rooted in the societies they serve and their independence of actions that otherwise limits governments and market organisations. International development donors often see them as an effective means of interacting directly with civil society and working in the interests of the poor. When state institutions are weak, or do not exist, NGOs are often the only source of basic services to poor communities.

Box 2. CSOs, CBOs, FBOs, and NGOs

Some definitions but the lines between them are not always clear and are disputed.

Civil society organisations (CSOs) are a 'catch-all' for any group of people working towards a common goal. They are usually voluntary organisations and are separate from the State and the market. They include NGOs, professional associations, social partners, and universities that can play an important role in improving local ownership of development processes.

Community-based organisations (CBOs) is essentially another name for CSOs that work specifically within communities and neighbourhoods. They are non-profit and are synonymous with community work and development.

Farmer-based organisations (FBOs) are another form of CSO. They are groups of commodity-based and market-oriented smallholder farmers who agree to work together to market their produce. They may also cooperate on the inputs needed to enhance productivity.

Non-governmental organizations (NGOs) are a form of CSO but usually they are more formally structured and registered with government. They are non-profit organizations, independent of government and funded by donations, though some rely primarily on voluntary inputs. They engage in many activities but in the context of this paper this include natural resources management initiatives, like sustainable water management, and working with farmers to build capacity, improve farm productivity and incomes, develop links between farms and markets, and engage in sustainability issues that are also important for rural livelihoods.

Box 3. Global Water Partnership – An International Network Works Through CSOs

In the water sector, an international network like the Global Water Partnership[2] (GWP), which promotes integrated water resources management (IWRM), relies on CSOs in member countries to provide effective two-way communications that ensures the needs of the public are made known to government and vice-versa. They encourage the public, as water users and taxpayers, to actively participate in planning and managing water resources.

Since the 1980s, NGOs have typically stepped in to provide access to information on agricultural development when public services, such as research and extension do not have the capacity to reach out to farmers. They provide a range of support services to farmers such as advice on finance and credit, marketing, insurance, and legal matters, and can act as brokers to establish links between rural populations and other support services from the state and the private sector. They can help to communicate farmer problems to governments through advocacy and hold governments to account for their rural strategies and activities.

Some NGOs are developing a professional outlook by providing specialised technical and consultancy services, manage microfinance institutions, and commercialise agricultural products. They occasionally keep NGO status because of tax privileges and donor preferences to work with NGOs but many are being encouraged toward private business status (Box 4).

3.3 Building social capital

Sustainable development requires us all to look beyond technology transfer and human capital development to increasing social capital which is about building community processes for collectively managing scarce resources.

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2 https://www.gwp.org/en/learn/iwrm-toolbox/Institutional_Arrangements/coordination_and_facilitation/Civil_society_organisations/

Box 4. NGOs Transfer Treadle Pump Technology to Africa

Treadle pumps are low-cost, simple human-powered suction pumps designed to replace engine-driven pumps to lift water from shallow depths to irrigate smallholder farms of 1-1.5 ha. The Lutheran World Federation (an NGO) developed the pump in Bangladesh in the 1970s using local materials to help lift impoverished farmers out of poverty. NGOs like, IDE, Kickstart, and others introduced and re-designed the pump for use in sub-Saharan Africa with considerable success. Some treadle pumps have now been adapted to sprinkler and drip irrigation systems.

Although the current number of pumps installed is not known, it is estimated that there are many thousands used in Bangladesh, India, Kenya, Malawi, Niger, Zambia, and Zimbabwe. With pumps cost less than US$150 and some NGOs have established supply chains for spares and pump maintenance and entry points for farmers into commercial food markets.

Sources: Practical Action [3]; Kay & Brabben, 2000

CSOs form part of a community's 'social capital' – broadly meaning the trust that grows as people, work together for a common cause. This plays an important part in the lives of poor people who tend to invest heavily in social cohesion for their survival. When communities are cohesive, they are better positioned to attract government and NGO resources. International NGOs also rely on social capital to influence development.

Thus, external support from donor aid or NGOs to strengthen CSOs can be beneficial but there is always the risk that imposing new rules can overwhelm local CSOs rather than enhance them (Allouche, 2014). An appropriate and productive balance is needed between formal and informal service delivery, water governance mechanisms, and appropriate investments.

3.4 Small is beautiful but…

CSOs tend to work with small groups of farmers and although Schumacher (1988) suggested that 'small is beautiful', too many small activities can create land scape problems which need catchment, regional, or national level solutions for sustainable development. A most prominent example in irrigation is the over-exploitation of groundwater. Many millions of smallholder farmers have been successfully lifted out of poverty by pumping groundwater for irrigation to supply produce to lucrative urban food markets. But the abstractions are largely unregulated and unsustainable as evidenced by falling groundwater levels and aquifer contamination through salt intrusion (Shah, 2014). In this case, the challenge becomes one of strengthening formal state institutions and human capacity that can regulate groundwater abstraction but work with the informal (bottom-up) systems rather than try to replace them. (see Section 7 Working together at a landscape level)

4. 'COMMERCIALISING' ADVISORY SERVICES

Smallholder farmers, despite all the problems they face, are still the bedrock of agri-food supply in most developing countries, but they are facing immense change. Most have only known subsistence farming and government support services, they now face the uncertainties and unprecedented growth in domestic markets, and a wave of investments by local and

[3] https://www.goldstandard.org/projects/treadle-pumps-project

international food manufacturers and retailers that want to supply food to domestic consumers and for export (Vorley et al., 2008). Modern food markets are driven by increasing urbanisation, economic growth, and consumer preferences. The traditional public sector-led agro-industries are giving way to the private sector, businesses and food retailing have grown and are adapting to these changes (UNDP, 2012).

The good news is that modern markets offer the ‘pull’ that encourages smallholders to produce more and increase farm income. They increase economic opportunities for producers, particularly those who grow high-value crops, like fresh fruit and vegetables. Markets can incentivise smallholders to adapt to these changes, but they must also learn that markets bring risks of over-production and low prices which can threaten the inexperienced. Irrigation offers more farmer-control over timeliness of supply, and produce quantity and quality which are essential components in producing food for increasingly sophisticated urban customers.

There are many examples of agro-business investment across sub-Saharan Africa, like fruit concentrate processing in Nigeria, soya bean and other oil seed plants across east Africa and grain production to replace imports to serve the brewing industries (UNDP, 2012). Although buyers usually favour large-scale suppliers, in many developing countries they do not exist, and so the biggest challenge for modern agri-food businesses is how to engage with the many thousands of smallholder farmers and organise the supply of produce that delivers the benefits of logistics, economies of scale, traceability, and private sector standards (Vorley et al., 2008). However, businesses are wary of high transaction costs, and large numbers of fragmented smallholders are seen as high-risk, unreliable, and lacking technical skills and technologies to produce the right products at the right time (quality, timeliness, and consistency).

4.1 Smallholder business models

Some agro-industries have established large farms to ensure supplies, but many realise that resilience depends on sustainable development and working with smallholders who own and farm the land. Argo-industries have searched for business models (“what a company does and how it makes money from doing it”) that are sensitive to emerging markets, include smallholder producers and address the needs of processors and retailers to manage costs and risks (Rwelamira, 2015). Three workable models have emerged that link smallholder farmers to agribusiness and changing markets (Table 2). Complementing the models is the growth in support services for smallholders, often provided by the link companies in the value chain, rather than by the state. They tend to be integrated services focused on producing the crop, rather than the ‘siloed ‘public services with specialists focused on soil management, pest and disease control, water management and irrigation.

Table 2. Typical business models for smallholder producers. Source: Vorley et al., 2008 in Rwelamira 2015

Model	Driver	Motivation
Producer driven	Smallholder groups, Farmer-Based Organisations (FBOs), associations, cooperatives	Access to new markets, increased bargaining power, access to inputs, technical assistance, secure market, position, farmer empowerment
Buyer driven	Processors, retailers, exporters, traders, wholesalers	Access to land, supplies, increase volumes, supply niche markets
Intermediary driven	NGOs, development agencies, governments	Local and national economic development, farmer empowerment

4.1.1 Produce-Driven

Producer-driven models are smallholder-based groups that form with a collective desire to participate in a market though they have had a mixed record in providing members with economic benefits in accessing markets (Vorley et al., 2008).

4.1.2 Buyer-Driven

Buyer-driven models tend to be more robust. They centre around commercial companies that approach existing FBOs or act as a catalyst to form them, and provide finance, agricultural inputs, and technical advice. The company provides specialist extension staff to advise farmers on all aspects of production, harvesting, storage, and transport. Irrigation advice would be an integral part of the extension package rather than some separate service. The sugar industry in South Africa is an example of this approach. It encourages smallholders to engage with commercial sugar producers. Sugar companies usually have large estates that supply cane, but they rely also on supplies from both local commercial farmers and groups of smallholders surrounding their estates. The sugar producer provides the inputs and technical advice for growers who would not normally be able to afford such services. The growers benefit from an assured income and the company benefit from additional and flexible cane supplies.

4.1.3 Intermediary Driven

A third model uses NGOs as intermediaries to encourage commercial companies to engage with FBOs and equally to encourage and train farmers to form FBOs in readiness for engaging with private companies. There are many ups and downs but there are cases where FBOs led by NGOs and the public sector can work well especially when the NGO has a strong business development focus. Important too, are a clear and consistent focus on the business case and a timeline for removing the support. NGOs taking on this role also need strong managerial structures and financial support from donors and charities on a par with the businesses they engage with. Equality of power and standing among the company, FBOs and the NGO engenders trust that is essential to building the business relationships between companies and FBOs.

An example of an NGO as an intermediary is Kilimo Trust [4]: a Ugandan-based NGO with strong business experience (Box 5) (Kilimo Trust, 2011). Others include FARM-Africa and Farm Concern International, long stablished and well-funded NGOs operating across east Africa, with the capacity to organise farmers groups and link them to the value chain groups [5].

In Bangladesh, there is a spectrum of institutions formed by farmers and many are supported by NGOs. BRAC [6] is a prominent national NGO engaged in supporting FBOs that also operates internationally. International NGOs undertaking similar work in Bangladesh include Action Aid, Save the Children, and World Vision (FAO, 2014).

Whatever the approach some form of grouping or organisation is crucial if smallholders are expected to engage with the value chain (Rwelamira, 2015).

[4] www.kilimotrust.org

[5] www.farmafrica.org and www.farmconcern.org

[6] BRAC was formerly Bangladesh Rural Advancement Committee http://www.brac.net/

Box 5. Kilimo Trust Links Smallholder Farmers with Markets

Kilimo Trust (KT) is a Ugandan based NGO, established in 2005, and funded by various international aid and charitable organisations including Bill & Melinda Gates Foundation, GIZ and many others. It supports smallholder farmers, typically farming 1-1.5 hectares to engage with markets and agri-businesses. KL works to establish FBOs and connect them with a lead commercial company already established in the value chain. They also assist FBOs to select suitable input suppliers and other services they will need to meet the exacting standards and requirements of the value chain. Between 2011 and 2018 KT has helped over 137,000 smallholders across east Africa to access markets using this approach. KL often works through small NGOs with local knowledge of producers, markets and commercial companies. KT supports irrigation interests as one of the many skills farmers need to work in the commercial sector.

How big is an FBO? – The ‘30-ton truck’ story

KT say that if you have enough good quality produce to fill a 30-ton truck and it can be reliably brought together in one place for collection then both smallholder farmers and transporters can profit from accessing markets. The challenge for smallholder farmers is to work together so they can bulk their produce. This means understanding the demands of business, appreciating contractual arrangements, and producing quality products on time.

Millers provide extension services to rice growers

Rice is the fastest growing food source in Africa with annual demand growing at close to 5%. In 2014 K initiated a 4-year programme across Burkina Faso, Ghana, Nigeria, and Tanzania to increase both irrigated and rainfed rice production among 30,000 smallholder farmers with the aim of doubling farm incomes. KT provided matched funding to eight rice-milling companies with established value chains to work with local FBOs and to bring them into their value chain. FBOs were formed and contracted to supply the millers with rice who in turn provided on-farm support services and inputs, including micro-finance, and market access. Irrigation advice was an integral part of the support package. Over the 4year period, irrigated rice yields increased from 2 to 4Tons per hectare (rainfed yields increased from 1.5 to 3.6 Tons per hectare) and average annual farm incomes increased from US$86 to US$338 for irrigated rice (rainfed from US$55 to US$108).

Source: Kilimo Trust, 2018

5. DEVELOPING CAPACITY

“Strong formal and informal institutions and human resources underpin good water governance. However, there is an acute lack of capacity, which is constraining the development and management of water resources in all its facets in most developing countries, particularly across sub-Saharan Africa and South and South-eastern Asia.” UN, 2018.

The United Nations synthesis report on SDG 6 (UN, 2018) drew attention to the fact that this is not a new problem, it is one of the leading constraints to water-related development for decades. FAO (2018b) reaffirmed these concerns and the need to strengthen capacity on family farms.

The need for comprehensive capacity-development programmes to create a cadre of specialists and technicians is well recognized. However, funds are often allocated for developing infrastructure rather than people. FAO (2004) reported serious deficiencies in human capacity among rainfed and irrigating farmers and institutional capacity among state organisations that traditionally provide support to farmers. Such criticisms are widely accepted among water professionals and aid agencies, although hard evidence to support the claims is sparse. However, indirect evidence comes from research that links water and economic growth (Sadoff et al., 2015). This shows that highly variable and ‘difficult’ hydrology, which affects most developing countries, and low investment in water security leads to low growth. In turn this implies not only a lack of funding but also a lack of institutional and human capacity to absorb investment.

Smallholders require finance, infrastructure, and technology, but they are not substituting for knowledge and skills needed to take advantage of them. Capacity is often expressed in negative terms, like a lack of capacity or inadequate capacity but this attitude is linked with past ‘top-down’ management approaches that set objectives for state organisations and encourage spending on infrastructure with ‘bolt-on’ training programmes. This was often followed by disappointment when the objectives were not met (ASARECA, 2007). A more positive approach is now emerging that puts capacity at the heart of sustainable development which suggests that public and private bodies should support smallholders to define their own path for development including their capacity to meet their aspirations. Farmer-led irrigation is an initiative led by Growing Africa’s Agriculture (AGRA)[7] and the World Bank[8] to unlock innovation, entrepreneurship, and positive change among smallholder farmers.

Embedded in capacity development is participation and empowering people to take responsibility for their own livelihoods. This includes developing individual capacity through education and training for farmers and professionals; organisational capacity, through water user associations, extension agencies, and private sector companies; and the capacity of states to create a socio-economic environment in which organisations and private companies can function and prosper.

The nature of smallholder farming and FBOs, will mean that the traditional ‘top down’ extension of ‘one size fits all’ messages will no longer be appropriate. Smallholders will still need extension, but agents will need to deal with a whole range of local farming issues as they try to identify problems, teach smallholders, and learn from them while working as facilitators rather than decision-makers – offering them a ‘shop window’ from which smallholders can select options that suit them.

Participatory approaches have proved to be an effective way of engaging with smallholders to adopt good water management practices and technologies. These include FAO’s programme in Participatory Training in On-farm Water Management and the Farmer Field Schools (FFSs). FFSs have helped increase production, productivity, and income in rural households (Davis et al., 2010). Effective communication strategies used in advisory services include farmer field days, farmer meetings, and in more recent times web-based information, mobile phones, radio and television (FAO, 2008; GFRAS, 2019).

More direct links between smallholder groups and research will become important rather than the ‘top down’ approach of promoting research through extension agents. Many researchers do not understand smallholder problems as is evidenced by the limited use of indigenous knowledge when researching new technologies. They will need to ensure their research is demand-led and directly addressing the needs of smallholders. The concept of ‘research farmers’ needs more exploration as more research is done on-farm. While researchers must learn to engage with smallholders, smallholders must also learn how to work with researchers if they are to benefit from their expertise and speed up farmer adoption of new technologies (ASARECA, 2007).

[7] https://agra.org/what-is-farmer-led-irrigation-unlocking-innovation-for-livelihood-food-and-water-security/

[8] http://www.worldbank.org/en/news/feature/2018/09/05/innovation-entrepreneurship-positive-change-join-the-farmer-led-irrigation-revolution

Capacity to produce more will also come from technological changes. Rural electrification using solar energy and cell phones can strengthen extension, advice, and expertise, and provide real-time information on irrigation, on-farm processing, and market advice. Opportunities may also exist for adopting biotechnologies and producing bio-fuels close to where they will be used, thus substituting for imports and generating off-farm income.

6. MAINTAINING CSO/NGO SYSTEMS POST-SUPPORT PERIOD

Most efforts to establish extension support services start with financial and at times, logistic seed inputs from the government or multilateral funded projects. The efforts run well as long as the necessary inputs, like funds for day-to-day operations are available. However, once communities are approached to pay for the running and operations costs, the problems of sustainability take over. Many times, corpus is provided which can generate adequate returns for maintaining the core services of the CSO/ NGO. Due to inflation and other effects, the corpus becomes insufficient and additional financial resources are needed to maintain the services. The beneficiary groups should see adequate value in continuing to pay some of their income towards upkeep of the entity. One example is Amul cooperative which has become a leader in the white revolution in India. This business model which makes economic sense to all levels of beneficiaries from the grassroot level to a corporate manager. Some water user association efforts are not able to ramp up, and are thus constrained when formulating demands for water from the government.

Entities involved in water management should be long-lasting and self-supporting. Water being part of the common pool resource, community participation and adjustments of concerns at inter-community level extending up to inter-regional level is necessary otherwise, the local policies adopted in a micro-context may harm the overall allocation and equity regime in downstream regions. In such cases, long-surviving CSO networks can help to resolve conflicts at regional level.

7. WORKING TOGETHER AT LANDSCAPE LEVEL – CASE STUDIES

There are many situations when CSOs/NGOs help lots of individuals and small farmer groups to improve their livelihoods and in doing so they create big problems at a landscape level [8]. They cannot solve them as individuals or small groups; they require a collective approach on a much larger scale. It is often referred to as the ‘tragedy of the commons’, when one group of smallholders takes action to sustain their livelihoods which begins to capture or degrade resources to the detriment of other groups and the ecosystems on which they all rely (Ostrom, 1990). In the absence of strong national institutions, CSOs/NGOs are stepping into the governance role to help communities to create sustainable solutions.

In 2011, FAO reported that in some regions, achievements in food production were associated with degrading land and water resources and causing related ecosystem goods and services to deteriorate. Changes in land use reduce water availability and quality, and in turn water shortages and poor water quality affect ability to produce more from the land. As GWP (2016) pointed out, farmers are often in danger of ‘killing the goose that lays the golden eggs’.

Smallholder farmers rely on aquatic ecosystems for services like clean and reliable water, soil fertility, and pollination. But they also need to protect the systems on which they rely. This means engaging all those involved to develop a deeper understanding of their landscapes and resource availability; prioritise actions and design appropriate strategies for effective

[9] Landscapes are contiguous areas with common ecological, cultural and socio-economic characteristics (WWF, 2002)

resources management. Involving economically and socially marginalised groups is an essential part of this process as they are often the most vulnerable.

FAO has developed natural resource management models that involve working with diverse stakeholders within a landscape to define shared productivity and sustainable management objectives and identify capacity gaps. This includes working with local extension services and CSOs to develop capacity and build social capital (FAO, 2017a, b).

7.1 India

The Andhra Pradesh Farmer Managed Groundwater Systems project, coordinated by FAO, demonstrated that Indian farmers in Farmer Field School (FFS)[10] groups could work together at landscape level and reduce over-exploited groundwater. Community members collected and shared groundwater data, estimated water available for the dry season crops, and reduced abstraction while improving crop production. Likewise, a project used the same farmer groups using an FFS-style intervention to help farmers to adapt to climate change at a local community level (Box 6).

Box 6. Farmer-Managed Groundwater Systems in Andhra Pradesh

The Andhra Pradesh Farmer Managed Groundwater Systems project demonstrated that it is essential for smallholders within in a hydrological unit to understand groundwater recharge and balance, and the effectiveness of working together as a community to sustain their livelihoods. A participatory hydrological monitoring programme was established to build farmers' groundwater knowledge, data, and skills and 638 Groundwater Monitoring Committees (GMCs) were formed at village-level to monitored local groundwater resources. These were federated into 63 Hydrological Unit Networks (HUNs) at the hydrological unit level. The GMCs and HUNs in each hydrological unit estimated the total groundwater available and planned cropping systems that were climate resilient and matched with water availability.

The farmer-led GMCs disseminated information to the entire farming community within each hydrological unit and acted as pressure groups. This encouraged water-saving and harvesting projects, promoted low investment organic agriculture and helped formulate rules that would ensure inter-annual sustainability of limited groundwater resources. The results were positive across most of the pilot area. Groundwater abstraction was substantially reduced through diversified cropping and water-saving practices and farm income increased.

A key outcome was farmer-to-farmer outreach. Farmer participants adapted local art forms, symbols, and materials to demystify groundwater science and disseminate key messages on groundwater management. The government acknowledged this approach as an effective model for groundwater management and adaptation to climate change in rain-fed areas of the country.

Source: World Bank, 2010

7.2 The Near East

In Jordan, CSOs/NGOs stand as the only refuge between farmers and government in areas where public trust is either broken or on the brink of collapse. This highlights the fragility in the country and the key role that CSOs/NGOs are playing as they have stepped in to bridge the gap between people, research, and governance.

In the Jordanian 'Badia' – or desert, CSOs/NGOs are creating the link between researchers and smallholder farmers to restore and sustain their livelihoods. The Badia experiences

[10] http://www.fao.org/3/i2561e/i2561e01.pdf

extremes of land and water degradation and climate change is just making the situation significantly worse. This is an importance ecosystem in Jordan, it covers a large area and the risks of degradation are compounded by smallholder farmers who have to contend with low and unreliable rainfall, depleted groundwater, and salinization, all of which are rendering farming uneconomic.

Restoring the Badia is being piloted by ICARDA and researchers work through CSOs/NGOs to improve traditional rainwater harvesting techniques and diversify agriculture away from traditional, and vulnerable, monocropping. Techniques are being re-introduced to improve 'green' water, utilization like contour ridges and furrows, runoff strips, and bunds, which also minimise soil erosion, capture sediment runoff, and increase soil fertility. Other examples of CSO/NGO involvement in Jordan are described in Box 7.

Box 7. CSOs Support Smallholders in Water Scarce Jordan

Re-using wastewater for agriculture in Amman

In Amman, Jordan's capital city, CSOs have worked closely with farmers to debunk socio-economic myths about re-using (grey) wastewater for irrigating food crops. One in every six household in Amman practices urban agriculture and there is stiff competition between domestic use and agricultural water consumption heightened by high water prices. Many households practice both rainwater harvesting and re-use of grey water for agriculture which has increased household incomes by US$70 in a country where the average monthly income is about US$130. This is mostly attributed to the work of CSOs/NGOs in raising the capacity of smallholder farmers to increase production, explore new water management techniques and agricultural practices that are helping to increase farmer incomes and food insecurity in a water scarce region.

Irrigation champions and WISE Irrigators (Hakim) in Azraq Basin (2)

Turning the now brown Azraq Lake back to its original blue colour is a laudable goal but doing so threatens local smallholder farmer livelihoods and food security that abstract lake water for irrigating their crops. Striking a balance between sustaining and improving the lake's aquatic ecosystems and the needs of farmers proved difficult for government which lacked trust among local farming communities. To resolve this, local CSOs/NGOs stepped in and have teamed up with research institutes to work with smallholders and develop Irrigation Champions and WISE irrigators or Hakim as locally known. Irrigation champions focus on training and licensing local university graduates as water/irrigation supervisors and experts. Hakim is a title solely reserved for farmers who adopt Water Innovation technologies and the services of the Irrigation Champions. The competitive and highly prized title has increased water-efficient irrigation technology adoption rates, and this has stimulated local industries to provide irrigation services.

Source: Mougeot, 2006

7.3 Guatemala

In Guatemala, CSOs/NGOs have entrenched and facilitated gender networks to safeguard water quality and ecosystem services (Colom, 2015). The "River Contract"; as a participatory management tool in the pilot Matarraña river basin emphasises the ability of CSOs/NGOs to help avoid complex political frameworks and ensure dialogue to resolve water-related conflict. From cities to farmlands, NGOs and (especially) CSOs have played pivotal roles in achieving the desired level of integration by acting as catalysts, citizen representatives, capacity builders, service providers and information brokers. In agriculture, CSOs/NGOs represent the interest of smallholders; provide technical expertise, knowledge, and capacity; serving as policy watchdogs to ensure transparency and accountability from her position of independence.

8. CONCLUSIONS AND FUTURE OUTLOOK

This background paper examined the changing nature of farmer support services, particularly the increasing importance of agricultural water management and irrigation as water becomes the limiting resource for food production; how food markets are growing and can incentivise smallholders to produce more, and critically, how farmers are finding new ways of acquiring the knowledge and expertise they need to do this.

Despite their many problems, smallholders are still the bedrock of food production in most developing countries and governments continue to look to them to 'produce more with less'. Most have only known subsistence farming, and though many have benefited from state-funded support services, these are now in decline as governments seek ways of reducing public expenditure.

Smallholders will inevitably need to take more personal responsibility for developing their capacity. They will increasingly need to rely on their own resources, on the private sector, and on support from CSOs (includes NGOs) to acquire knowledge and skills, and build social capital so they can confidently engage with commercial value chains that connect farmers to food markets. CSOs are beginning to close the gap left by inadequate 'formal' state services by helping farmers to help themselves by forming producer groups to tackle issues collectively rather than on their own.

New business models are emerging that 'commercialise' advisory services driven largely by 'market pull' which encourages smallholders to produce more. There are a growing number of examples of agri-businesses learning how to engage with the many thousands of smallholder farmers, and equally, how smallholders are learning to organise themselves so they can respond to agri-business needs. CSOs are helping to build the valuable links between business and smallholders and the links between agricultural research and smallholders that overcome the inadequacies of traditional extension services. Irrigation, as part of an integrated approach to service provision, offers more farmer-control over timeliness of supply, and produce quantity and quality which are essential components in producing food for increasingly sophisticated urban customers.

In the absence of strong national institutions, CSOs are also stepping into governance roles to help communities create sustainable solutions for landscape level problems like sustaining aquatic ecosystems on which farmers depend for ecosystem services. However, care will be needed at this level to ensure an appropriate and productive balance between formal and informal service delivery, water governance mechanisms, and appropriate investments.

There are wide-ranging services for irrigators from specialist crop water scheduling to planning and design, and advisory services for on-farm irrigation practices for both large schemes involving many smallholders and individual smallholder farms. But advice from irrigation experts has not always been well received. Support needs to respond more to the real interests and priorities of farmers rather than the desires of water resources managers and researchers.

Essentially, all CSOs form part of a community's 'social capital' – broadly meaning the trust that grows as people, come together for a common cause. This plays an important part in the lives of poor people who tend to invest heavily in social cohesion for their survival. When communities are cohesive, they are better positioned to attract government and NGO resources

Finally, capacity is still the main constraint as support has always been for infrastructure rather than on capacity development. However, there are signs that this is changing as the private sector and others focus on production and are beginning to support smallholders with the wherewithal to produce the goods. Technology too is helping with rural electrification, solar energy and cell phone which strengthen extension and empower farmers with market knowledge.

9. ACKNOWLEDGMENTS

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Background Paper — Sub-Theme 3

IMPROVING AGRICULTURAL WATER PRODUCTIVITY WITH FOCUS ON RURAL TRANSFORMATION

ABSTRACT

As a result of population growth, economic development and climate change, feeding the world and providing water security for all will require important changes in the technologies, institutions, policies and incentives that drive present-day water management, as captured among others in Goal 6.4 of the Millennium Development Goals. Irrigation is the largest and most inefficient water user, and there is an expectation that even small improvements in agricultural water productivity, defined as a biomass, production or output price relative to water withdrawn, applied or consumed, will improve water security.

This paper argues that improvements in water productivity that irrigated agriculture is expected to deliver involves complex and comprehensive rural transformation that goes beyond mere adoption of water saving technologies. Rural-urban migration, improved living standards and changes in diets, and access to internet, mobile phones, energy and affordable technologies all play a role. Many of the measures to improve water productivity require significant changes in the production systems of farmers and in the support that is provided by public and private service providers – extension services, input suppliers, agricultural off-takers, and others.

The paper uses Molden's four pathways for increasing water productivity at the irrigation system or at basin level, and provides concrete cases that are located on each of these pathways, showcasing the diverse experience in the use of technologies, institutions, policies, and incentives to improve water productivity.

Looking forward, water use and competition over water are expected to further increase. By 2025, about 1.8 billion people will be living in regions or countries with absolute water scarcity. Demand for water will rise exponentially, while supply becomes more erratic and uncertain, prompting the need for significant shifts of inter-sectoral water allocations to support continued economic growth. Advances in the use of remote sensing technologies will make it increasingly possible to cost-effectively estimate crop evapotranspiration from farmers' fields.

1. INTRODUCTION

Estimates show that with current population growth and water management practices, the world will face a 40% shortfall between forecast demand and available supply of water by 2030. Population growth has led to dwindling per capita water resources (see Figure 1) and to intensifying competition over scarce water resources. In many countries, groundwater tables have declined precipitously, and water quality is becoming a growing concern. Climate change and more volatile water availability are putting additional pressure on those sectors that use water inefficiently to conserve water and use it more efficiently. In addition, as countries and economies develop and people move out of poverty, eating habits change in favour of more water intense diets. Growing competition over water, climate change and changing diets all require a more thoughtful use of water to ensure that water makes the highest possible contribution to achieving societal objectives.

As a vital resource, water is an important factor fuelling the growth and development of human societies. During the past two decades, and in the latter years of the 20th century in particular, water and its management have turned into a daunting global challenge. A comparison between the countries located in temperate areas and those located in semi-arid and arid areas shows that water scarcity (especially good quality water) has acted as an important factor hindering the agricultural, economic, and social development activities in those countries that are located along the belt of arid, semi-arid, and tropical areas across the world.

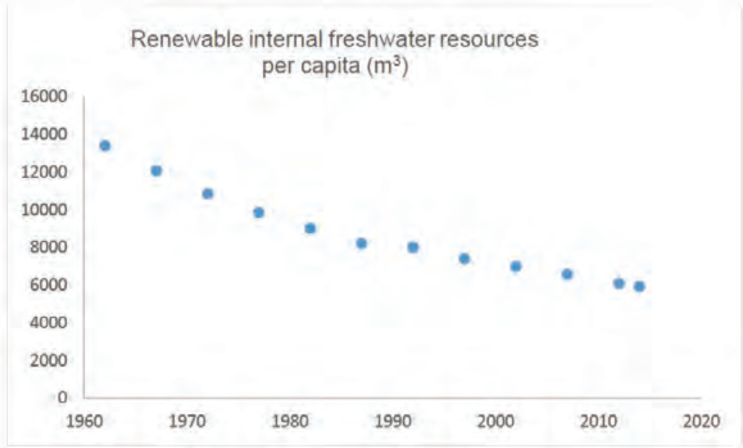

Figure 1. Global per capita water availability (FAO Aquastat)

Today, not only water security but also food security is facing high levels of risk. Fundamental reasons behind these elevated levels of risk include the rapid population growth in parts of the world, reduced availability of water resources due to excessive exploitation, human interventions in natural cycles, and the use of chemical contaminants (Kadi et al., 2003). In the near future, competition for water is likely to occur between agriculture, potable water use, industrial uses and the environment. The challenges will be even worse in semi-arid and arid areas. Some 7% of the world's population live in areas suffering from water scarcity [1]; the figure has been forecasted to increase to more than 67% by 2050 (Howell et al., 2001).

In view of the above, feeding the world and providing water security for all will require important changes in the technologies, institutions, policies and incentives that drive present-day water management. Irrigation is the largest and most inefficient water user, and there is an expectation that even small improvements in agricultural water use could have significant implications for local and global water budgets, and therefore for the water security of other water users. While feeding more people, agriculture will need to use less water to produce more. The associated water savings should be allocated to other parts of the economy so that overall each drop of water contributes most to achieving agreed societal objectives.

The need to use water more efficiently has among others been recognized in the Sustainable Development Goals (SDGs). In particular, Goal 6.4 aims to "by 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity, and substantially reduce the number of people suffering from water scarcity." Irrigated agriculture will need to invest in water savings so that these savings can be allocated towards sectors that produce more value for society (see Figure 2). The productivity of water use, however defined, is increasingly becoming an important metric to benchmark the performance of irrigation.

[1] Based on existing international standards, water scarcity refers to a situation where a country consumes more than 1,000 m^3 per person per year.

This paper will review the experience in technologies, institutions, policies and incentives to improve agricultural water productivity. The paper recognizes that increasing water productivity requires no less than a rural transformation. At the same time, on-going changes in rural areas prompt farmers to respond, adapt and seize emerging opportunities. Business as usual is no longer an effective response. The paper will contribute to a better understanding of the key issues and the roles and responsibilities associated with scaling up water productivity, as well as practical action on the ground.

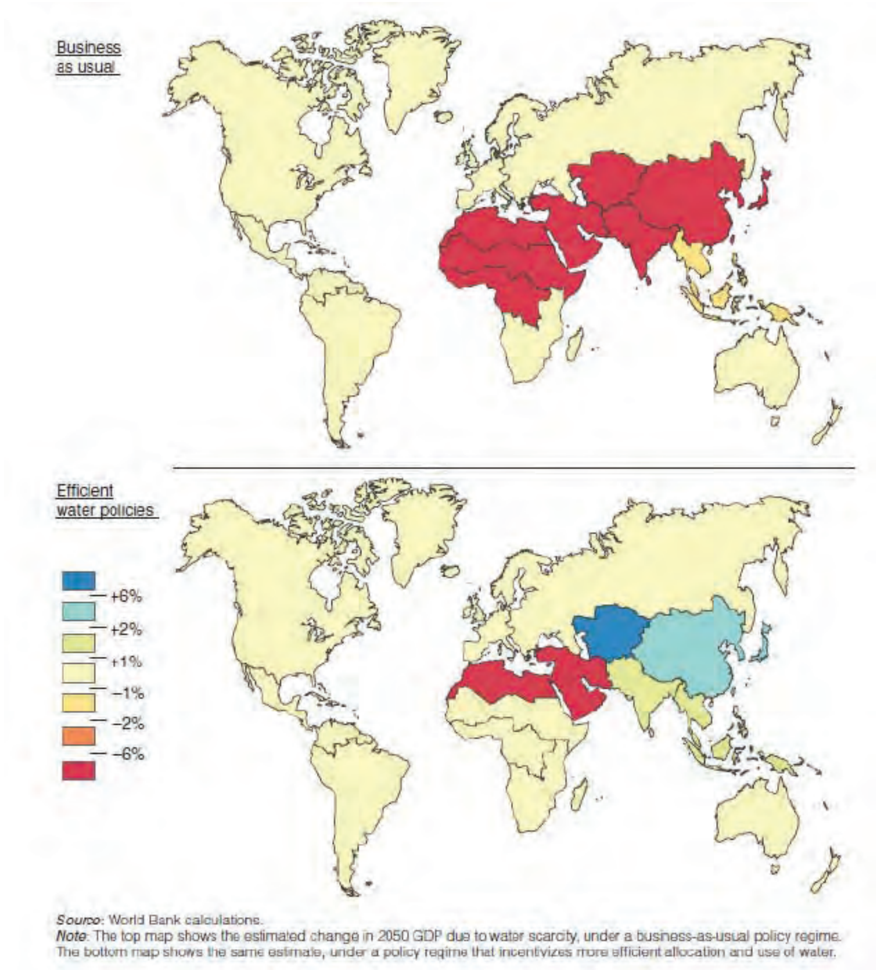

Figure 2. The Estimated Effects of Water Scarcity on GDP in Year 2050, under Two Policy Regimes

2. WHAT IS AGRICULTURAL WATER PRODUCTIVITY?

Numerous definitions of water productivity have been proposed, and none has been broadly accepted or consistently applied. In this paper, we define water productivity as a biomass or production relative to water withdrawn, applied, or consumed. Water productivity is expressed as yield or biomass in relation to one of the measures of water use for the case of a particular crop at the field or farm level. If water productivity is estimated for more than one crop at the farm level, for example, output prices are often used for aggregation, and water productivity is expressed in economic terms [2]. We will use consumption (i.e., evapo-transpiration, ET) as the measure for use and ignore return flows or rainfall.

According to the definition provided in this paper, "agriculture water productivity" is an index ratio with consumed amount of water (ET) in its denominator and various quantities in its numerator. These can include crop yield, net income (profit), produced amount of caloric energy, value-added, etc. In general, physical water productivity and economic water productivity are more popular for water management analyses and decision making. Physical water productivity refers to the produced amount of crop (biomass) per unit volume of consumed water, which is usually expressed in kg/m^3. On the other hand, economic water productivity considers the economic value of the benefits produced per unit of water used, i.e. how much economic value is generated for the consumed amount of water It is usually expressed in US$/m^3.

In order to draw a more comprehensive picture of the "agriculture water productivity" index, it is necessary to identify the specific part(s) of the crop which is (are) considered as final product. Indeed, although all parts of a plant need water before it can grow, only specific part(s) of the plant generate profit (i.e. carry economic value) for the farmer. Therefore, depending on the type of the cultivated plant, the cropping pattern, various farming operations, and merchantability of the produced crop all play a role in the definition of "agriculture water productivity".

Using agricultural water productivity to benchmark the performance of irrigated agriculture has sometimes been questioned because the over-emphasis on the performance of just one production factor. Agricultural productivity depends on a number of inputs, and each farmer will strive to use the proper mix of these inputs to obtain optimal results within the particular context that he or she operates. Maximizing production per cubic meter of water may often not be the only or even the most rational thing to do; maximizing nutrition or labour input per cubic meter might be a better option for many farmers.

Similarly, the concept of agricultural water productivity has sometimes met with skepticism because it doesn't consider the costs and risks to a farmer. Water productivity is often not the driver of investment decisions; the ratio between the costs and benefits of investing in more productive water use is, it is argued, a more appropriate yardstick.

Water efficiency and water productivity are sometimes used interchangeably. Yet, they refer to very different concepts and apply to very different contexts. Water use efficiency often relates to the amount of water used to meet crop ET. Any excess over and above the amount of water required to meet ET is counted towards inefficiency. Water productivity relates to the value produced with a given volume of water. Water productivity can increase even if water use efficiency does not, e.g., by growing higher value crops with the same amount of water and the same amount of return flow. Water productivity does not only relate to agriculture – in fact, saving water in agriculture and reallocating these savings away from agriculture can often increase water productivity as the value produced with a given amount of water is often higher outside agriculture. In open river basins (those basins that have unused water available), the emphasis is often on capturing more water for productive uses. In closed basins (i.e., no usable water is left in the basin), increasing water productivity and allocation water to those users that add most value to the economy becomes increasingly important.

The schema prepared by Molden (2003, Figure 3) is helpful in better understanding water availability and efficiency.

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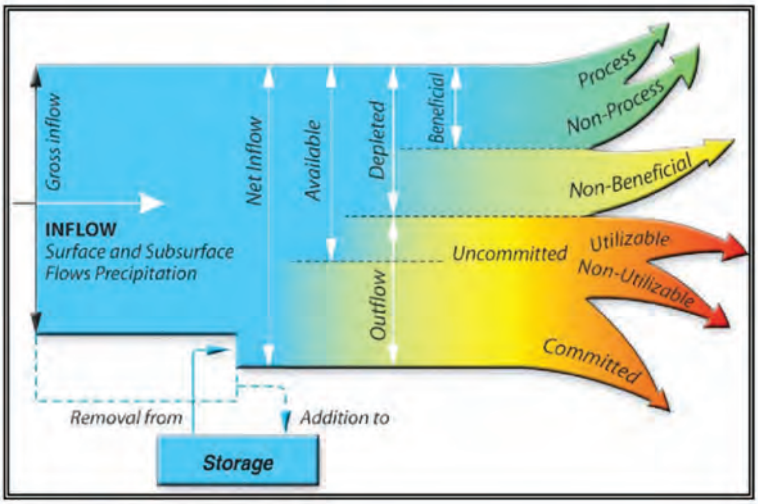
[2] Beyond Crop per Drop Assessing Agricultural Water Productivity and Efficiency in a Maturing Water Economy. Susanne M. Scheierling and David O. Tréguer

Molden et al. (2001a, 2003, 2007b) identifies the following four pathways for increasing water productivity at the irrigation system or at basin level: (i) increase yield per unit of water consumed, (ii) reduce non-beneficial depletion, (iii) tap uncommitted flows, and (iv) re-allocate water among uses. While the pathways relate to different definitions of water productivity, they are helpful for water practitioners to define strategies to increase water productivity.



Water accounting framework (Molden et al., 2001).

Figure 3. Water Allocations

Partly as a result of misunderstandings in the definition of water productivity and its application, myths associated with water productivity abound. The ones encountered most frequently include:

(a). Efficiency at scheme level is often confused with efficiency at river basin level. While there is a general recognition that irrigation efficiency at scheme level is often low, some authors have pointed out (Horst 1992, Seckler 1996) that, when excess water from inefficient irrigation is returned to the river and used for irrigation in downstream irrigation systems, overall efficiency at basin level can actually be high. E.g., in cascades of tank irrigation systems, downstream tanks often rely on the return flows from inefficiently used irrigation water in the upstream tanks. In fact, increasing irrigation efficiency at tank level may lead to reduced return flows and reduced inflows into the downstream tanks in the same cascade. Efficiency improvements turn out to be zero-sum efforts.

(b). Recent research has provided a growing body of evidence that suggests that investments in more efficient irrigation don't necessarily unlock water for use for alternative purposes. In many cases, investments in more efficient irrigation technologies have led to an expansion of the irrigated area and to more and not less water consumption. This is particularly true when farmers don't save money when saving water. In these cases, the only rational reason for a farmer to invest in water savings is to expand his irrigated area using the saved water. Where farmers do pay per m3 of water, they use it more efficiently: in Spain, for example, groundwater irrigators apply less water than surface water irrigators and achieve higher returns for their output per unit of water applied (Garrida et al. 2005, Shah 2014). In West

Bengal, research found that electricity metering resulted in a significant reduction of hours pumped during the summer season, and that the resulting 33% decrease in water use did not affect the crop yield of summer paddy or cropping patterns (J.V. Meenakshi et al., 2013).

In summary, there is an urgent need to develop a clear definition of water productivity and apply this in a consistent and coherent manner. The definition should account for the fact that in many basins, return flows are recycled numerous times, make a clear distinction between water efficiency and water productivity, and consider the benefits from agriculture and other sectors.

3. WHAT IS RURAL TRANSFORMATION?

Rural transformation is an active, positive procedure of change and development in rural communities in terms of social and economic national and international changes (Long, Zou, Pykett, & Li, 2011; Wang, Khan, & Zhang, 2013). This often includes a growing urban influence on rural livelihoods and changes in the systems and processes, which often significantly affect the lives of those living in villages. It is essential to note that rural transformation is not equivalent to rural development. Rural development is the process of improving people's livelihoods in rural areas (Moseley, 2003). Rural development is traditionally focused on utilization of natural resources including agriculture and forests. Rural transformation is a more dynamic notion than rural development; in fact, transformation concerns the people's attitudes in life (Shaw, 2011).

Rural transformation may be defined as a process of comprehensive societal change whereby rural societies diversify their economies and reduce their reliance on agriculture; become dependent on distant places to trade and to acquire goods, services, and ideas; move from dispersed villages to towns and small and medium cities; and become culturally more similar to large urban agglomerations. (Julio A. Berdegué, Tomás Rosada, Anthony J. Bebbington (2014).

Rural transformation should be supported with adequate policy decisions along with intervention from the private and public sectors so that the rural space turns into a more sustainable, society-based ecologic entity.

4. HISTORICAL DEVELOPMENT

Both total and agricultural water withdrawals have increased dramatically since 1900, but their rates of growth have declined since about 1980 (see Figure 4). In most Organisation for Economic Co-operation and Development (OECD) countries, total and agricultural water withdrawals have tended to remain stable or decrease (OECD 2015).

Evaluation of past trends in water productivity is problematic because of limited data availability. It is only in the past 20 years that remote sensing technologies have become available that have spurred more accurate estimates of water productivity. Most historic analyses are therefore based on crop-hydrology models. E.g., Cai and Rose grant (2003) use the IMPACT-WATER model for the analysis of water productivity for irrigated rice. Figure 5 presents water productivity estimates for irrigated rice based on the IMPACT-WATER model.

In addition to water productivity increases, important transformations are happening in rural areas that have an impact on and are impacted by water use. Increasing agricultural water productivity is both driven by and is a driver of rural transformation. Significant changes in the population and its build-up have taken place, with a higher percentage of young people, and migration of many of these young people to cities. Standards of living in rural areas have been rising, triggering among others a change in diets. Infrastructure services have reached rural areas, including internet and mobile phones, while access to energy (including through solar panels) has improved. Affordable technologies have become available for farming, including low-head pumps, micro irrigation and solar powered irrigation systems that in combination with "net-metering [3]" have the promise of revolutionizing the productivity of agricultural water.

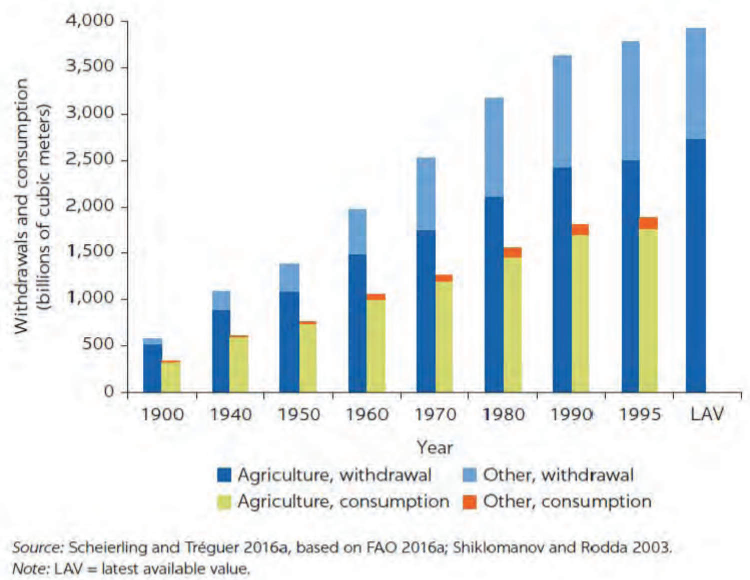


Figure 4. Global Trends in Agricultural and Total Water Withdrawals and Consumption

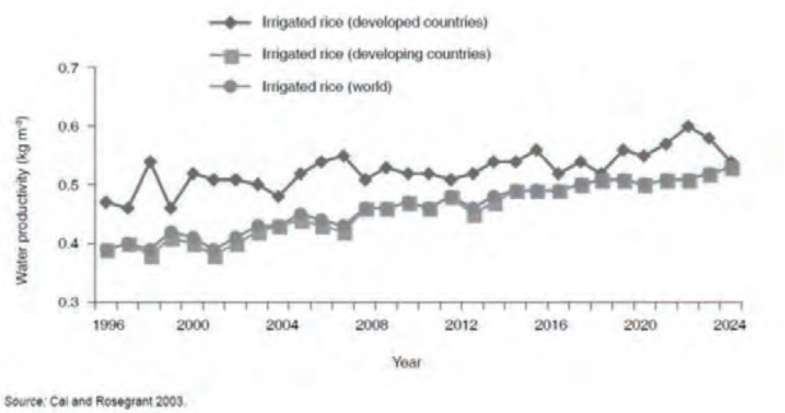


Figure 5. Water Productivity Estimates for Irrigated Rice

[3] Net metering credits owners of solar energy systems for the electricity they supply back to the grid.

5. STATE OF THE ART

This paper distinguishes between different interventions to increase agricultural water productivity: technologies, institutions, policies, and incentives. Each one of these may operate on the four pathways identified by Molden.

With the emergence of remote sensing technologies, monitoring of water productivity and evaluation of the effectiveness of efforts to improve it have come within reach. This is important as a clear understanding is required of what works and what doesn't. Similarly, the use of drones in irrigation management, e.g., to detect non-beneficial ET and leakages is being scaled up throughout the world. Innovative ICT products and services include Irrigation Analyst, Geographic Information System and IrriSat system, and numerous mobile apps that have been developed. Advanced hydrological models such as Groundwater Flow Modelling for Managed Aquifer Recharge in Thailand also help in monitoring, forecasting and evaluating water productivity. In Nebraska (USA), the Agricultural Water Management Network installed soil moisture sensors in highly efficient irrigation systems and conducted extensive farmer outreach. As a result, over USD $35 million was saved in energy costs through increases in water use efficiency (Irmak, 2012). In western India, farmers are using mobile phones to activate electric irrigation pumps in their fields (PC World, 2009), and pastoralists in Kenya are uploading on-the-ground water conditions to calibrate satellite data, forming a real-time map of forage and water conditions (Kamadi, 2012). In Iran, Khoshnavaz et al. (2016) used satellite images and applied SEBAL algorithms to estimate productivity across farms in Qazvin Plain, Iran, using estimates of water productivity as per the satellite images.

In a research, Diani et al. (2004) prepared a geographic information system for Kowsar Irrigation and Drainage Networks in Khuzestan Province, Iran, and provided the farmers with the required amount of water for irrigating different parts of the farms by identifying critical parts of the farm based on salinity and drainage, selected cropping pattern, meteorological parameters, and local soil properties.

Water Accounting+ in Sri Lanka[1]

Water accounting is the process of communicating water resources related information and the services generated from consumptive use in a geographical domain, such as a river basin, a country or a land use class; to users such as policy makers, water authorities, managers, etc.

A study was conducted to assess the annual water balance for each of the 103 river basins in Sri Lanka by using observed rainfall and remotely sensed actual evaporation rates. The SEBAL algorithm was used to assess the actual evaporation and storage changes in the root zone on a 10- day basis. The water balance was closed with a runoff component and a remainder term. Evaporation and runoff estimates were verified against ground measurements. The remainder term appeared to be less than 10% of the rainfall, which implies that the water balance is sufficiently understood for policy and decision making.

The results show that the irrigation sector uses not more than 7% of the net water inflow. The total agricultural water use and the environmental systems usage is 15 and 51%, respectively of the net water inflow. The consumptive use of rain-fed and irrigated agriculture is approximately equal. The study found that evaporation rates in agriculture and mixed vegetation are similar, so that low productivity rangelands can be transformed into rain-fed agriculture without detrimental effects on water availability to downstream users. The unused water flow to the Indian Ocean is 34% of the net inflow, hence there is scope for further water developments in Sri Lanka.

[1]http://www.wateraccounting.org

Agronomic innovations to improve water productivity include zero tillage, systemerizicoleintensif (SRI) in combination with rice ratooning as practiced in West Sumatra, laser land levelling, use of “happy seeder”, mulching, changing crop planting dates to match periods of less evaporative demand, and intercropping (e.g., of wheat and maize in China). It may also include the added value of tourism, e.g., in Bali’s subak system. Improvements in the access to agricultural markets, reduction of post-harvest losses, and grading and standardization (to name a few) all have a demonstrated impact on water productivity. Greenhouse agriculture represents another approach to optimal use of water for crop productivity. Saliha (2005) found that irrigation with magnetized water adds to crop yields and quality of the final product. Zanganeh (2006) showed that magnetized water can be used to enhance water productivity and germination rate.

Important improvements in water productivity can also be achieved through better linkages between farmers and markets. In many cases, farmers don’t adopt higher value crops because the markets for higher value products either don’t exist, or are too demanding in terms of the harvest date, the quality and the uniformity of the produce. Higher value crops are often perishables and require well performing markets with adequate critical mass of buyers and sellers. In view of these challenges, farmers often prefer to continue growing lower value cereals, thereby foregoing the benefits of higher water productivity.

Improving livestock water productivity in sub-Saharan Africa (SSA)[1]

Livestock keeping is the fastest growing agricultural sector in SSA. Besides the economic benefits, rising livestock production could also deplete water and aggravate water scarcity at local and global scales. Innovative and integrated measures are required to improve water productivity and reverse the growing trends of water scarcity.

The study found that livestock water productivity (LWP), defined as the ratio of livestock outputs to the amount of water depleted, could be improved through: (i) raising the efficiency of the water inputs by integrating livestock with crop, water and landscape management policies and practices. Improving feed water productivity by maximizing transpiration and minimizing evaporation and other losses is critical; (ii) increasing livestock outputs through improved feed management, veterinary services and introducing system- compatible breeds; and (iii) because livestock innovation is a social process, it is not possible to gain LWP improvements unless close attention is paid to policies, institutions and their associated processes.

Policies targeting infrastructure development would help livestock keepers secure access to markets, veterinary services and knowledge.

[1]Amede, Tilahun et al (2009)

https://www.researchgate.net/publication/235961349_Harnessing_benefits_from_improved_livestock_water_productivity_in_croplivestock_systems_of_sub-Saharan_Africa_Synthesis

Incentivizing farmers to adopt micro-irrigation [1]

Many investments can contribute to on-farm water saving—but in the end it will only happen if the farmer him/herself is both motivated and enabled. On-farm technologies like piped distribution, drip, and bubbler are widely available, and can cost as little as US$250 to $500/ha. Treadle pumps that can irrigate up to 0.5 ha using family labour cost only $50 to $100. A wide range of water management and crop management improvements is known. Yet adoption of water saving technologies has been slow and performance below potential.

Investment in water saving will be optimal in the private and public interest only where both available technology and favourable incentive and institutional structures are present. In the end, the incentive structure is the key: if water is too cheap, markets are dysfunctional, or water rights are insecure, farmers will not save water. In the end, only the prospect of higher farmer net income and lower risk will drive investment and water saving.

[1] World Bank (2005) http://web.worldbank.org/archive/website00660/WEB/PDF/WATER_FO.PDF

Examples of successful technologies include a broad set of pressurized micro- or precision irrigation technologies and sub-surface drainage systems. Other technologies include desalination and wastewater treatment. Better water management and improving the quality of irrigation service delivery can help make water supply more predictable so that farmers can invest in more and better inputs. “Tail to head” supply, such as practiced in Telangana (India), can help reduce wastage and improve water efficiency and productivity, as well as supplemental and deficit irrigation, and alternate wet and dry irrigation of rice. Increased water storage can help transfer excess water from the wet season to the dry season, while ensuring a more productive use of water at basin level throughout the year. Agricultural mechanization often serves as a fundamental and effective factor in enhancing the production and productivity of water. Among others, through the utilization of agricultural machinery (for land preparation, planting, cultivation, and harvesting) contributes to enhanced production and water productivity (Abbasi et al., 2017).

Innovative Financing for Water Productivity: Gujarat’s Drip Pool Programme[1]

To promote adoption of micro-irrigation, the government of Gujarat has formed a Special Purpose Vehicle (SPV) called Gujarat Green Revolution Company (GGRC). GGRC provides subsidies to farmers to install micro-irrigation technologies, such as drip irrigation. These subsidies cover about 40 per cent of the cost of installation and the remaining amount is expected to be borne by the farmers themselves. As small and marginal farmers do not have the financial resources to pay this additional amount, large and medium farmers constitute 60 per cent of the beneficiaries of this subsidy.

To address the gap, the Drip Pool Programme has set up a community financing mechanism to provide interest-free loans to such farmers. The loans help them avail the subsidy by providing the additional amount required for installation of drip irrigation units. The fund is currently managed by Farmer Producer Companies (FPCs). The programme is also strengthening capacities of FPCs to manage the fund on their own and by connecting farmers to the market. About 98 per cent of the farmers who availed the subsidy are small and marginal farmers.

[1]https://www.candafoundation.org/en/our-work/results-and-learning/drip-case-study.pdf

Improving water productivity requires ‘institutions of innovation’ that involve a range of actors, from public and private actors, academia and research institutions, producers, and water management agencies. E.g., the International Water Management Institute (IWMI) presented new approaches to rainwater management in Ethiopia which involved the integration of technologies, institutions and policies (Sharma, 2012). Institutions for improving water productivity include in particular grassroot organizations (e.g., in the Urmia Lake Basin) that monitor water use and use social collateral for reducing losses. Introduction of cooperative water management of canals can also improve the quality and quantity of water supply. The Natural Resources Districts in Nebraska provide an interesting example of how local level management and control of groundwater can improve both productivity and sustainability (Bleed, 2013).

Regulation, policies and demand management are indispensable as part of a comprehensive package of water productivity reform measures. Examples include the introduction of volumetric water fees in the Zhanghe Irrigation District in Hubei Province (Molle and Berkoff 2006), adoption of water withdrawal caps in Australia and introduction of water withdrawal rights. Efforts to reallocate water among users, e.g., through establishment of water markets or the introduction of river basin organizations also need mention. Faramarzi et al. (2010) adopted a virtual water strategy to optimize water consumption and crop yield through regional trade, and found that adjustments in cropping patterns lead to water savings while increasing crop yield.

Water Users Associations and Irrigation Water Productivity in Northern China[1]

A study was conducted in China to examine the underlying causes of differences in WUA performance by analyzing the impact of WUA characteristics on the productivity of irrigation water. Applying a random intercept regression model to data collected among 21 WUAs and 315 households in Minle County in northern China, the study found that a number of factors that are commonly identified as common pool resources need to be taken into account if WUAs are to be successful in promoting higher water productivity. E.g., group characteristics is an important factor in water productivity: large groups tend to have greater difficulties in overcoming problems of collective action and free-riding. A large number of sub-groups, i.e., water users' groups (WUGs), within a WUA can promote water productivity by allowing more crop diversification and by a better tuning of planting and irrigation decisions among member households. Another group characteristic that affects water productivity is heterogeneity of land endowments, which is found to have a positive effect on water productivity of member households in a WUA.

Another factor that explains differences in water productivity is the pressure on the water resource. The study found that a high pressure caused by a large unmet water demand negatively affects water savings in crop production, while the share of households with migrant heads in a WUA positively affects the productivity of water use. Another noteworthy result is that the study does not find evidence that resource characteristics, i.e., resource size and degree of overlap between the WUA boundaries and natural boundaries, affect water productivity in our research area.

[1]https://www.sciencedirect.com/science/article/pii/S0921800913002711#bb0005

Irrigation Charges in Morocco[1]

Morocco has a clear policy for irrigation service charges in all major schemes, requiring full recovery of operation, maintenance, and replacement costs, plus a large part of capital costs. Charges, levied volumetrically—at US$0.02 2/m^3 or more (equating to $100 to $200/ha)—are high by international standards for surface irrigation. Even at this price, demand for water would exceed supply, because returns on water are about 10 times the volumetric price. Demand management is therefore achieved through quotas specified and measured at farm level. Cost recovery is high, and most systems cover at least operation and maintenance costs.

[1]Source: Cornish and Perry 2003. In: Shaping the Future of Water for Agriculture a Source book for Investment in Agricultural Water Management

6. RURAL TRANSFORMATION AND AGRICULTURAL WATER PRODUCTIVITY

Many of the measures to improve water productivity require significant changes in the production systems of farmers and in the support that is provided by the public and private service providers – extension services, input suppliers, agricultural off-takers, etc. E.g., switching from low value cereals to higher value horticulture crops requires significant changes to the farmers' knowledge, equipment, staffing, marketing channels, fertilizer use, finance, etc. Cold storage needs to be developed in addition to investments in marketing infrastructure and market intelligence. Converting to higher value crops may also require changes in the public policy when lower value cereals are subject to a guaranteed price and other biased support measures that provide a disincentive to convert.

Changes also need to be made to the irrigation infrastructure. Conventional flood irrigation systems need to be retrofitted to accommodate the more frequent supply of smaller amounts of water that are required by higher value horticulture crops. This often requires installation of sub-surface pressurized pipe systems and/or development of on-farm storage. The quality and reliability of irrigation services require a quantum leap; in many cases, on-demand delivery of water will be expected by farmers to meet the demands of markets.

In many irrigation systems, these changes cannot be made by an individual farmer. Converting to higher value production requires rural transformation at the tertiary unit level. Support is required in the early days of this conversion to address market failures, and care should be taken that this support does not provide perverse incentives and crowds out private sector initiatives.

Given the above discussion, it is important to take great care in the design and implementation of the rural transformation process. Increasing agricultural water productivity through rural transformation must strive to achieve the highest societal value of water which requires institutional support, multi-sector capacity strengthening and empowerment of rural communities to provide incentives to adopt the changes. In that regard, taking particular account of the inhabitants' domestic, local knowledge is imperative.

7. FUTURE OUTLOOK

Water use and competition over water is expected to further increase. Freshwater withdrawals have tripled over the last 50 years, and demand for freshwater is increasing by 64 billion cubic meters per year. Today, 70% of global water withdrawals are for agriculture. Feeding 9 billion people by 2050 will require a 15% increase in water withdrawals based on today's irrigation efficiency. By 2025, about 1.8 billion people will be living in regions or countries with absolute water scarcity. The combined effects of growing populations, rising incomes, and expanding cities will see demand for water rising exponentially, while supply becomes more erratic and uncertain.

Significant shifts of inter-sectoral water allocations will be required to support continued economic growth. Due to population growth, urbanization, industrialization and climate change, improved water use efficiency will need to be matched by reallocation of as much as 25 to 40% of water in water stressed regions, from lower to higher productivity and employment activities. In most cases, this reallocation is expected to come from agriculture, due to its high share of water use. However, recent evidence suggests that water savings achieved in agriculture are often used to expand existing agriculture and are not reallocated away from agriculture.

Technological innovations combined with changes in the policy environment will need to play an increasingly important role in agricultural water management. Advances in the use of remote sensing technologies are now making it possible to cost-effectively estimate crop evapotranspiration (the sum of evaporation and plant transpiration to the atmosphere) from farmers' fields and to improve water accounting and management at the regional and basin-wide levels, e.g., in the Xinjiang Turpan Water Conservation Project in China. Institutions need to be strengthened, including Associations of Water Users and councels and agencies for River Basin Management, and institutional and policy reforms need to be pursued and scaled up to underpin the improved capacities.

Most importantly, incentives need to be provided to farmers to use water more efficiently and productively, including through adequate demand management measures. Adoption of appropriate technologies needs to be scaled up and support needs to be provided to accompanying the rural transformation to take the quantum leap in the improvement of water productivity that is required to ensure sustainable use and water security for all.

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Sub-theme 1. Enabling Policy Environment for Water, Food and Energy Security

Topic 1.1 Sustainable water Resources management policy; integration of surface water and groundwater to ensure water sustainability for environment and ecosystem, to support water, food, and energy security.

Topic 1.2 Sustainable development of small and large scale irrigation system, lowland development and management for food security policy within the framework of global climate change, land consolidation management, and land conversion protection

Topic 1.3 Improvement of irrigation water productivity policy including efficient and effective water use, financing aspect, incentive and disincentive system, capacity building including non-state actors, Utilize SMART irrigation management.

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MICRO IRRIGATION INFRASTRUCTURE ON CANAL COMMANDS FOR SUSTAINABLE RICE AND WATER PRODUCTIVITY UNDER DECLINING WATER AVAILABILITY IN NORTH-WESTERN PLAINS OF INDIA

Neeraj Sharma[1], Rakesh Chauhan[2], A K Bhardwaj[3] and T. Pandiaraj[4]

ABSTRACT

Rice is a predominant crop of north-western plains of India contributing substantially to the country's agricultural growth and food security. Rice cultivation requires extensive irrigation, which implies dependence on large quantities of canal & ground water. The Rice crop consumes 3000-5000 liters of water to produce one-kilogram rice, causing decline in ground water table 40-50cm per annum as conventional methods of water conveyance and application are highly inefficient. The quality of ground water is also not suitable for irrigation in most of the parts of North Western plains, so farmers largely depend on canal water which is also not available at tail end in the dark zones of the region. To overcome the water crises and to improve rice productivity, the existing irrigation infrastructure of open channels at field level has been converted into solar/grid connected pressurized pipe irrigation system in the canal commands, readily available for installing Micro Irrigation Systems. To motivate the farmers towards Micro Irrigation Systems in Rice crop an on-farm trial was initiated for two years with three planting methods i.e. manual and mechanical transplanting in puddled soil and direct dry seeding of rice (DSR) with three irrigation practices of flood, drip and sprinkler. Preliminary results revealed that drip irrigation potentially saved 56% and sprinkler irrigation 50% water in comparison of flood irrigation. The analysis of results indicates that pressurized irrigation is a viable option for higher rice and water productivity in canal commands.

Keywords: Rice, Micro irrigation system, Water Use, Yield, Solar/Grid, Canal Command.

1 Executive Engineer, Command Area Development Authority (Haryana), India.
2 Chief Engineer, Command Area Development Authority (Haryana), India.
3 Advisor, Jain Irrigation System Ltd.
4 Assistant Professor, Department of Agronomy, College of Agriculture, (NDUAT), Azamgarh, UP, India

EFFECTS OF IRRIGATION WATER SALINITY ON SOIL N^2O EMISSION AND YIELD OF SPRING MAIZE UNDER MULCHED DRIP IRRIGATION

ChenchenWei[1], Peiling Yang[1,],Shumei Ren[1], Shuaijie Wang[1], Yu Wang[1] and Ziang Xu [1]

ABSTRACT

Brackish water has been widely used to irrigate crops in parts of the world due to insufficient water supply for agriculture. In order to achieve the goal of efficient utilization of brackish water and N_2O emission reduction, a two-year field experiment (2017-2018) was conducted in Hetao Irrigation District, Inner Mongolia, China. The experiment with one local conventional irrigation (1.1 g/L, flood irrigation) and four salinity levels of irrigation water (1.1, 2.0, 3.5, 5.0 g/L, drip irrigation), was carried out to study the effects of different irrigation methods and water salinity on soil properties, soil N_2O emission, and yield of spring maize under mulched irrigation. The results showed that the N_2O emission peaks in all treatments were mostly concentrated in 1-5 days after irrigation and fertilization. Compared with flood irrigation treatment, drip irrigation treatments significantly reduced N_2O emission. Although it promoted the accumulation of salt in soil tillage layer, it was still suitable for maize growth. Compared with 1.1-2.0 g/L drip irrigation treatments, 5.0 g/L treatment significantly increased N_2O emission, and increased soil water and salt content ($Ec_{1:5}$), which accelerated soil salinization and resulted in negative influences on maize growth. The correlation analysis showed that the average N_2O emission flux was positively correlated with soil water content and soil $Ec_{1:5}$. Irrigation method had no significant effect on yield and IWUE of spring maize, irrigation water salinity had significant effect on yield and IWUE. The yields of 2.0-5.0 g/L treatments were decreased by 7.60%-23.93% in 2017 and 13.86%-31.47% in 2018 compared with 1.1 g/L treatment. These results suggested that reducing irrigation water salinity may be an effective way to reduce soil N_2O emissions, alleviate soil salinization degree and increase yield.

Keywords: irrigation water salinity, soil N_2O emission, yield, soil properties, spring maize.

1 College of Water Resources and Civil Engineering, China Agricultural University, Beijing 100083, China; weichenchen@cau.edu.cn (C.W.); cauren@126.com (S.R.); wangshuaijie118@163.com(S.W.); wangyucau@cau.edu.cn(Y.W.); xzang1996@163.com(Z.X.); 32+Correspondence: yangpeiling@126.com; Tel.: +86-10-6273-7866; Fax: +86-10-6273-7866

SUSTAINABLE MANAGEMENT OF WATER IN NORTHERN CALIFORNIA, USA, FOR FOOD, ENERGY, AND ENVIRONMENTAL SECURITY

W. Martin Roche[1]

ABSTRACT

Sustainable management of water for food security, municipal and industrial use, energy, and the environment is important in the twenty first century. In Northern California, USA, surface and ground water resource are generally adequate in most years to meet all needs and to provide water to other areas of California where water demand usually exceeds local supplies.

The average annual runoff in the Sacramento River Basin in Northern California is over 27 billion cubic meters (22 million acre-feet) per year, over one third of the total runoff in all of California. The area also includes some of the foremost groundwater basins in California. In recent years over 3.33 billion cubic meters (2.7 million acre-feet) of groundwater was used each year, about 30 percent of the total water use. In addition to agricultural irrigation, many cities obtain part or all of their water supply from groundwater. Some agricultural areas are able to pump groundwater which makes available some of their surface water supply to flow out of the area for environmental preservation and for sale to water short areas in California.

In 2014 California adopted the Sustainable Groundwater Management Act, which resulted from growing concern throughout the state of overuse of groundwater. Groundwater Sustainability Agencies have been formed, with the goal reaching sustainability of their groundwater basins within 20 years. In Northern California most of the groundwater basins are already sustainable, with the opportunity to provide much needed water to other areas of California where sustainability will be difficult to achieve.

One of the major food crops raised in the area is rice. Of the approximately 243,000 hectares (600,000 acres) of rice production in California, 95% are in Northern California. About 30 percent of rice is consumed domestically, with 70 percent going to world markets. Yields can exceed 11,200 kilograms per hectare (10,000 pounds per acre), about 20% higher than United States and world average. Although small by comparison to total world production, rice produced in Northern California contributes to food security throughout the world. Rice grown on one hectare of land in Northern California can provide a subsistence diet for 111 people of about 975 calories per day(one acre provides subsistence for 45 people).

Energy sustainability is also important in California and throughout the world. California has set a goal of meeting all energy demands from renewal resources by 2045. One rice grower and dryer in Northern California has installed 2.3 megawatts of solar panels, which provides all the energy needs for the rice dryer.

Keywords: Water Management, Food Security, Energy Security, Environmental Security, Groundwater

1 Consulting Engineer, 13879 Naomi Way, Grass Valley, California, USA; E-mail: wmroche@usamedia.tv

NITROGEN AND PHOSPHORUS LOSS CHARACTERISTICS UNDER AN IMPROVED SUBSURFACE DRAINAGE

YuanTao[1], ShaoliWang[1], XiaoyanGuan[1], Di Xu[1] and Haorui Chen[1]

ABSTRACT

In this paper, nitrogen and phosphorus loss under improved subsurface drainage with different filter materials (gravel, layered sand-gravel, mixed sand-gravel, straw) were compared with the conventional subsurface drainage. The pH values, total nitrogen, ammonia nitrogen, and total phosphorus were studied. The results showed that the nitrogen and phosphorus concentrations of drain outflow under improved subsurface drainage with gravel filter were larger than that with layered sand-gravel filter and mixed sand-gravel filter. The improved subsurface drainage with layered sand-gravel filter and mixed sand-gravel filter had an effect on reducing the ammonia nitrogen and total phosphorus concentrations of the outflow. While the characteristics of nitrogen and phosphorus loss under the improved subsurface drainage with straw filter were different from layered sand-gravel filter and mixed sand-gravel filter. For the improved subsurface drainage with layered sand-gravel filter outflow, the ammonia nitrogen, total phosphorus concentrations were about 13%~78%, 38%~63% less and total nitrogen concentrations were 24%~80% more than that under conventional subsurface drainage. Tthe improved subsurface drainage with straw filter outflow, compared with conventional subsurface drainage outflow, the percentage changes of the total nitrogen, ammonia nitrogen and total phosphorus concentrations were about -76%~62%, -152%~-274% and-103%~-400% respectively. In the outflow in all types of drainage filters, high total nitrogen concentrations were observed which should be focused and appropriate agricultural water management should be adopted.

Keywords : Improved subsurface drainage; nitrogen and phosphorus loss; filter materials; field experiment.

1 Department of Irrigation and Drainage, China Institute of Water Resources and Hydropower Research, Beijing, 100048.); E-mail: taoyuanss.good@163.com

MULTIFRACTAL CHARACTERISTICS OF SOIL PARTICLE SIZE DISTRIBUTION UNDER SEWAGE IRRIGATION IN DIFFERENT IRRIGATION YEARS

GUAN Xiao-Yan[1,2,] and LV Ye[1]

ABSTRACT

Soil particle size distribution (PSD), is one of the most important soil physical properties, has strong influence on soil hydraulic characteristics, soil fertility condition, the soil erosion and so on. Sewage irrigation causes the differences in soil PSD. Thus, soil may have massive organic contaminants and suspended particles. In this paper, the frequency and multifractal necessity of soil PSD under sewage irrigation in different years were analyzed. Soil PSD has a heterogeneous characteristic under sewage irrigation, and this heterogeneity can be characterized using the multifractal technique, which calculates the multifractal spectrum parameters. The results showed that the the width of multifractal spectrum $\Delta\alpha$ is directly proportional to clay content; a remarkable effect of sewage irrigation on multifractal parameters was observed. The soil structure quality decreased with increasing sewage irrigation years, However, the soil structure improved when the soil was irrigated with freshwater for a long period after sewage irrigation.Therefore, multifractal parameters may be a potential indicatorsfor soil physical property and soil quality.

Keywords: Soil particle size distribution, sewage irrigation, multifractal, heterogeneity

1 corresponding author : guanxy@iwhr.com, [1]State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing100038, China

2 National Center of Efficient Irrigation Engineering and Technology Research-Beijing, Beijing100048, China

OPTIMAL IRRIGATION PLANNING AND OPERATION OF RESERVOIR USING SELF-ADAPTIVE CUCKOO SEARCH ALGORITHM (SACSA)

Sriman Pankaj Boindala[1], Vasan Arunachalam[2]

ABSTRACT

Irrigation planning and operation of reservoir is one of the popular applications of optimization in water resource management. The complexity of this problem lies in its large dimensions (variables) and multiple constraints. This study focusses on determining the optimal cropping pattern which would maximize the annual net benefits from crop production. Cuckoo search is one of the promising Swarm Intelligence (SI) based metaheuristic algorithms for solving various engineering problems. There are two main parameters which govern the convergence speed and accuracy, (i) step length (α) and (ii) switching parameter (pa). It is a tedious task to find out the most suitable values of these two parameters which can efficiently solve a particular problem. To overcome this problem a self-adaptive version of this cuckoo search algorithm is proposed in this work. An Indian case study Mahi Bajaj Sagar project, Rajasthan, India is taken as an example for reservoir optimization problem. The results show that the optimal cropping pattern is obtained for a smaller number of function evaluations using SACSA making it much better suitable algorithm for solving this complex water resource problem. The improvement in the performance of SACSA than the original cuckoo search is due to its problem adaptive nature.

Keywords: Cuckoo Search, Swarm Intelligence, Self-adaptive Cuckoo Search, water resource management, reservoir optimization.

1 Graduate student, Department of Civil Engineering, Birla Institute of Technology and Science E-mail: srimanpankaj@gmail.com

2 Professor, Department of Civil Engineering, Birla Institute of Technology and Science E-mail: vasan@hyderabad.bits-pilani.ac.in

ENERGY PRODUCTIVITY OF INDIAN AGRICULTURE: ARE ENERGY GUZZLING DISTRICTS GENERATING HIGHER AGRICULTURAL VALUE?

Abhishek Rajan[1] and Kuhelika Ghosh[2]

ABSTRACT

Groundwater irrigation has been central to India’s irrigated agriculture. India is the largest extractor of groundwater, pumping nearly 250 km^3 every year for irrigation. The abstraction of groundwater is closely coupled with access to subsidized or free electricity in the country. Supply of free electricity has led to the perverse groundwater-energy nexus in the country. This nexus has resulted in grave economic and environmental repercussions. There is a mounting fiscal burden of energy subsidies in the country, which has led many power utilities at the helm of bankruptcy. At the same time, free power has attributed to the groundwater depletion at an alarming rate in many parts of the country. Hence, it becomes important to understand whether these economic and environmental costs of groundwater irrigation are commensurate with its benefits. This study takes a look at the energy productivity of groundwater irrigated agriculture in the districts of India and assesses its contribution to the agricultural output.

Keywords: Water-Food-Energy Nexus, Energy Productivity, Water Productivity, Sustainable Groundwater Use, India.

1 Research Consultant; IWMI-Tata Water Policy Program, Anand, Gujarat, India, E-mail: rajan_msit@yahoo.com
2 Research Consultant; IWMI-Tata Water Policy Program, Anand, Gujarat, India, E-mail: k.ghosh@cgiar.org

RECKONING THE GROUND WATER RECHARGE IN SEMI-ARID REGION: AN ASSESSMENT OF COMMUNITY LED POLICY PERFORMANCE IN SAURASHTRA

Praharsh Patel[1] and Dipankar Saha[2]

ABSTRACT

Easy access, round the year availability even in the draught years and lack of regulations coupled with advanced and cheap technology to create extraction structure have been major factors responsible for indiscriminate extraction of groundwater. With a rise in population leading to increasing water requirement, the untapped groundwater resource has been the biggest bone of contention amongst multiple stakeholders with a threat of serious depletion in many parts of the world especially regions without perennial surface water availability and arid or semi-arid climate. India is the largest extractor of groundwater and the alarming situation has already tapped in. Semi-arid region of Saurashtra has the most extreme case with just 500 mm of rainfall and almost 40 percent of coefficient of variation leading to frequent drought-like condition. Saurashtra's almost 83 per cent of the total irrigated area is through groundwater. High extraction of groundwater of Saurashtra caused major groundwater depletion in the region. The condition even intensified during consecutive drought years of 1985-87 when Saurashtra received just 93 mm of total rainfall during 1987 on top of 60 per cent rainfall in 2 consecutive drought years of 1985 (299 mm) and 1986 (298 mm). Severity of the condition led to a mass movement for rainwater harvesting as well as a decentralized groundwater recharge at an unprecedented scale. The community-led movement with the support of local leaders, merchants and religious gurus in the early 90s got support from the state government. The movement was formalized as Sardar Patel Sahkari Jal Sanchay Yojana (SPSJSY) soon after Narendra Modi assumed office as Chief Minister of Gujarat. Under this pan-Gujarat scheme, 5 lakh structures created (113738 check dams, 55917 bori bandhs, 240199 farm ponds, besides 62532 large and small check dams) making way for 808 MCM (Million Cubic Meter) of storage capacity. The scheme performed best in Saurashtra as almost 60 per cent of this storage capacity (482 MCM) confined in 7 districts of Saurashtra. The success of the program was much lauded by state and central governments making it exemplary for other semi-arid regions like Marathawada and Vidarbha those that have comparable terrain, soil and aquifer characteristics. The comparative analysis of the movement's success with pre-post analysis by considering monsoonal groundwater recharge during good rainfall spell of 1975-84 (pre) and 2004-09 (post) show almost a two-fold increase in the groundwater recharge during the similar monsoon years in Saurashtra. This temporal analysis enables to establish the impact of the collective efforts by people as well as the government for groundwater rejuvenation in Saurashtra. With availability of dependable irrigation, Saurashtra has also emerged as a major contributor to Gujarat state's agriculture growth which has normally been shadowed by other regions of the state making the state agriculture growth reaching the double-digit figure.

Keywords: Groundwater; Semi-Arid India; Saurashtra, Water Policy; Impact of Managed Aquifer Recharge; Impact Analysis.

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1 This paper is part of working paper named "Sustainability of Groundwater Through Community Driven Distributed Recharge: An Analysis of Arguments for Water-Scarce Semi-Arid India" Research Consultant, IWMI-Tata Water Policy Program (ITP), Anand, p.patel@cgiar.org

2 Ex-Member (Head Quarter), Central Ground Water Board, MoWR, RD & GR, Govt. of India, dsaha002@yahoo.com

A MODEL TO INTEGRATE AND ASSESS WATER-ENERGY-FOOD NEXUS PERFORMANCE: SOUTH AFRICA CASE STUDY

Luxon Nhamo[1], Tafadzwanashe Mabhaudhi[2] and Sylvester Mpandeli [3]

ABSTRACT

The main limiting factor impeding the operationalisation of the WEF nexus has been lack of metrics and tools to translate the concept into a full-fledged operational framework to support policy and decision-making. This study developed a WEF nexus model by (i) defining WEF nexus sustainability indicators, and(ii) calculating composite indices for those indicators to establish numerical relationships among WEF nexus resources using South Africa as a case study. The composite indices show WEF nexus performance as well as monitoring and evaluation of WEF resources management. The indicators were integrated through the Analytic Hierarchy Process (AHP) in a multi-criteria decision-making (MCDM). The established quantitative relationships indicate resource utilisation, management and performance through a spider graph to illustrate WEF nexus performance, providing a general overview of the level of interactions, inter-relationships and inter-connectedness of resources. The shape of the spider graph is determined by the level of the interdependencies and interactions among the WEF nexus sectors, whose management is viewed either as sustainable or unsustainable depending on the classification of the developed integrated index. The spider graph for South Africa showed an over-emphasis on food self-sufficiency and water productivity at the expense of other sectors. The deformed shape of the spider graph is a demonstration of the sectoral or “silo” approach in resource management. The calculated integrated WEF nexus index of 0.203 for South Africa classified the country under the low sustainability category. The developed model is a decision support tool that provides evidence for interventions in priority areas. The model demonstrates the capabilities of the WEF nexus to evaluate synergies and trade-offs in a systematic and integrated way to increases efficiency and productivity in resource management for sustainable development.

Keywords: Adaptation, climate change, composite indices, resilience, livelihoods

1 Researcher, International Water Management Institute (IWMI-SA), 141 Cresswell St, Weavind Park, Silverton, 0184, Pretoria, South Africa; E-mail: l.nhamo@cgiar.org
2 Senior Researcher, Centre for Transformative Agricultural and Food Systems, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, P/Bag X01 Scottsville 3209, Pietermaritzburg, South Africa; Email: Mabhaudhi@ukzn.ac.za
3 Executive Manager, Water Research Commission, 4 Daventry Street, Lynnwood Manor, Pretoria 0081, South Africa; Email: sylvesterm@wrc.org.za

ANALYSIS OF IRRIGATION WATER EFFICIENCY IN GUANGDONG PROVINCE BASED ON STOCHASTIC FRONTIER ANALYSIS (SFA)

Kang ZHANG[1], Zhipeng MA[2], Qunfang FAN[1 2], Jiangli ZHENG[3,]

ABSTRACT

Agriculturre has always been the largest user of water in most countries in the world. In particular, irrigation water for farmland accounts for more than 60% of total water use in China. With the increase of population and the development of social economy, the shortage of water resources has become an important bottleneck restricting development in most provinces or cities of China. In order to achieve sustainable socio-economic development, China has formulated a policy of water conservation priority and fully implemented the most stringent water resources management system, which mainly contains control the total water use, control the water use efficiency and restriction of pollutants in the water function areas. The key to saving water is improving water use efficiency. For agriculture, the effective use coefficient of irrigation is the main indicator which reflects the efficiency of irrigation water use, and it is also an important indicator of the most stringent water resources management system assessment.

However, the evaluation method for measurement result of the effective utilization coefficient of irrigation is still relatively Simple. In this paper, the technical efficiency of agricultural production is calculated and analysed by taking the Stochastic Frontier Analysis (SFA) model of econometrics in Guangdong Province of China. And the main influencing factors of food production such as labor force, total power of agricultural machinery, pure fertilizer use, grain sown area, and irrigation water consumption were analysed. Moreover, the index of irrigation water efficiency is calculated as single input factors of agricultural production, and a compared analysis with the effective utilization coefficient of irrigation is also conducted.

The main conclusions are as follows: (1) The water saving space of irrigation water is 23.9% under the condition that the other agricultural factors of agricultural production in Guangdong Province are kept constant; (2) The economic efficiency of irrigation water calculated by econometric model has a good correlation with the effective utilization coefficient of irrigation, and the correlation between them is linearly positive and the correlation coefficient R is 0.94 (3) Econometrics model of irrigation water efficiency can be used as reference for the assessment of the effective utilization coefficient of irrigation water in the most stringent water resources management system.

Keywords: Water Use Efficiency (WUE); Irrigation Water; Stochastic Frontier Analysis (SFA); Econometrics

1 Key Laboratory of the Pearl River Estuarine Dynamics and Associated Process Regulation Ministry of Water Resources, Guangzhou, China;
2 The Pearl River Hydraulic Research Institute, Guangzhou, 510611.
3 Corresponding author: zhangkang01@gmail.com

GRAVITY DRAINAGE FOR CROPPING INTENSIFICATION IN POLDERS OF THE COASTAL ZONE OF BANGLADESH

Manoranjan K. Mondal[1], Sudhir-Yadav[2], Elizabeth Humphreys[3], S V Krishna Jagadish[4], Zahirul H. Khan[5], Asish Sutradhar[6] and Farhana A. Kamal[7]

ABSTRACT

Bangladesh is currently self-sufficient in rice production; but is facing immense challenges of sustaining it due to the population growth and adverse effects of climate change. There is little scope to further increase cropping intensity except for the underutilized 1.2 M ha lands enclosed in the polders of the coastal zone. The rivers in the coastal zone are tidal with semi-diurnal water level fluctuations of 2 to 3 m and offer tremendous opportunities for agricultural development in the polders, which is not recognized by the professionals and policymakers. The late rice harvest and waterlogged soil prevent timely cultivation of dry season crops. But there are tremendous opportunities to capitalize on polder ecosystem services especially the tidal river dynamics, dense canal networks, water management infrastructure and community water management organizations to reduce waterlogging by gravity drainage during low tides and greatly increase land productivity. Synchronized crop and water management studies were conducted in a medium saline polder from 2015 to 2018 to assess the water inflow and outflow dynamics in relation to land topography and tidal fluctuations in the peripheral rivers and examine possibilities of cropping intensification in the coastal polders. The study demonstrated opportunities for cropping systems intensification and diversification with two to three times higher productivity than with the traditional farmers' practice through improved drainage capitalizing the water management infrastructure in the polders.

Keywords: Coastal zone, polder, tidal river, drainage, agricultural intensification, community water management, climate-resilient cropping, food security.

1 Water Scientist, Sustainable Impact Platform, International Rice Research Institute (IRRI), House 103, Road 1, Block F, Dhaka 1213, Bangladesh, email: m.mondal@irri.org

2 Senior Scientist, Sustainable Impact Platform, IRRI, Los Banos, Philippines, email: s.yadav@irri.org

3 Former Senior Scientist, Crop and Environmental Sciences Division, IRRI, Los Banos, Philippines, email: liz.humphreys2242@gmail.com

4 Associate Professor, Kansas State University, Manhattan, USA, email: kjagadish@ksu.edu

5 Director, Coast, Port and Estuary Division, Institute of Water Modeling (IWM), House 496, Road 32, Mohakhali DOHS, Dhaka 1206, Bangladesh, email: zhk@iwmbd.org

6 Junior Specialist, IWM, Mohakhali DOHS, Dhaka 1206, Bangladesh, email: ash@iwmbd.org

7 Associate Specialist, IWM, Mohakhali DOHS, Dhaka 1206, Bangladesh, email: fal@iwmbd.org

ASSESSING AGRICULTURAL RESERVOIRS AS THE SOURCES OF ENVIRONMENTAL FLOW: CASE STUDY IN KOREA

Kwang -Sik Yoon[1]*, Young-Jun Jo[2], Seung-Hwan Yoo[1]and Younggu Her[3]

ABSTRACT

The Yeongsan River, one of four major rivers in Korea, has been suffering from water quality degradation, which is caused by nutrient loadings from its drainage areas and accelerated by the large temporal variation of precipitation and water flow slowed due to hydraulic control facilities such as a weir. The Korean government is exploring affordable ways of securing environmental flow (EF) to improve the water quality in dry seasons, and agricultural reservoirs attract the attention of policymakers as an alternative source of EF. Recently, four large reservoirs located in the Yeongsan River basin were reinforced by raising the dam heights, and now they have the capacity of providing part of EF for the Yeongsan River while continuing tomeet their operational goals. This study assessed the EF supply potential of the four agricultural reservoirs with the goal of providing information required to develop EF supply plans for the Yeongsan River. A reservoir water balance model was prepared to mathematically represent the reservoir systems and quantify the temporal variations of the amount of water available for the EF supply. The simulation model was designed to explicitly consider inflow from the upstream drainage area, irrigation water requirement, and hydrological processes happening in the reservoirs. In the reservoir water balance analysis, five different supply periods were evaluated, and agricultural water supply was given priority over the EF. Results showed that the four reservoirs could hold a total 76 Mm^3 of surplus storage capacity, which can be used for purposes other than irrigation, by adding 48 Mm3 to the current capacity of the Yeongsan River basin. The surplus capacity turned out to be enough to satisfy the various EF supply requirements in the scenario analysis. This study also demonstrated that it would be necessary to consider the temporal variations of EF when developing reservoir operation rule and plans to secure water resource supply stability. The study results highlighted the unconventional roles of agricultural reservoirs as resources that can be used to improve the environmental quality and ecosystem. The methods presented in this study are expected to be a useful tool for the assessment of the EF supply potential of an agricultural reservoir.

Keywords : Agricultural Reservoir, Environmental Flow.

1 Department of Rural & Bio-systems Engineering, Chonnam National University
2 Korea Rural Community Corporation, Naju, Republic of Korea
3 University of Florida, Department of Agricultural and Biological Engineering / Tropical Research and Education Centre

* Corresponding author: Department of Rural & Bio-systems Engineering, Chonnam National University, 61186 Gwangju, Republic of Korea, ksyoon@jnu.ac.kr

GROUNDWATER QUALITY CONCERNS STILL EXIST IN HIGH WATER PRODUCTIVITY AREAS

Chittaranjan Ray[1] , Crystal A. Powers[1,2], and Mesfin M Mekonnen[2]

ABSTRACT

Water productivity (WP) of a crop is the ratio between the economic or physical yield and the amount of water used to produce that crop. The water can be green water (rain water or soil moisture) or blue water such as surface and groundwater used for irrigation. In water stressed regions, a yield enhancement is generally obtained with irrigation. While high water productivity (efficiency) is desired for food & economic security impacts on groundwater quality are less well-studied. As the water moves down the soil profile, it carries dissolved chemicals to the underlying aquifer. Groundwater contamination from nitrate and pesticides is ubiquitous in shallow unconfined aquifers, and is appearing in deeper unconfined aquifers with some time delay. While a conversion of gravity (flood and furrow) irrigation to sprinkler or drip systems uses less irrigation water per unit land, ground water quality impacts cannot be eliminated unless close attention is paid to water, nitrogen and other management factors. Residual soil moisture, rain events prior to planting or in early stages of plant growth, and one time application of all nitrogen fertilizer for a field season are some of factors that contribute to excess leaching of nitrate to ground water.

Keywords: groundwater quality; gravity irrigation; sprinkler irrigation; nitrate; uranium; arsenic; fertigation

1 Nebraska Water Center, [2] Robert B. Daughery Water for Food Institute, University of Nebraska, 2021 Transformation Drive, Suite 3220, Lincoln, NE 68588, USA

WATER ENERGY FOOD NEXUS IN PRACTICE : EXAMPLES FROM SOUTH ASIA

S.A. Prathapar[1], A. Cauchois[2] and L. George[3]

ABSTRACT

The Nexus among Water, Energy and Food (WEF) in three potential investment projects in South Asia were studied to understand how these three resources interact and affect the project outcomes. The Projects considered are (1) Ara Canal Water Productivity Improvement Project (ACWPIP), Bihar, India, (2) Mechanized Innovation Irrigation Project (MIIP), Nepal and (3) Rural High Voltage Distribution System (HVDS), Maharashtra, India. All of them aim to provide adequate and reliable access to water or electricity in an equitable manner. Only the linkages between water and food, and water and energy are assessed. Linkages between energy and food are not discussed.

In the ACWPIP, there's no significant change in surface water required for irrigation, groundwater pumping is expected to decrease, and the cropping intensity is expected to increase. Increase in cropping intensity will increase beneficial consumption due evapotranspiration. In MIIP, despite an increase in groundwater withdrawal, monsoon rains are expected to sufficiently recharge the aquifers and reduce flooding. In Maharashtra, it is possible that energy supply feeders may traverse through semi/critical or dark blocks. Hence there's a possibility that the increase in food production may be at the expense of depleting groundwater resources.

In the ACWPIP, there's no evidence of competition for water between hydropower generation and irrigation. Releases from reservoirs appear to be based on water stored rather than the demand for either hydropower or irrigation. There appears a willingness between State Agencies responsible for water and electricity to ensure enough electricity is available to support the Buried Pressure Piped System proposed.

Optimal use of any of the three resources is often constrained by other factors such as the land holding, land fragmentation and availability of capital. Despite the lack of consultation among the three sectoral agencies when project concepts were formulated, there appears enough consultation among them during project planning. Sectoral agencies are often focussed on protecting their own mandates as well as heeding to National Agenda, such as poverty alleviation and increased rural incomes. This prevents them focussing on WEF Nexus to guide their investments. Proponents of WEF analysis to influence policy formulation need to recognise these ground realities.

Keywords: Reliability, Adequacy, Equity, Inter-agency cooperation, National Agenda

1 Senior Water Resources Specialist, Asian Development Banks, Manila, Philippines
2 Principal Water Resources Specialist, Asian Development Bank, Kathmandu, Nepal
3 Senior Energy Specialist, Asian Development Banks, Manila, Philippines

VULNERABILITY ASSESSMENT OF AGRICULTURAL RESERVOIR WATER SUPPLY CAPACITY

Jehong Bang[1], Jin-Yong Choi[2]

ABSTRACT

Paddy rice is a staple food crop in South Korea, and 60% of paddy fields are supplied by irrigation water from about 17,000 reservoirs. Therefore, the assessment of agricultural reservoir water supply capacity is crucial to determine drought resistance capability for securing the stable food supply. However, operation rule has been set up with a conventional method and vague standards which only consider real-time water storage rate. To provide a reasonable basis for reservoir operation rule, in this study, we assessed the vulnerability of agricultural reservoir daily which considers two variables: potential water supply (PWS) and irrigation water requirement (IWR) within the irrigation period. As a pair of PWS and IWR can be produced for a year, more than 30 sets were calculated with long term weather data. The vulnerability of a reservoir means a probability that water requirement is higher than water supply; mathematically, P(IWR>PWS). We assessed the vulnerability of four study reservoirs daily, and the most hazardous periods was turned out to be the beginning of the transplanting season.

Keywords: Drought response, vulnerability probability, agricultural reservoir, potential water supply capacity, irrigation water requirement

1 Ph.D. Course in Department of Rural Systems Engineering, Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea; E-mail: jaehong999@snu.ac.k

2 Professor in Department of Rural Systems Engineering and Research Institute for Agriculture & Life Sciences, Seoul National University, Seoul 08826, Republic of Korea; E-mail: iamchoi@snu.ac.kr

ISSUES RELATED TO CONFIRMATION OF RIGHT FOR IRRIGATION WATER TO FARMERS IN CHINA

Changshun LIU[1], and Lijuan DU[2]

ABSTRACT

Agriculture is the largest water user in China. Irrigation is related to the rights and interests of hundreds of millions of farmers. The confirmation of right for irrigation water to farmers is a major project and an important task for establishing and improving the national water right system and strengthening water resources management. The State requires that the control targets of the total water consumption shall be gradually broken down and assigned to rural collective economic organizations, cooperative organizations for water use of farmers, farmers and other water users for specific water sources. Water rights shall be confirmed and the total consumption control shall be implemented. However, the stakeholders and government sectors involved have not reached a consensus on whether the right for irrigation water shall and can be confirmed to farmers. Relevant policies have general principles for the confirmation of right for irrigation water to farmers. On the basis of numerous investigations, the key issues on whether the right for irrigation water shall and can be confirmed to farmers and whether management can be put in place are discussed herein. To sum up, in terms of the national development strategy, institutional orientation, technical process and water supply management, the right for irrigation water shall be confirmed to farmers, which is technically feasible with basically guaranteed services and management. Therefore, it is suggested that the confirmation of right for irrigation water to farmers shall be taken as an important part of deepening water conservancy reform in the new era. Organically combined with comprehensive reform on agriculture water price and standardization of water permits to actively, steadily and orderly advance the confirmation.

Keywords : Right for irrigation water, Confirmation of right for irrigation water to farmers, Five-step method, Water resources management personnel.

1 Deputy Chief Engineer of Department of Water Resources, China Institute of Water Resources and Hydropower Research (IWHR). No. 1 Yuyuantan South Road, Haidian District, Beijing, China. CP. 100038); E-mail: liucs@iwhr.com

2 Department of Irrigation and Drainage, China Institute of Water Resources and Hydropower Research (IWHR). No. 1 Yuyuantan South Road, Haidian District, Beijing, China. CP. 100038); E-mail: ljdu@iwhr.com

INTEGRATION OF GROUNDWATER RESOURCES IN WATER MANAGEMENT FOR BETTER SUSTAINABILITY OF THE OASIS ECOSYSTEMS - CASE STUDY OF TAFILALET PLAIN, MOROCCO

El Khoumsi Wafae[1], Ali Hammani[2], Marcel Kuper[3], Ahmed Bouaziz[4]

ABSTRACT

Oases have always existed in a complex environment characterized by an arid climate. Despite the severity of the physical conditions, farmers have ensured palm groves sustainability by practicing irrigation and settling along the rivers and groundwater table. Currently, oases are threatened. In addition to the constraining space in which the oasis regions are located, they are under intense pressure on natural resources, both physical and human. This degradation has been amplified by the succession of drought periods, desertification, the effect of climate change and above all the overexploitation of groundwater resources in or near the oases. The preservation of oases requires a good understanding of the interactions between water and palm, which is the framework of the oasis agroecosystem. This relationship is generally studied based on the surface water irrigation. However, the palm is also fed by the groundwater table. The objective of this paper is to study the interaction between the groundwater table and the palm plantation as well as the quantification of the direct groundwater uptake by the root system. This work highlights the importance of groundwater resources in the conservation and revitalization of the oasis system. The study took place in the plain of Tafilalet which is one of the largest palm groves in Morocco. The methodology adopted is based on surveys and field investigations coupled with an experiment. The results obtained led to the conclusion that groundwater table is the basic resource for the survival of palm trees in these sub-desertic zones. In less than 40 years, the thickness of the groundwater table has dropped by 50% and the piezometric levels have decreased; at the same time, a 50% reduction in the number of the date palm was observed. However, areas with higher groundwater table levels were the least affected by the downsizing. Indeed, this invisible resource is not only the main resource that supplies irrigation water, but it also contributes to the direct feeding of crops, especially the date palm. The present work also showed that the presence of a groundwater table strongly affects the development of the root system. Indeed, in a situation of water stress, the roots of the date palm develop in depth until reaching the level of the groundwater table to satisfy the water needs. The results of the experiments show that the date palm is not a major consumer of water, compared with the context in which it is located, its annual transpiration was estimated at 42m^3 and constitutes 49% of the total evapotranspiration. In addition, the groundwater table can contribute to 50% in this transpiration even for a depth that exceeds 4m. Taking this participation into account when determining water requirements could reduce water supply and save up to 50% of irrigation water, which is very scarce and very costly to mobilize in these environments. The integration of this parameter in the establishment of water balances would also help to better understanding the dynamics of groundwater resources and thus to ensure a more rational and controlled management of water.

Keywords : Oases; Sustainability, Ecosystem, Groundwater Table; Date Palm; Transpiration; Root uptake, water management, Tafilalet; Morocco.

1 Researchers in the department of rural engineering, Agronomic and Veterinary Institute Hassan II, Madinat Al Irfane BP 6202-Instituts 10101-Rabat, MAROC mail: w.elkhoumsi@iav.ac.ma
2 Researchers in the department of rural engineering, Agronomic and Veterinary Institute Hassan II, Madinat Al Irfane BP 6202-Instituts 10101-Rabat, MAROC mail: a.hammani@iav.ac.ma
3 Researcher in CIRAD, Avenue Agropolis, 34398 Montpellier Cedex 5, France. Mail marcel.kuper@cirad.fr
4 Researchers in the department of Agronomy, Agronomic and Veterinary Institute Hassan II, Madinat Al Irfane BP 6202-Instituts 10101-Rabat, MAROC; mail ahmedbouaziz55@gmail.com

MALAYSIA'S NATIONAL WATER BALANCE MANAGEMENT SYSTEM: MANAGEMENT OF WATER RESOURCES AND IRRIGATION DEMAND WITH WATER RESOURCES INDEX (WRI)

N. Mohd Ghazali[1], M.R. Husain[2], A. M. Ishak[3], N. Redzuan[4] and F.H. Lim[5]

ABSTRACT

Freshwater is the vital resource for survival needs of humans and all other living creatures on earth. Water resources security is utmost important to the security for water supply and irrigation for food. Malaysia receives abundant rainfall averaging 3,000mm annually, but itself is not immune from the risk of water scarcity and droughts due to climate change, poor land governance and development. The drought episodes are also part of the natural weather cycle and are prevalent in some parts of the country such as Perlis and the northern part of Kedah. Excessive use of water for paddy irrigation and increasing potable water demand are the major causes of concern. In order to strengthen our water resources security, a holistic approach has been taken through the development of National Water Balance System (NAWABS) under the National Water Resources Policy (NWRP). The system will serve as a Decision Management Support System (DMSS) in water resources management based on an integrated water resources model in which hydrologic and water resources model are used to perform analysis and modelling decision management and planning. The outputs of the water resources models are used to determine the water resources index (WRI), which will provide the management information on the status of water resources for drought management decision-management. It defines the "ratio of the actual water resource availability (WRA)" to the "average water resources capacity (WRC)" for a consecutive duration of T (day). The water resources index (WRI) is an index calculated to reflect the water resources availability and useful for water resources management and decisions making. WRI and rainfall data are used to as indicators to determine the water availability, water resources and drought management in the water resources system where impounding reservoir and interbasin transfer are used to augment the raw water supply. WRI are consistent with the water shortage and drought conditions during the actual historical drought year. The WRI is able to determine the water resources status using the historical data, and proven to be representative to the actual scenario during drought years.

Keywords: DMSS, Water Balance, Drought, Water Resources, Water Resources Index, WRI, Climate Change

1 Department of Irrigation and Drainage, Malaysia, E-mail: hisham.water@1govuc.gov.my
2 Department of Irrigation and Drainage, Malaysia, E-mail: mrazali@water.gov.my
3 Department of Irrigation and Drainage, Malaysia, E-mail: drasnor@water.gov.my
4 Department of Irrigation and Drainage, Malaysia, E-mail: nurhareza@water.gov.my
5 Angkasa Consulting Services Sdn Bhd, Malaysia, E-mail: fhlim@acssb.com.my

REVALUATION OF LOCAL KNOWLEDGE AS A SUSTAINABLE DROUGHT ADAPTATION STRATEGY

Muhamad Khoiru Zaki[1], Keigo Noda[2], Kengo Ito[3] and Komariah[4]

ABSTRACT

Local knowledge can be defined as a person's ability to use his/her understanding and senses to respond to an event, object, or situation in the local environment. The aim of this study was to revaluate Pranata Mangsa as a form of local knowledge that can aid in adapting to drought. Pranata Mangsa is used on the Indonesian islands of Java and Bali, particularly by farmers, for managing agricultural activities in the fields and is based on Titen, or natural signs. The relationships between natural signs and farming activities are arranged in four primary and twelve secondary Mangsa, or seasons. Each Mangsa is characterized by activities such as Bero (maintaining fallow land) and burning rice straw, which reduce the loss of crops from meteorological drought and soil moisture deficits caused by agricultural drought. These practices suggest the potential for applying local knowledge to drought adaptation and indicate that a revaluation of the local knowledge of Pranata Mangsa with its specific characteristics could offer an effective strategy for adapting to drought and meeting the 2030 Sustainable Development Goals.

Keywords : Local knowledge, Drought, Soil moisture, Rain-fed farmland

1 The United Graduate School of Agricultural Sciences, Gifu University. Yanagido 1-1, Gifu, Japan. 501-1193. E-mail: zakimuhamad30@gmail.com

2 Faculty of Applied Biological Sciences, Gifu University. Yanagido 1-1, Gifu, Japan. 501-1193. E-mail: anod@gifu-u.ac.jp

3 Faculty of Applied Biological Sciences, Gifu University. Yanagido 1-1, Gifu, Japan. 501-1193. E-mail: joroken@gifu-u.ac.jp

4 Faculty of Agriculture, Sebelas Maret University. Jl. Ir. Sutami 36A, Surakarta, Indonesia. 57261. E-mail: komariah23@gmail.com

ALLOCATION OF WATER-LAND-ECOLOGY-ECONOMY FOR SUSTAINABLE RICE DEVELOPMENT IN SJP OF CHINA

Longzhu Guo[1], Fengqing Liu[2]

ABSTRACT

An integrated modelling framework for Water-Land-Ecology-Economic Integrated Platform (WLEEIP) will carry out to analyze different scenarios for allocation of Water-Land-Ecology-Economy (WLEE). By muti-objective linear programming to find the global optimal solution of WLEE allocation.First, we analyzed the water balance of different zone of SanJiang Plain (SJP), and found there are many conflicts between water/land demand and supply. To solve this problem, we design some typical scenarios to study the resources' allocation at 2020/2025. They include Jiamusi, Hegang, Shuangyashan's WLEE under normal/Dry year at 2020/2025. For example in the case, the water demand will be70.28×10^8 m^3, 72% of which is for primary industry. The paddy will undergo an increase from 1.45×10^4 to 1.98×10^4 km^2, and the wetland will keep constant at about 0.53×10^4 km^2, so the ecological service value has steady increase. The yield of grain will double, the GDP will increase 45%.This approach is useful as it allows policy makers to consider not only the physical dimensions of distributing water and land, but also the economic and associated ecological consequences.

Keywords: Water-Land-Ecology-Economy (WLEE); resources allocation; sustainable development; SJP.

1 College of agricultural engineering, Hohai University, Nanjing 210098, China.
2 College of Electronic and optical Engineering, Nanjing University of Posts and Telecommunications, Nanjing 210023, China.

PROJECTING AGRICULTURAL WATER SUPPLY RELIABILITY UNDER DIFFERENT ET APPROACHES AND CLIMATE CHANGE

Cho Gun-Ho[1], Kim Sang-Hyun[1], Mirza Junaid-Ahmad[1], Han Kyung-Hwa[2] and Choi Kyung-Sook[3]*

ABSTRACT

Agricultural reservoirs are the principal source of irrigation water supply and play a major role in paddy water management in Korea. This article projects the water supply reliabilities of 12 agricultural reservoirs to sustain paddy cultivation by the end of 21st century. The future net duty of water (NDW) for paddy cultivation was quantified using the Modified Penman (MP) and Penman Monteith (PM) approaches. Currently, in Korea, the MP approach is being used to estimate the rice crop evapotranspiration (ET_c) and NDW; but the FAO recommends the PM approach due to its sound physical basis. During the baseline period (1980 - 2010), the MP approach over-estimated the ET_c rates by 17% compared to the PM approach. In the future, the trend of rice seasonal temperature and rainfall rose consistently and gradually till the end of 21st century. ET_c increments prompted by the future climate warming were expected to enhance the baseline-NDW; but it decreased in the future due to substantial seasonal rainfall increments. This indicated the positive rainfall influences might outweigh the negative climate warming impacts on agricultural water demands in this area. Adopting the PM approach in place of the previously used MP approach stabilised the water supply reliabilities of all the reservoirs in the future. The reservoirs having small effective storage capacities and irrigation areas demonstrated insufficient water supply reliabilities in the future based on the MP approach; but the same reservoirs had adequate water supply reliability when adopted the PM approach. However, the water supply reliability of the reservoirs with large effective storage capacities and irrigated areas were compromised in the future even after adopting the PM approach. It was concluded that adopting the PM approach could help in better understanding the inevitable detrimental impacts of climate change regarding the management of the reservoir operations in Korea.

Keywords: Paddy rice, Climate change, Agricultural reservoir, Water supply reliability, ET approaches

1 Dept. of Agricultural Civil Engineering, Kyungpook University. 80 Daehak-ro, Buk-gu, Daegu, Republic of Korea.
2 Dept. of Soil and Fertilizer, National Institute of Agricultural Sciences. Wanju 55365, Republic of Korea.
3 *Dept. of Agricultural Civil Engineering, Institute of Agricultural Sciences and Technology, Kyungpook University. 80 Daehak-ro, Buk-gu, Daegu, Republic of Korea.; E-mail: ks.choi@knu.ac.kr

DEVELOPMENT OF QUANTITATIVE ASSESSMENT FOR INTEGRATED IRRIGATION-AGRICULTURE

Sahid Susanto[1] and Nurul Pertiwi[2]

ABSTRACT

A quantitative instrument was developed for assessing integrated irrigation-agriculture scheme. The input-process-output element approach was used in the instrument. The element has indicator, that is biological resource, environment, social economy, infrastructure, production process, yield, farmer response, farmers' income, and B/C analysis. Weighted factor was used in each indicator to produce score for each element. The final score is the result of the input-process-output element which indicates the performance of integrated agricultural-irrigation system. The final score ranges from 1-4. It means 1 is less, 2 is sufficient, 3 is good and 4 is very good. Instruments was applied to assess the performance of agriculture-irrigation activities through a demonstration area of integrated agriculture-irrigation system, namely DemArea. In DemArea includes ground water irrigation management which is integrated with complex agriculture in an integrated manner.

The Dem-Area was carried out in part of the area of Wadaslintang Reservoir Irrigation System. It is located in Grabag District, Purworejo Regency, covers an area of 0.6 ha. This area only gets irrigation water supply during Planting Season I (Nov-Peb) and II (Mar-June). During Planting Season III (July-Oct), the farmers in this area are lifting available groundwater from their land for irrigating their paddy land. Integrated ground water irrigation-agricultural system was realized in the form of irrigation pipeline, horticulture agriculture, livestock farming and fisheries. The results show that the DemArea produce a final score of 3, which means good. By utilizing ground water in Planting Season III, which is harmonized with the integrated production process of mixed farming, there is an increase in farmer income of 15.47%.

Keywords: quantitative assessment instrument, input-process-output, Demonstration Area (DemArea), integrated irrigation-agriculture scheme

1 Professor of hydrology and water management at The Faculty of Agricultural Technology, GadjahMada University. Correspondence author.

2 Undergraduate alumny of The Faculty of Agricultural Technolgy, GadjahMada University

ANALYSIS OF CORRELATION WITH ENERGY CONSUMPTION IN SUPPLYING WATER FROM RESERVOIRS TO RICE PADDY FIELDS

Eunhee Choi[1], Seungheon Lee[2] and Seungoh Hur[3]

ABSTRACT

Global resource security crisis is emerging as the demand for essential resources such as water, energy and food increases due to climate change, population growth, urbanization and resource depletion, and MATCHING the supply and demand of these resources is becoming difficult. The study for 'Development of Water-Energy-Food Nexus platform associating with climate change impacts (Smart Nexus for Agriculture in Korea, SNAK) aims to build a platform that includes a system that applies and evaluates user - based scenarios and climate change scenarios simultaneously based on modeling of individual resources and linkage analysis system of resources.

System dynamics for Nexus built at SANK is composed of simulated resource usage by production system, water resource, energy supply system and carbon emission simulation according to energy use. In order to simulate resource usage, water footprint per unit production, energy use for supplying water, and energy footprint for treating wastewater are essential, which can be applied to field data. For this model, 3 types of agricultural water supply methods were analyzed, as the agricultural water supplied through the reservoir, the agricultural water supplied through sewage reuse system and the agricultural water supplied through brackish water desalination system. In this study, the parameters required for platform construction are collected and verified in agricultural water supplied through the reservoir preferentially among 3 type of agricultural irrigation water supply options. The results of this study were utilized to develop the sank model.

Keywords: Water-Energy-Food Nexus, Water saving, Irrigation Energy, Water balance.

1 Associate Researcher, Rural Research Institute (RRI), Korea rural Community & Corporation (KRC). Ansan, Republic of Koea.Zip Code.15634; E-mail: ehchoi@ekr.or.kr

2 Director, Environmental Resource Department of Environment Project Office, Korea rural community & Corporation (KRC), Naju, Republic of Korea, ZIP Code, 58327;E-mail:shyi@ekr.or.kr

3 SeniorResearcher, National Institute of Agricultural Science, RDA, Jeonju, Republic of Koea, Zip Code.55365.); E-mail:soilssohur@korea.kr

MODERNIZATION AND USERS PARTICIPATION, A KEY ISSUE TOWARDS IRRIGATION SUSTAINABILITY IN VALDICHIANA, CENTRAL ITALY

Graziano Ghinassi[1] and Lorella Marzilli[2]

ABSTRACT

Water supply for irrigation purpose can be done either by individual users or through collectively managed structures that deliver water from the intake to the farm inlet. Due to a number of reasons, such as ineffective cost recovery or limited participation, worldwide experience on transformation from individual to participatory irrigation is not always success stories. Modernization can play a fundamental role, on condition that users are trained on infrastructure use and informed on the expected benefits. In Valdichiana, an irrigated area of inland Central Italy, after decades of uncontrolled individual water withdrawals mainly from in-farm wells, a new piped network to deliver high quality freshwater for irrigation at the farm hydrant, was completed. Conversion towards collective management began in 2012 under the Reclamation and Irrigation Consortium named Alto Valdarno 2. At the end of 2018, collective water management involved around 20% of the irrigable area, a rather low value despite the benefits offered such as the low or nil energy cost for lifting. However, compared to previous individual withdrawals, the average supplied volumes decreased considerably. This work aims to provide a brief overview on the evolution of irrigation during the initial 7 years of collective management, , cropping pattern and irrigation systems, in addition to farming constraints and users attitude, in order to collect information to assess whether participation can actually support the achievement of expected individual and collective benefits.

Keywords: Modernization, Reclamation and Irrigation Consortia, Irrigation districts, user participation.

1 Department of Agricultural, Environmental, Food and Forestry Science and Technology (DAGRI) University of Florence Via San Bonaventura, 13 – 50145 Firenze graziano.ghinassi@unifi.it
2 Consorzio 2 Alto Valdarno, via Ernesto Rossi, 2 – 52100 Arezzolorella.marzilli@cbaltovaldarno.it

WASTEWATER AND GROUNDWATER CONJUNCTIVE USE OPTIMIZATION MODEL IN VARAMIN IRRIGATION NETWORK

Maryam Yousefi[11], Mohammad Ebrahim Banihabib[2] and Jaber Soltani[3]

ABSTRACT

In recent years, the use of treatment plants' wastewater, as a component of unconventional water has been considered a supplementary to groundwater resources in irrigation and drainage networks. The rate of nitrogen leaching into the soil and aquifer due to the use of chemical fertilizers and wastewater containing high nitrogen should be assessed. The wastewater due to the presence of some nutrients such as nitrogen and phosphorus can provide a significant portion of the plant's fertilizer needs, saving the cost of purchasing fertilizers. In this research, development of cropping pattern optimization model was addressed for quantitative-qualitative conjunctive use of unconventional surface water (wastewater) and groundwater. The three objectives of the model are, maximizing profits from cropping pattern, reducing nitrogen leaching and improving the rate of aquifer recharge. In order to integrated management of wastewater and irrigation water resources., A nonlinear three objectives optimization model was tested for 7 scenarios (one-objective, two-objectives and three-objectives) in water year 2012-2013 in Varamin irrigation network. Solving one-objective model by first objective (first scenario: improving of network's profit) showed the 49 percent improvement of network's net profit. The second objective (scenario: reducing of fertilizer consumption) showed the 95 percent reduction in fertilizer consumption, and the third objective (third scenario: improving the aquifer recharge) showed the 120 percent improvement in the aquifer recharge, in comparison to the current situation.

Solving the three-objectives model (seventh scenario: combined objectives of improving network's net profit, reducing of fertilizer consumption and improving the aquifer recharge) showed a 23 percent reduction in cultivated area and 71 percent of nitrogen fertilizer consumption and 13 percent of conjunctive withdrawals of wastewater and groundwater, 6 percent increase in net benefit, 29 percent increase in aquifer recharge and 22 percent increase in water productivity was achieved. Therefore, seventh scenario was chosen as the best scenario. Integrated quantitative-qualitative management of irrigation water and wastewater resources in irrigation and drainage networks in terms of controlling the environmental impacts of nitrogen leaching into the soil and groundwater environment is an important issue, the proposed three-objective model of this paper can be used to improve the performances of agriculture, environment and water resources systems in irrigation and drainage networks.

Keywords : Wastewater, Fertilizer, Nitrogenleaching, Aquifer recharge.

1 ,2,3 University of Tehran, Iran. E-mail: maria_yusefi@yahoo.com

ASSESSMENT OF REGIONAL DIFFERENCES IN SUSTAINABILITY OF RURAL RESOURCES BY NEXUS-BASED ANALYSIS

Yoonhee Lee[1], Jin-Yong Choi[2], Pureun Yoon[1], Kwihoon Kim[3]and Sang-hyun Lee[4]

ABSTRACT

Stable agricultural production needs resource-intensive agricultural production structure, but the stability of securing resources such as water has been deteriorating due to recent climate change. The investment in facilities to meet water requirement for agriculture requires high cost Therefore, this study aims to provide more information on securing resources needed for agricultural production by establishing the linkage between resources in addition to the total amount of resources required for agricultural production. We assessed the sustainability of securing the resources needed for agricultural production through data on regional production, agricultural energy use, and water use in eight regions of South Korea. In South Korea, Jeonnam, Jeonbuk, and Chungnam regions were found to have higher resource efficiency than other regions.

Keywords : Nexus, Rural resources, Trade-off, Sustainability.

1 Department of Rural System Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, Email: ukuleo@snu.ac.kr
2 Professor, Department of Rural System Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, E-mail: iamchoi@snu.ac.kr
3 MS student, Department of Rural System Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, E-mail: kgh0330@snu.ac.kr
4 Research Institute of Humanity and Nature, 457-4 KamigamoMotoyama, Kita-ku, Kyoto, Japan. E-mail: sanghyunsnu@gmail.com

EVALUATION OF WATER-ENERGY-FOOD LINKAGES BASED ON THE GREENHOUSE TEMPERATURE MODEL AND ANN

Kwihoon Kim[1], Pureun Yoon Nahun[2], Yoonhee Lee[3], Sang-Hyun Lee[4] and Jin-Yong Choi[5]

ABSTRACT

To feed 9 billion people in 2050 (DESA, 2017), the most crucial task in agriculture is achieving higher crop productivity. WEF (Water-Energy-Food) Nexus was first introduced in World Forum 2011 to interpret inter-linkages among the resources and stakeholders. The objective of this study was to evaluate the linkages of three resources, which are water, energy, and food. Of the various kinds of farming methods, this study analysed protected greenhouse farming, as it is one of the most resource-intensive farming practices. For the analysis, reference evapotranspiration and heating energy load were simulated as 1-2 Win a four-span greenhouse. The inside temperature was simulated based on the equation suggested by van Henten (1994). This study acquired climate data in 2011 and 2012 from the KMA (Korea Meteorological Administration) for calculation. Furthermore, ANN (Artificial Neural Network) with multi-layer perceptron was applied to match the productivity with statistics reported by RDA (Rural Development Administration) annually. The input data for the model were crop productivity simulated from Aqua Crop model, and census data from the RDA reports. Data from 2013 to 2016 were used for the validation of this study. Among the various agricultural products, this study chose tomato for the analysis. The results of this study will help construct the WEF Nexus platform for protected greenhouse complex in Korea.

Keywords: Water-Energy-Food Nexus, Greenhouse, Temperature simulation, Evapotranspiration, Heating energy load, Republic of Korea.

1 Department of Rural Systems Engineering, Seoul National University. Gwanakro-1 Gwanak-gu, Seoul Republic of Korea. E-mail: kgh0330@snu.ac.kr
2 Department of Rural Systems Engineering, Seoul National University. Gwanakro-1 Gwanak-gu, Seoul Republic of Korea. E-mail: vnfms3259@snu.ac.kr
3 Department of Rural Systems Engineering, Seoul National University. Gwanakro-1 Gwanak-gu, Seoul Republic of Korea. E-mail: ukuleo@snu.ac.kr
4 Research Institute of Humanity and Nature, 457-4 KamigamoMotoyama, Kita-ku, Kyoto, Japan. E-mail: sanghyunsnu@gmail.com
5 Department of Rural Systems Engineering, Seoul National University. Gwanakro-1 Gwanak-gu, Seoul Republic of Korea. CP. 62550.); E-mail: iamchoi@snu.ac.kr

DETERMINATION OF DEPENDABLE FLOW FOR MICROHYDRO POWER PLANT IN IRRIGATION NETWORK

Afida Zukhrufiyati[1], Joko Triyono[2], Segel Ginting[3] and Eko Winar Irianto[4]

ABSTRACT

Electrical energy at this time has become one of the basic needs of society. Along with economic growth, people's electricity needs have increased. This needs to be met by increasing capacity to provide electricity. One of the electricity sources that can be developed is micro hydro power plant. Irrigation networks have the potential to develop micro hydro power plants if they have water availability indicated by dependable flow in irrigation networks and have a minimum head of 2 meters in irrigation networks. Dependable flow in irrigation networks shows the availability of water supplies to irrigation channel. Calculation of dependable flow on irrigation networks is influenced by the schedule of water supply. This study explains some approaches that can be used in determining dependable flow. Determination of dependable flow in irrigation networks at this time is still constrained by data availability. The approach in determining dependable flow in irrigation networks is divided into two i.e. information on discharge data in irrigation buildings available and information on discharge data in irrigation weirs available. Dependable flow in the irrigation networks used to calculate the energy potential of micro hydro power plant is determined using the flow duration curve method in the irrigation channel. The results of the study indicate that the most optimum probability of discharge for micro hydro potential applied in the Tajum Irrigation Area is 50% (Q50). Q50 can produce electrical power according to the micro hydro criteria based on water availability for 6 months.

Keywords: micro hydro, electricity, dependable flow, irrigation networks, flow duration curve

1 Researcher, Experimental Station for Irrigation, Research Center for Water Resources,Research and Development Agency, Ministry of Public Works and Public Housing. Bekasi 11713, Indonesia; E-mail: afida164@gmail.com

2 Researcher, Experimental Station for Irrigation, Research Center for Water Resources,Research and Development Agency, Ministry of Public Works and Public Housing. Bekasi 11713, Indonesia; E-mail: joko3triyono@gmail.com

3 Researcher, Experimental Station for Irrigation, Research Center for Water Resources,Research and Development Agency, Ministry of Public Works and Public Housing. Bekasi 11713, Indonesia; E-mail: gintingsegel@gmail.com

4 Head of Water Resources Research and Development Center, Research and Development Agency, Ministry of Public Works and Public Housing, Bandung 40135, Indonesia; E-mail: ekowinar1966@gmail.com

AN IRRIGATION STRATEGY TO EXTERMINATE APPLE SNAILS (POMACEA CANALICULATA) EGGS IN TAIWAN PADDY FIELDS

Yu-Chuan CHANG[1], Kunihiko YOSHINO[2], Ching-Tien CHEN[3] and Gwo-Fong LIN[4]

ABSTRACT

Water submersion is of particular importance because apple snails lay egg masses on trunks or stems of plants or on walls above the water 150 mm-200 mm not only to avoid aquatic predators, but also to avoid negative effects of the water itself on hatchling success of their eggs. These effects may include altering the permeability of the egg capsule, reducing oxygen availability due to low levels of dissolved oxygen, or lower incubation temperatures in water as compared to air temperatures.

In paddy field, ponding water management may cause water levels to rise quickly and remain elevated for hours to days. Therefore, eggs which are laid above the water level on a stationary object such as bunds or stems may become sub-merged. In this study, we applied different duration of water submersion on the various ages of snail eggs. Base on a field survey, an irrigation strategy was introduced to decrease the hatchling rate of apple snail eggs in paddy field.

Our results demonstrated that water submersion could dramatically decrease the hatching rates to maximal 8.0% on P. canaliculata. Water submersion that began in 6 hours after the eggs were laid or lasted for more than 24 hours significantly decreased the snails' hatching rate to 25%. This breeding characteristic of P. canaliculata makes the physical control by water treatment feasible. Considering that there exists a set of limited ponding depth during the rice growth stage which will cause flooding damage when the water level is higher than 40% of plant height.It is suggested to apply an irrigation strategy of deep-water intermittent irrigation and field ditch to decrease the hatching rate of P. canaliculata. This technique would have no negative effects on rice yield, neither on ecological environment.

Keywords : Irrigation strategy, apple snail, paddy field, Taiwan

1 Corresponding author, Hsing Wu University, e-mail: 096062@mail.hwc.edu.tw
2 University of Tokyo
3 National Chiayi University
4 National Taiwan University

SUSTAINABLE RAINWATER RESOURCES MANAGEMENT POLICY TO SUPPORT WATER, FOOD AND ENERGY SECURITY

Susilawati Cicilia Laurentia[1], Kristono Yohanes Fowo[2], and Charly Mutiara[3]

ABSTRACT

Rainwater is the potential water resource that must be managed wisely, to meet the needs of water. The needs of water can be distinguished as: 1) clean water for household, 2) irrigation water for agriculture, to fulfil the food security, and 3) development of renewable energy. These needs have impacts on water availability, food security and renewable energy. This has been encouraging the study the sustainable rainwater resource management policies, which support water, food and energy security. The regional climatology studies are needed to determine the potential of rainwater that can be used to meet the need of clean water, agricultural and environmental water. These studies include: rainfall characteristics, to predict the potential and trends of the existing daily rainfall distribution; rainfall analysis to determine the potential available water from the rainwater management system. Secondly, it is necessary to study the suitability of land to ensure food security for the study-area. These studies include: land suitability studies by FAO's agro-ecological zoning (AEZ) method, and the length of growing period (LGP) analysis to find the right planting period that provide optimal crop certainty and efficient water management. Thirdly, the study of renewable energy potential is carried out together with an analysis of rainwater resource management. Finally, a policy study is conducted to support the mass movement of rainwater resource management so that it can be sustainable. From the sustainable rainwater resources management policy supported by existing local wisdom, water is available to meet household needs, agricultural needs that produce food security, and the availability of renewable energy. This has an impact on the economic development of the study area, in making it an independent and prosperous area.

Keywords: Rainwater resources management, sustainable, water security, food security, energy security

1 Lecture, Civil Engineering Department, Engineering Faculty, Soegijapranata Catholic University, Jl. Pawiyatan Luhur IV/1, Bendan Dhuwur, Semarang 50234, Indonesia
2 Lecture, Agrotechnology Department, Agriculture Faculty, Flores University, Jl. Sam Ratulangi, Ende-Flores 86317, Indonesia
3 Lecture, Agrotechnology Department, Agriculture Faculty, Flores University, Jl. Sam Ratulangi, Ende-Flores 86317, Indonesia

RAINWATER HARVESTING IN THE 21ST CENTURY – AN AUSTRALIAN PERSPECTIVE

Michael Smit[1]

ABSTRACT

Increasing demand for clean water and its limited resources demand more efficient water supply systems using our water sources in radically new combinations, guided by big data and high end computing analysis.

ICID has formed a new working group called the ICID Rainwater Harvesting Working Group with a mandate to promote rainwater harvesting based on a set of principles, research and good design practice.

Active rainwater harvesting stores rainwater collected from a roof in a tank for later use, and passive rainwater harvesting uses the landscape itself to capture, store and make water available. (American Rainwater Catchment Systems Association, 2015 1st Edition).

Passive rainwater harvesting provides an important source of natural irrigation for agriculture.

Australia provides an important case study with one in four houses using rainwater havesting in a country where water sources are limited. Nationally awarded research methodologies knowns as the systems framework provide big data analysis to recognise the cumulative importance of widespread changes at the lot scale.Rainwater harvesting occurs at the local scale of an individual roof or piece of land. Changes at this micro scale are efficient and have non-linear cumulative benefits at the city and regional scale.

Rainwater is arguably the most accessible and sustainable source of water in the world. Rainwater falls on the roof of the building where it is used, so everyone has access to rainwater without expensive transport costs. A roof is a non-trafficable surface so there are few opportunities for contamination. Rainwater is simple to manage and treat at low cost. Rainwater Harvesting is most efficient as part of an integrated water management approach with multiple water sources for seasonal water security.

The author celebrates the seminal work of Professor PJ Coombes in this field.

1 Technical and Sustainability Manager, Kingspan Water and Energy, Committee member ICID Rainwater Harvesting Working Group, Committee member Rainwater Harvesting Australia, Irrigation Australia

SIMPLE TOOL FOR ANALYZING CANAL SYSTEMS IN MIXED URBAN AND RURAL ENVIRONMENTS

Brian Wahlin[1], Bert Clemmens[2], Brent Travis[3] and Jorge Garcia[4]

ABSTRACT

In many locations throughout the world, urbanization is encroaching on rural areas. In the United States, this encroachment typically leads to conversion of open channel irrigation ditches into underground pipes. Years of urbanization from a wide variety of land developers can convert an open channel system to a patchwork system that changes from open channels to a piped system and back again several times along the length of the canal. This constant change of the physical conditions of the irrigation system makes determining the capacity of the overall system challenging. As an example, the Salt River Project (SRP), an irrigation water provider in Phoenix, Arizona, USA, has a partnership with the City of Goodyear, Arizona, USA, that allows the City of Goodyear to utilize SRP's infrastructure to deliver water to a water treatment plant if there is sufficient capacity in SRP's system to carry that additional water. However, SRP's lateral system was composed of a number of open channel and piped sections, making it difficult to know the current capacity. To determine the capacity in these complicated systems, a simple spreadsheet tool was developed that includes automatic calculation of backwater between structures. Using this tool, the hydraulics for combination of piped and open channel systems can be easily determined using this spreadsheet tool.

Keywords : Urbanization, Infrastructure, Open Channels, Pipelines

1 Vice President, WEST Consultants, Inc.; 8950 S 52nd Street, Suite 210, Tempe, AZ, 85284; E-mail: bwahlin@westconsultants.com

2 Senior Hydraulic Engineer, WEST Consultants, Inc.; 8950 S 52nd Street, Suite 210, Tempe, AZ, 85284; E-mail: bclemmens@westconsultants.com

3 Director of Applied Research, WEST Consultants, Inc.; 8950 S 52nd Street, Suite 210, Tempe, AZ, 85284; E-mail: btravis@westconsultants.com

4 Engineer Principal, Salt River Project; Mail Station SSW303, P.O. Box 52025, Phoenix, AZ 85072; E-mail: jorge.garcia@srpnet.com

MANAGING COMPLEXITY FOR SUSTAINABILITY. EXPERIENCE FROM GOVERNANCE OF WATER-FOOD-ENERGY NEXUS

Dubravka Bojic[1], Domitille Vallée[2]

ABSTRACT

The 2030 Agenda and the Sustainable Development Goals have given strong impetus to the debate on the interdependencies between multiple sectors and have illuminated the practical need for greater cross-sectoral coordination and policy coherence to achieve sustainable development. A Nexus approach has been promoted by researchers and development agencies as a tool for policy makers to better understand and frame linkages between relevant sectors, with the ambition to align policies and integrate management across sectors and scales in support to both resource efficiency and people's livelihoods. Water-food-energy (WFE) together form a highly complex and intertwined nexus. While the debate about theWFE nexus was helpful in attracting attention on sustainability challenges and the interdependencies between the three systems, addressing governance of the nexus proved challenging. Relatively little is said about the political and institutional changes that are necessary to lead a major transformation in the present water resources, agriculture and energy development paradigms, which could accelerate progress towards sustainable development. Using examples from Jordan and Morocco,where FAO is supporting governments using a nexus approach, this paper reflects on some of the complex WFE interlinkages and related governance challenges and discusses potential innovative mechanisms experimented to tackle complexity and governance at the heart of nexus. This paper suggests that despite its limitations, a nexus concept offers a good starting point to address complexity of integrated decision making and implementation. There is a need for improvement in the nexus scope; increased focus on power relations, institutional fragmentation and stakeholders' interests; and the readiness to question structural inequalities and existing more dominant technocratic and administrative solutions.

Keywords: Nexus, water, food, energy, food security, sustainability, governance, cross-sectoral coordination, power relations.

1 Programme Officer, Governance and Policy Support Unit, Economic and Social Department, FAO. Dubravka.bojic@fao.org
2 Project Coordinator, Regional Office for Near East and North Africa, FAO. \Domitille.vallee@fao.org

POLICY FRAMEWORK FOR IMPLEMENTING FOOD-WATER-ENERGY NEXUS IN AGRICULTURE IN SOUTH ASIA

Golam Rasul[1], Nilhari Neupane[1], Jelle Beekma[2]

ABSTRACT

South Asian countries face mounting challenges in meeting the growing demands for food, water, and energy for a rapidly growing population and middle class. South Asian countries have provided a variety of policy support to increase cereal production, including providing incentives by subsidizing water and energy and guaranteeing rice and wheat prices. While such incentives have increased cereal production, the current policies on food production has promoted unsustainable use of irrigation, using more water than is being replaced in the system, and exploiting high levels of energy. This has increased the demand for water and energy, degraded the resource base, and made irrigation system economically unviable and environmentally unsustainable.

Despite the inherent interconnections between food, water, and energy production, agencies often work in fragmented and isolated ways.The focus of policies is short-term and primarily on cereal production, without taking into account the cross-sectoral implications and long-term sustainability of irrigation and agriculture system. Poor sectoral coordination and institutional fragmentation have triggered an unsustainable use of resources and threatened the long-term sustainability of food, water, and energy (FWE) security in the region, which thereby poses challenges in achieving the Sustainable Development Goals (SDGs). Greater policy coherence among the three sectors is critical for decoupling from increased water and energy intensive food production, and moving towards a sustainable and efficient use of resources. The nexus approach can enhance understanding of the interconnectedness of the sectors and strengthen coordination amongst them. It, however,requires a major shift in the decision-making process towards taking a holistic view and developing institutional mechanisms to coordinate the actions of diverse actors to strengthen complementarities and synergies among the three sectors. A framework is suggested for cross-sectoral coordination and for implementing food-water-energy nexus in agriculture.

Keywords: Food-water-energy (FEW) nexus, framework, SDGs, policy environment, cross-sectoral externalities, policy coherence, policy coordination.

1 International Centre for Integrated Mountain Development, Kathmandu, Nepal.
2 Asian Development Bank, Manila, The Phillippines

GREEN AND BLUE WATER REQUIREMENTS FOR SUSTAINABLE PAKISTAN'S STAPLE CROP PRODUCTION UNDER FUTURE CLIMATE CONDITIONS

Mirza Junaid Ahmad[1], Gun-Ho Cho[1], Seulgi Lee[1]and
Kyung-Sook Choi[2]*

ABSTRACT

Sustainable wheat production is crucial for economic and food security of Pakistan; since wheat is a staple for masses and millions of agricultural workers rely on its production for employment and livelihood. In this work, green and blue water requirements were projected to sustain future wheat production in Punjab, Pakistan using the statically bias-corrected climate change projections from nine global circulation models by the end of 2080. Climate projections envisaged substantially hotter and drier future wheat growing season featuring significant yield losses. During the 2030s (2021 – 2050), the seasonal cumulative crop evapotranspiration (ET) and irrigation requirements declined due to growth span shortening induced by the moderate warming; whereas, during the 2060s (2051 – 2080), they both increased despite a significant growth span shortening caused by intense warming. The future wheat production was more irrigation-dependent since the green water contribution would be limited. Future wheat total water footing (TWF) continuously increased; implying that the apparent ET decrease would not necessarily result in TWFs reduction. The projected green water footprints (GWF) declined and inclined during the 2030s and 2060s, respectively, indicating higher green water availability during 2nd half of the 21st century. During the 2030s, despite the limited green water availability, the blue water footprint (BWF) increments were marginal due to moderate warming. The BWF increments were higher during the 2060s compared to the 2030s; highlighting that higher green water contribution would not suffice warming driven 2060s-ET increments. The CO_2 enrichment effects showed promises to partially compensate for the detrimental climate change impacts over wheat yield and WFs; nevertheless, the reliability of such estimates demands a further in-depth examination of crop yield responses to climate change under field conditions.

Keywords: Climate change, Water footprint, Wheatyield, Aquacrop

1 Dept. of Agricultural Civil Engineering, Kyungpook National University, 80 Daehakro, Bukgu, Daegu, 702-701 Korea
2 *Dept. of Agricultural Civil Engineering, Institute of Agricultural Science &Technology, Kyungpook National University, 80 Daehakro, Bukgu, Daegu, 702-701 Korea, Email: ks.choi@knu.ac.kr

IDENTIFICATION OF FACTORS AFFECTING WATER QUALITY AND POLLUTANT OF SEDIMENT IN AGRICULTURAL RESERVOIRS

Sang-Yun You[1], Ju-Tai Song[1], Suk-Goun Youn[1], Jae-Woon Jung[2], Jae-Chun Lee[2], Jae-Young Lee[2], Dae-Hoon Kim[2], And Kwang-Sik Yoon[3]

ABSTRACT

Since South Korea's agricultural reservoirs are located upstream of rivers, the management of water and sediment quality of agricultural reservoirs is very important for the preservation of water quality in rivers. To do this, it is necessary to identify the factors affecting water and sediment quality of agricultural reservoirs through scientific methods. In this study, 22 reservoirs located in the Youngsan and Seomjin River basins in Korea were monitored twice in July and September of 2018. Water quality constituents such as turbidity, COD, TOC, T-N, T-P, SS, and Chl-a and the sediment quality such as COD, T-N, T-P and SRP (Soluble Reactive Phosphorus) were analyzed. The GIS was used to classify the land use characteristics of the watershed of agricultural reservoirs and number of live-stock was investigated by site visits. The physical factors such as the effective storage, residence time, and water exchange rates of the agricultural reservoirs were derived from the data of Korea Rural Community Corporation. Correlation analysis with water and sediment quality data of agricultural reservoirs, land use, livestock rearing heads, and reservoir physical characteristics was conducted to figure out factors affecting water quality and sediment quality of agricultural reservoirs. As a result of correlation analysis between water quality and sediment pollutant, COD of water and sediment T-P were found significantly correlated. COD, TOC, T-P and SS concentrations of water showed a significant positive correlation with the ratio of agricultural area (paddy and upland) within watershed, but a significant negative correlation with the ratio of forest area. In addition, COD and TOC concentration of water showed a significant negative correlation with the effective storage capacity of agricultural reservoirs, but there was no significant correlation with residence time, water exchange rate, and number of livestock rearing.

The pollutant in sediment and the influential factor analysis showed a significant negative correlation between the TOC in sediment and the effective storage capacity. T-P in sediment showed a significant positive correlation with the area ratio of agricultural land, but showed a significant negative correlation with the forest area ratio. There were significant correlations between the SRP in sediment and the rearing numbers of livestock, but there was no significant correlation with other pollutants in sediment. Both TP in water and sediment correlated positively with ratio of agricultural land area within watershed. This is because fertilizer is used to grow crops in agricultural land, so phosphorus adsorbed in farmland soil is released during rainfall period; it is accumulated in reservoirs and affects water quality. Based on the above results, it can be concluded that the major influential factor on the water and sediment quality of agricultural reservoirs is farmland, and farmland management is necessary for conservation of water and sediment quality.

Keywords: Agricultural reservoirs, Water quality, Sediment quality, Influential factors

1 Korea Rural Community Corporation, 62359 Gwangju, Republic of Korea

2 Jeollanam-do Environmental Industries Promotion Institute, Gangjin-gun, Jeollanam-do, 59205, Republic of Korea

3 Department of Rural & Bio-systems Engineering, Chonnam National University, 61186 Gwangju, Republic of Korea

URBAN DRAINAGE SYSTEM, URBAN AGRICULTURE AND SWAMP RETENTION DEVELOPMENT IN PALEMBANG CITY

F.X. Suryadi[1], Akhmad Bastari Yusak[2], R.A. Marlina Sylvia[2], Eka Gustini[2], and MohdSharizal Ab Razak[3]

ABSTRACT

In 2018, Palembang was experiencing a series of heavy rainfalls which caused a serious inundation on several parts of Palembang City. This inundation problem was caused by several triggers, i.e. exceptionally high rainfall intensity, insufficient capacity of urban drainage system to store the runoff, and weak operation and maintenance of urban drainage system (routine).

As the capital of South Sumatra Province, this situation needs to be improved. In this research besides hydrological and hydrodynamic analysis of the urban drainage system, several possible measures were checked. In this case, besides checking the capacity of the urban drainage system, two measures related to the urban agriculture and utilisation of the swampy areas which can be used as storage areas with two important functions which is first to store the runoff during heavy rainfall and second to serve as raw water resources during the dry season.

In this particular measure, two areas were analysed i.e. Gandus and TalangKepu in order to control the runoff in Lambidaro area. The correlation curves between storage area of the swamp retention basin against the outlet capacity are presented and will be an important consideration for the decision makers. Besides as an important measure to control runoff, the conservation of the swampy areas needs to be maintained and urban agriculture is one of the possible measures to overcome the urban flood as well as to optimize the use of runoff water. On the other hand, (routine) operation and maintenance of urban drainage system that included pumping stations and river systems in Palembang City needs to be improved.

Keywords: Urban flood, conservation swamp, river restoration, inter basin transfer, urban agriculture

1 Land and Water Development, Department of Water Science Engineering, IHE Delft Institute for Water Education, Delft, the Netherlands; E-mail: f.suryadi@un-ihe.org
2 Water Resources and Spatial Planning Services, Municipality of Palembang, Indonesia; E-mail: akhmadbastari70@yahoo.com, marlinasylvia@yahoo.co.id, ekagustini@yahoo.co.id,
3 Civil Engineering Faculty, Universiti Putra Malaysia, Serdang, Malaysia; E-mail: f.suryadi@un-ihe.org

CAUSAL LOOP DIAGRAM OF WEF SECURITY NEXUS: AN IMPLEMENTATION OF GROUP MODEL BUILDING

Aries Purwanto[1], Janez Sušnik[2], F.X. Suryadi[3], and Charlotte de Fraiture[4]

ABSTRACT

This paper develops a qualitative causal model of the water, energy and food (WEF) security nexus system to be used in analyzing the interlinkages among those three sectors and other sectors that influence and are influenced by each sector in a local context. Local stakeholder's engagement through a group model building (GMB) approach was applied in Karawang Regency, Indonesia to improve problem understanding, raising consensus among participants, and building the spirit of acceptance and commitment to the final decision. After recognizing the problem on WEF sector and eliciting the variables, the next stage was to build a basic conceptual framework to describe the system and to develop an integrated causal loop diagram (CLD) that describes the critical system (inter-)linkages. Vensim modelling software has been used to develop this qualitative system dynamics model. The developed Karawang WEF security (K-WEFS) Model as the result of this study is composed of six sub-models with water, energy, and food sectors as endogenous factors. In addition, the variables of population, economic, and ecosystem services were considered as exogenous drivers. It is expected to ensure all the internal and external drivers are covered, including possible feedback mechanisms and to scope key variables that will be analyzed further in the system. Thus, the future achievement of WEF security targets can be based on robust evaluation and planning processes underpinned by a thorough understanding of whole dynamics and the impacts of changes in the linked sectors. In this way, a first step towards breaking silo thinking in regional planning may be attained. In the end, the targets of sustainable development goals (SDGs) number 2 (zero hunger), 6 (clean water and sanitation) and 7 (affordable and clean energy) in an integrated manner can be achieved at all levels.

Keywords: causal loop diagram, WEF security, nexus, system dynamics, group model building, sustainable development goals

1 PhD Researcher, IHE-Delft, Land & Water Development Chair Group, P.O. Box 3015, 2601 DA, Delft, the Netherlands, E-mail: a.purwanto@un-ihe.org

2 Senior Lecturer, IHE-Delft, Integrated Water Systems & Governance Department, P.O. Box 3015, 2601 DA, Delft, the Netherlands, E-mail: j.susnik@un-ihe.org

3 Senior Lecturer, IHE-Delft, Land & Water Development Chair Group, P.O. Box 3015, 2601 DA, Delft, the Netherlands, E-mail: f.suryadi@un-ihe.org

4 Professor of Hydraulic Engineering for Land & Water Development IHE-Delft and Wageningen University & Research (WUR), Water Resources Management, the Netherlands, E-mail: c.defraiture@un-ihe.org

RECENT ADVANCES IN SALINITY MANAGEMENT IN AGRICULTURE: INDIAN EXPERIENCE

Gurbachan Singh[1]

ABSTRACT

Salinity related land degradation is becoming a serious challenge for food, nutritional and environmental security in the developing world. Predicted climate change triggered melting of glaciers and subsequent rise in sea water level is likely to further enhance salinity problem in coastal areas. Recent estimates indicate that nearly 6.74 million hectare area in India is affected by soil salinity and alkalinity. Ground water quality in about one fourth of the total geographical area of the country is underlain by poor quality water, which is used for irrigating agriculture crops. Further, the salinity problem is becoming more serious with expanding irrigation in arid and semi-arid regions without adequate provisions for drainage. Rise in water table to the tune of 30 to 100 cm per year is reported in most of the canal command areas of the country. In the absence of adequate management strategies, the country will have to face salinity problem in more than 11 million hectares of otherwise productive land by 2025, a serious threat to future food and nutritional security. Research and development efforts are in progress to reclaim and manage salt-affected soils in different regions of the country. About 2 million ha area under salinity, sodicity, irrigated with saline or sodic waters had already been reclaimed which is adding more than 15 million tonnes of food grains to the national pool. Alternate approaches to mechanical and chemical modes of reclamation focusing on biological methods have also been developed for salinity management in resource constrained situations. Rice, wheat and mustard crops varieties have been developed for cultivation in high salt content soils. A large number of salinity and alkalinity tolerant grasses, forest and fruit trees and high value aromatic and medicinal crops including halophytes have been identified and cultural/agronomic practices standardized for cultivation in salty soil and water environment, without employing mechanical and chemical methods of amelio-ration. A brief account of the technologies developed, in pipeline and the area reclaimed and targeted for the future is reviewed in this paper. The information is discussed under the following sub-heads : (i) nature, distribution and extent of salt-affected soils and waters in India, (ii) sodic (Alkali) soil reclamation by amendments, (iii) drainage including sub-surface and bio-drainage for managing saline water-logged soils, (iv) salt tolerant crops and varieties, (v) bio-saline agriculture, (vi) social economic perspectives and constraints (vii) future policy for research and development.

1 Founder Chairman, Gurbachan Singh Foundation for Research, Education and Development; Chairman, ASRB, New Delhi; Agri. Commissioner, Govt. of India; Director, CSSRI, Karnal; ADG, ICAR, New Delhi; Founder President, ISSWQ; President, Indian Society of Agronomy, Beant Villa, Adjacent Adarsh Public School, Near Power House, Kunjpura Road, Karnal-132001, Haryana, India E-mail: dr.gurbachan@gmail.com

SUSTAINABILITY OF WATER RESOURCES MANAGEMENT POLICY: TIME FOR A PARADIGM SHIFT FOR ENSURING FUTURE FOOD SECURITY AND WATER RESOURCES

Bashir adelodun[1], Seul Gi Lee[1], Kyung Sook Choi[2]*

ABSTRACT

Sustainability of water resources in global food production systems is of utmost priority. The reoccurring and prolonged drought periods, in addition to the accelerated urbanization and changing lifestyle in a water-scarce country like Korea create a daunting challenge onthe availability of freshwater for food production. A common approach to addressing the challenges of agricultural water conservation has been centered on the field during crop production. This method, though very impactful, cannot secure the projected future food demand considering the ecological deficit and other limiting factors associated with food production.The alternative idea to ensuring food availability is therefore indispensable, specifically by exploring the prodigious food loss and waste (FLW) that could have far-reaching benefits in terms of resources conservation and food security. This study quantifies and analyses the FLW of various food groups in each stage of the food supply chain (FSC) for Korean specific food production data (2007 - 2013) using the top-down approach of global FLW mass flow model. Furthermore, the quantity of water inherent in FLW was assessed using the representative water footprint of food types. The results showed that 14.14 million tonnes (0.78 kg/capita/day) equivalent to 54.92% of domestic production were either lost or wasted with only consumer stage responsible for 48.79%. An average of 56.49 Gm^3/year of water resources was associated with the FLW, representing a considerable 44% of the country's total water resources (129.7Gm^3). Among the food wastages, cereals and meats wastages accounted for the most significant depletion of water resources with This study shows that minimizing food wastage, rather than field water conservationalone,can substantially improve available freshwater andmeet the growing food demand while using the resources sustainably.

Keywords: Food loss and waste, water footprint, food production, Republic of Korea

1 Land & Water Engineering Lab., Department of Agricultural Civil Engineering, Kyungpook National University, Daehak-ro 80, Buk-gu, Daegu, 702-701 Republic of Korea Email: adbash2008@gmail.com

2 Department of Agricultural Civil Engineering, Institute of Agricultural Science & Technology, Kyungpook National University, Daehak-ro 80, Buk-gu, Daegu, 702-701, Republic of Korea. Email: ks.choi@knu.ac.kr

THE PRELIMINARY STUDY ON ENHANCEMENT STRATEGY FOR WATER QUALITY MANAGEMENT IN XILUO IRRIGATION AREA OF TAIWAN

Ke-Chun Lin1, Ying-Chun Lin2, Ching-Ru Tang[2], Chong-Yuan Lin[2] and Pi-Hui Suzi Chang[3]

ABSTRACT

Yunlin County, known for its valuable agriculture and animal husbandry, is located at the south-central part of western Taiwan. Due to the geography, there is not enough surface runoff for irrigation purposes. Alternatively, the scheme of regional drainage reused for irrigation (RDRI) has been adopted by Taiwan Yunlin Irrigation Association (Yunlin IA) within certain irrigation areas, such as the Xiluo irrigation area, but some degradation of irrigation water quality occasionally happens. Aims of this study were (1) to understand how irrigation water quality was affected by RDRI, and (2) to propose enhancement strategies for Yunlin IA improving the irrigation water quality in the Xiluo irrigation area including the work-stations of Xiluo, Yinxi and Dayi. The affected areas of RDRI were accounted for 18.7% in Xiluo work-station, 31.1% in Yinxi work-station, and 100% in Dayi work-station, which was considered as the area seriously facing the problem of irrigation water quality deterioration. According to the industrial distribution in Yunlin County, animal waste could be the most influential sources polluting irrigation water. Since more than 80% of the livestock ranches in the Xiluo irrigation area were swine ranches, and many of them seemed not dealing with animal waste properly, the main pollution source might be the disposal of animal waste without appropriate pre-treatment. In conclusion, Yunlin IA should enhance the management on the discharge of animal husbandry waste via increasing waste pre-treatment, raising frequency of monitoring irrigation water quality, and cleaning irrigation ditch sediment while RDRI is applied. Along with the act of Taiwan Environmental Protection Administration on “livestock’s wastewater and solid waste recycling into the surrounding rural soils” started from 2017, co-operation between the livestock ranches and the surrounding agricultural land was strongly recommended to effectively promote the reuse of livestock waste and encourage farmers to practice recycling agriculture.

Keywords: Regional drainage reused for irrigation (RDRI), Animal husbandry, Livestock waste, Swine ranch, Manure, Wastewater, Recycling agriculture

1 Research Division III, Taiwan Research Institute on Water Resources and Agriculture (TRIWRA).19F, No.27-8, Sec. 2, Zhongzheng E. Rd., Tamsui Dist., New Taipei 251, Taiwan; E-mail: kclin@triwra.org.tw

2 Irrigation Management Division, Irrigation and Drainage Section, Taiwan Yunlin Irrigation Association (Yunlin IA). 5F, No. 2, Xinghua St., Douliu City, Yunlin County 640, Taiwan; E-mail: annie01171@gmail.com

3 Research Division III, Taiwan Research Institute on Water Resources and Agriculture (TRIWRA). 19F, No.27-8, Sec. 2, Zhongzheng E. Rd., Tamsui Dist., New Taipei 251, Taiwan; E-mail: suzichang@triwra.org.tw

DEVELOPING POROUS STRUCTURES TO IMPROVE WATER QUALITY ON TIDAL LOWLAND AGRICULTURE OF SOUTH SUMATERA INDONESIA

Momon Sodik Imanudin[1*], Bakri[2] and Birendrajana[3],

ABSTRACT

The problems of agriculture in tidal lowland reclamation areas include limited water supply and poor water quality for plant growth. Water often contains high levels of iron and acidity. The research aims to develop a porous structure that can reduce iron levels and increase pH. The materials used are cement, sand, lime and rice husk ash. Volumetric ratio of cement, sand, lime and rice husk ash are 2: 2: 1: 3. Porous structures are made with hexagon models. The purification application is carried out by soaking the structure into poor water quality from the swamp. The purification results showed significant increase in pH to alkaline and decrease of iron levels. Increasing the pH of water in the treatment of the porous structure of the cone block model shows very high neutralization power in the neutralization test of water with a volumetric ratio of 1: 4 (1 part cone block and 4 liters of water) showed reduced iron content from 11.3 to 0.3 mg/L and increased water pH from 3 to 8.9. Changes in pH from very acid to neutral were achieved on the third day after soaking the porous structure.
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Keywords : Orous structure, water quality, tidal lowland

1 ,*Department of Soil Science Sriwijaya University Indonesia. Email momon_unsri@yahoo.co.id
2 Department of Soil Science Sriwijaya University Indonesia
3 Head of River Basin Agency of Sumatra VIII Ministriy of Public Work Indonesia

THE WESTERN CONJUNCTIVE MANAGEMENT FALLACY: GROUNDWATER IN THE WESTERN UNITED STATES

Sarah Liljefelt[1] and Therese Ure[2]

ABSTRACT

In the United States, federal government policies and statutes have historically shaped the systems of water law adopted across the country, but state law governs individual rights to divert water and place water to beneficial use. The states adopted two primary Water right systems, those being reasonable use in the eastern states, and prior appropriation in the western states. In the West, the prior appropriation system of “first in time, first in right,” has been applied inconsistently to later-developed groundwater use rights, resulting in different systems of conjunctive management of surface water and groundwater amongst western states. Moreover, states have struggled to consistently apply groundwater science to equitably distribute water resources between surface water and groundwater users.

This paper will briefly describe the history and water development policies shaping the current conjunctive management statutory schemes in the western United States. This paper will focus on specific examples of conjunctive management challenges and inconsistencies in particular western states, making recommendations for more equitable and just management of water resources in order to protect senior rights in the prior appropriation system, while allowing continued water use by junior appropriators when the science does not support regulatory shut offs.

Keywords: Conjunctive Management, groundwater, surface water, reasonable use, prior appropriations, Western United States.

1 Schroder Law Offices, PC; 1915 NE Cesar Chavez Blvd., Portland, Oregon 97212, United States of America; s.liljefelt@water-law.com

2 Schroeder Law Offices, PC; 10615 Double R Blvd., Ste. 100, Reno, Nevada, 89521, United States of America; t.ure@water-law.com

DEVELOPING NATIONAL DESIGN STANDARD FOR IRRIGATION AND DRAINAGE TO SUPPORT WATER AND FOOD SECURITY IN CAMBODIA

Ketya Hun[1], Sytharith Pen[2], Pinnara Ket[3], Bin Dong[4], Garry Ellem[5] and Sarann Ly[6]

ABSTRACT

Irrigation plays a very important role in rice and other crops production in rural Cambodia where over 75% of the people are residing and depend on agriculture as a source of livelihood and family incomes. Cambodia has an ancient tradition of irrigated agriculture dating back to Angkor Era started in9th Century. After several decades of civil wars, the country aims to become one of the major rice exporters and is therefore investing heavily in the expansion and restoration of its irrigation systems. Several of these multi-million-dollar projects are built by different foreign contractors/developers using their preferred design standard in the absence of national technical standards to apply across all development projects. Cambodia's irrigation and drainage has many similarities with other countries but also has some unique characteristics, which do not permit the automatic transfer of design standards from other countries to be applied in Cambodia. The draft of Cambodian 2019-2033 National Irrigation Program acknowledged this serious challenge to the sustainable irrigation development. There is a need for Cambodian design standard for irrigation and drainage to bring all irrigation projects under one common standard. The developed standard should be applicable in terms of climate, geology, hydrology, geography, economic condition, human resources and local practices and livelihood in Cambodia.

The Wuhan University (WHU) and Institute of Technology of Cambodia (ITC) have worked in partnership with the Cambodian Ministry of Water Resources and Meteorology, Cambodia Agriculture Value Chain Program (CAVAC) and Cambodian University of Agriculture, in assessing, testing and producing a Cambodian Irrigation Design Standard. The project reviewed existing standards applied by various developers and proposed a draft standard for consideration of the Government and the partners. The existing irrigation standards of neighbouring countries and other countries with similarity in terms of environmental and economic condition were reviewed. The methods and design parameters applicable in Cambodian context were adopted. Key findings include: such standards should be carefully specified for the range of agro-ecologies and contexts of irrigation and drainage in Cambodia. Further refinement and interim improvement of some design and feasibility criteria could be achieved by establishing irrigation research stations in each agro-ecological zone, and within representative irrigation areas.

1 Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia; E-mail: sytharithpen@yahoo.com
2 Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia; E-mail: ketyah@live.com
3 Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia; E-mail: ketyah@live.com
4 School of Water Resources and Hydropower Engineering, Wuhan University; E-mail: dongbin@whu.edu.cn
5 Cambodia Agricultural Value Chain Program; E-mail: garyellem@cavackh.org
6 Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia; E-mail: ketyah@live.com

RAINFALL DISTRIBUTION ANALYSIS TO ASSIST CROP SELECTION AND IRRIGATION PLANNING

J. Niharika[1], K.Yella Reddy[2], L. Narayana Reddy[3], and K.V.Jayakumar[4]

ABSTRACT

Even though weather is uncertain by nature, and the impacts of climate change are extremely difficult to predict at a regional level, attempts have been made to suggest more focus on this side to achieve sustainable management of water. This study was conducted to analyses the precipitation data of 406 rain gauge stations located in Telangana state, India, for Probable Wet and Dry spells, Onset & Withdrawal of monsoon and Length of Monsoon which can help farmers to know about critical periods of dry spells. Critical evaluation of dry spell could be used in decision making with respect to supplemental irrigation, field operations, a profitable crop variety in a given location, frequency of irrigation and in the management of water in water-stressed areas. The results exhibited that the wet week probabilities are decreasing from Northern zone to Southern zone. Number of dry spells with less frequent rains occurred in some parts of southern Telangana zone. There are very few weeks in Southern Telangana Zone, where, the wet week probability is greater than 50%. This suggests that growing high water requiring crops like paddy is not economical in Southern Telangana Zone and the weeks other than these are to be planned for supplemental irrigation. The continuous wet week probabilities in Northern Telangana zone were increasing from 26th week to 30th week, and then again decreasing. This indicates period of water conservation. About 93% of regions have continuous wet week probabilities in 30th week. Whereas in Central Telangana Zone, all over the zone, Wet week probability is greater than 50 % is starting from the weeks 23rd and 24thand ending in 38thweek. This pattern is uniform all over the Central Telangana Zone. This period is fairly enough for farmer to take agricultural operations during the start of season. Some regions had a wet spell after a long dry spell. This indicates that care must be taken, for the critical stages of crop in respect of moisture, not to sync with this critical dry period. Most of the rainfall turns to runoff which can be controlled with water harvesting structures like on-farm reservoirs. These can be used to give supplemental irrigation to the crops during critical dry spell. At times when the rainfall is not sufficient, and surface water alone cannot meet the water requirements of crop, groundwater can be planned to be used in conjunction with surface water.

Keywords : Markovian chain, Wetspell, Dry spell,Onset of monsoon, Withdrawal of monsoon, Supplemental irrigation

1 Assistant Hydrologist, AP Ground Water Department, India, email: niharika.janga@gmail.com
2 Dean, Faculty of AE&T, ANGRAU, Guntur, AP, India, email: yellark@gmail.com
3 Former Director General, WALAMTARI, Hyderabad, India, email: aproop1993@gmail.com
4 Dean (IR&AA), Professor, National Institute of Technology, Warangal, India, email: kvj@nitw.ac.in

A HOLISTIC WATER MANAGEMENT FOR WATER-FOOD NEXUS SECURITY : THE CASE OF EGYPT

Amin Elshorbagy[1,2] and Ahmed Abdelkader[1]

ABSTRACT

The water-energy-food (WEF) nexus is an emerging theme that brings multicentricity to the traditional integrated water resources management. Thus, the WEF nexus approach enables the evaluation of sector-based (water) policies from the perspective of other sectors, e.g. food and energy. The accelerating water and food gaps, and the fact that they exacerbate each other in a vicious cycle, especially in arid regions, make the problem of water and food security an urgent problem that needs to be treated in an integrated way. Globally, half of the land area of challenged economies in developing countries is in arid regions. Therefore, effective management of agricultural water use, which is the major water consumer, is a national priority. In this study, cropping pattern planning is identified as a major policy variable for agricultural water management in arid regions. We consider the case study of Egypt, as an example of a hyper-arid climate, to show case the inseparable nature of water and food security. A framework for the generation and assessment of alternative cropping patterns (ACPs) is developed. The framework is applied to Egypt, for which a simulation-based national water, food, and trade (NWFT) model was already developed. The framework is formulated to simultaneously minimize the national agricultural water demand, food (virtual water) imports, and the economic cost of imports as well as maximize the national gross margin of agriculture. Additional filtering criteria (intended to be an intervention tool by policy makers) are employed to account for national fertilizer use as well as the inter-annual stability of the set objectives. The objective functions and the filtering criteria of the ACPs generated are evaluated using the NWFT model during the baseline period (1986-2013) as well as projected up to year 2050 under various combinations of national development and global food price scenarios. The quantifiable tradeoffs between Egypt's food self-sufficiency, the national water demand of agriculture, the gross margin in the agriculture sector, and the economic cost of imports is the key contribution of this study, representing important information for policy makers to aid in important decisions.

Keywords : Water-food nexus, virtual water, system dynamics, Cropping pattern, Global market, Egypt.

1 Department of Civil, Geological, & Environmental Engineering, University of Saskatchewan, Saskatoon, SK, Canada; E-mail: amin.elshorbagy@usask.ca

2 Global Institute for Water Security (GIWS), University of Saskatchewan, Saskatoon, SK, Canada.

EFFICIENT AND PRODUCTIVE WATER USE FOR SUSTAINABLE WATER RESOURCES MANAGEMENT IN INDIA

S Masood Husain[1], Navin Kumar[2] and Chaitanya K S[3]

ABSTRACT

India is home to 1/6th of the humanity and its attainment and sustenance of food, energy and water security has a larger bearing on achieving 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals. India has largely succeeded in achieving food security with over five-fold increase in food grain production after attaining independence. Amongst other inputs, expansion of irrigated agriculture has contributed significantly to this. However, irrigated agricultural sector has been struggling with deep seated problems such as low water use efficiency and poor standards of management and maintenance of infrastructure.

Irrigation sector accounts for lion's share of water utilization in India even though domestic and industrial water demands are on the rise. Any saving in water use in the irrigation sector releases substantial quantity of water for meeting growing demands of other sectors. No realistic national level assessment of overall irrigation efficiencies is possible due to presence of multitude of players and lack of consensus on utilization data among the States, especially in water stressed river basins.

Achieving food, water and energy security and adapting to climate change while preserving robust health of environment are going to be major challenges ahead. This paper explores the utility of Water-Energy-Food nexus as a conceptual tool to understand the inter-dependencies, linkages and synergies between various sectors and what can be done to ensure sustainable water resources management. Specific instances of the nexus at regional and basin scales are discussed. Further, the paper proposes that water productivity alongside water use efficiency should gain currency and become part of sustainable water resources management in India. The paper also discusses the constraints in estimating 'Agricultural Water Productivity' and suggests the way forward to monitor the same.
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Keywords : India ; micro irrigation ; sustainability ; water-energy-food nexus ; water use efficiency ; water productivity

1 Chairman, Central Water Commission and Chairman, Cauvery Water Management Authority, 2nd Floor(S), Sewa Bhawan, Sector-I, R.K.Puram, New Delhi - 110066; E-mail: chairman-cwc@nic.in

2 Member(Water Resources), Cauvery Water Management Authority, 9th Floor(S), Sewa Bhawan, Sector-I, R.K.Puram, New Delhi – 110066 ; E-mail: navinkumar-cwc@nic.in

3 Deputy Director, Inter State Matters-2 Directorate, Central Water Commission, 5th Floor(S),Sewa Bhawan, Sector I, R.K.Puram, New Delhi - 110066; E-mail: chaitanyaks-cwc@gov.in

WATER QUALITY CHARACTERISTICS TO THE WATER-ENERGY-FOOD (WEF) NEXUS

Yuliya Mahdalena Hidayat[1] and Dini Nur Utami[2]

ABSTRACT

Upper Citarum Watershed is one of the sources of water that is used to fulfill raw water for agriculture or irrigation, with an area of irrigation reaching 16,659 hectares. There is a close relationship between water security and food security. In general, water resistance is measured through quantity indicators, while quality indicators are still not widely studied. Water quality indicators will also affect energy security. When water quality decreases dramatically with the waste being discharged into the water, energy is needed to manage waste that has been disposed of. If waste is not managed it will have an impact on the quality of the food produced.

This research will show how the characteristics of water quality in water-energy-food-nexus. The research was conducted in the Upper Citarum watershed, by examining the characteristics of metals in water and grain or rice. After knowing the metal characteristics in both of them, water-energy-food-nexus analysis was carried out. The results showed that in areas contaminated with metals, grain or rice also contained metal. The presence of metals in certain concentrations in food has a certain level of danger for consumption. To anticipate the dangers of food consumption due to pollution of water quality, several management practices can be carried out, including the prevention of waste by applying clean production and the manufacture of WWTP installations.

Keywords: Irrigation, Water quality, Water-Energy-Food-Nexus, Clean production, WWTP

1 Research Center for Water Resources, Research and Developmenrt Agency, Ministry of Public Works and Housing, Jalan Ir. H. Juanda No. 193 Bandung, West Java, Indonesia. Email : yuliya96119@gmail.com

2 Research Center for Water Resources, Research and Developmenrt Agency, Ministry of Public Works and Housing, Jalan Ir. H. Juanda No. 193 Bandung, West Java, Indonesia. Email : dininurut@gmail.com

WATER SECTOR AS A SILENT GAMECHANGER: CASE STUDY OF INDIA

Vivek P. Kapadia[1]

ABSTRACT

Water and food security have been viewed as a basis for sustainability of any nation. But at the same time the present competitive environment compels to review the water and agricultural sectors from profitability point of view at the annual financial planning stage. After all, the game is for optimizing the monitory benefits. There has been a general perception that dependence on agriculture for any nation is a sign of backwardness leading to the tenet that industrialization is synonymous to modernization. Dependence of India on agriculture is well known in the world. The paper focuses on the journey of India since its independence from the British rule and concludes that, on the anvil of competitiveness from fiscal aspects point of view, water and agricultural sectors have performed better than other sectors associated with industries; rather, water sector has nourished their growth. Returns from water and agricultural sectors have clearly proven their worth. In the present time when several countries have been facing survival related challenges, India has withstood the shocks of the time as it was fortunate to have agriculture as its basis. It has been finally drawn from the analysis that water sector is the most crucial domain for survival of India. Other countries may learn a lot from the case study of India and make the globe a better place to live on.

Keywords: Agriculture, Competitiveness, Profitability, Sustainability, Water

1 Chief Engineer, Water Resources Department, Government of Gujarat, India; E-mail: vivekpkapadia@gmail.com

APPLYING CIRCULAR ECONOMY ON POLLUTION REMEDIATION AND INTEGRATED MANAGEMENT IN DONGGANG RIVER BASIN, TAIWAN

Lu,Tai-Ying[1], Ting, Cheh-Shyh[2]

ABSTRACT

Donggang River has a total length of 44 kilometers at Pingtung Plain, Taiwan. It is a typical water-flowing river with an average daily flow of 2.06 million m^3. It provides water for daily supply of 300,000 to 350,000 m^3 of Kaohsiung City. In the past ten years, nearly 74% of the animal husbandry effluent pollution in the basin has caused serious water quality problems. Over the years, there has been no departmental integration mechanism and effective governance policies. This study is concerned about Kaoshiung-Pintung water resources from the role of civil NGO and started to make progress over the governance with further analysis of Donggang River through several public and private meetings and discussions. After the discussion, a so called Circular economy model– an innovative multi-dimensional solution was formulated that converts pollution sources into resources for energy.

In addition, lots of efforts were made to enter the six-year Forward-looking infrastructure construction, starting in mid-2017. The project has been upgraded to the key management level of the Executive Yuan, and the case is expected to solve the problem of sustainable development of water resources through technical, policy and social interventions. From the perspective of policy framework, this forum will demonstrate the Circular Economy Model has solutions that have been proposed for many years of technological innovation, meanwhile to develop the governance of the integration of various departments. A model case for Taiwan's river pollution remediation was eventually established that simultaneously solves river pollution, creates renewable energy and resources. .

Keywords: watershed integration management circular economy river pollution remediation renewable energy.

1 Doctoral candidate of Civil Engineering Institute, National Pingtung University of Science and Technology, Taiwan. (no.3, Ln140, Tzu-li 2nd Rd, Kaoshiung, 80046 Taiwan(R.O.C)); E-mail: luty1961@gmail.com

2 Dean of the College of Engineering, National Pingtung University of Science and Technology,Taiwan.(1, Shuefu Road, Neipu, Pingtung 91201, Taiwan (R.O.C)); E-mail:csting@mail.npust.edu.tw

CLIMATE CHANGE IMPACT ON WATER AND POWER OPERATION IN URBANIZED AREA - A CASE STUDY OF TAOYUAN CITY, TAIWAN

Kai-Yuan Ke[1] and Yih-Chi Tan*[2]

ABSTRACT

Taoyuan City is the sixth special municipality of Taiwan since 2014, and was the satellite city of Taipei metropolitan area. A population boost of 25% for the last two decades made Taoyuan City total residents of 2.2 million. Therefore, Taoyuan City is the only city that is considered under significant urbanization in Taiwan. The population growth results in possible water shortage and insufficient power supply. The water supply mainly comes from Shihman Reservoir, which also supplies part of the power needed in Taoyuan. The study applies SWAT and Vensim to assess the climate change impact on reservoir operation in terms of water supply/demand and power generation under various scenarios.

Keywords: Climate Change, system dynamic model, SWAT

1 Center for Weather Climate and Disaster Research, National Taiwan University; E-mail: yctan@ntu.edu.tw
2 Center for Weather Climate and Disaster Research, National Taiwan University; E-mail: kent0115@gmail.com

PRO-POOR AGRICULTURAL POWER POLICY FOR WEST BENGAL

Manisha Shah[1], Sujata Daschowdhury[2], and Tushaar Shah[3]

ABSTRACT

Sitting on one of the world's best aquifers, large swathes of West Bengal has groundwater in abundance. Even so, the state's farmers incur one of the highest irrigation costs in India. In spite of a series of groundwater and electricity policy changes, West Bengal's farmers fare no better. This paper brings findings from a yearlong research pilot based in Monoharpur village of Birbhum district. The pilot shows how the current electricity tariff structure has made irrigation unaffordable for small and marginal farmers, and has made irrigation services market tightly oligopolistic. If not revised, the agricultural economy, especially that of summer paddy which ensures household security of poor farmers, is likely to taper off in future.

Keywords: Farm power, pro-poor irrigation, electricity tariff, summer paddy, water markets

1 International Water Management Insitute (IWMI), Jal Tarang Building, IRMA-Mangalpura Road, Anand 388001, India [E-mail: shah.manisha90@gmail.com]

2 Independent Researcher, 'SOPAN', Gurupally South, Santiniketan, Birbhum 731235, India

3 IWMI, Jal Tarang Building, IRMA-Mangalpura Road, Anand 388001, India

CHALAKUDY RIVER DIVERSION SCHEME, KERALA: DOES IT SHOW THE FUTURE OF CANAL IRRIGATION IN INDIA?

Harikrishnan Santhosh[1], Amal Mohan[2] and Sruthi Laura George[2]

ABSTRACT

During the Green Revolution era, paddy cultivation was promoted with much vigor within Kerala. The canal systems that supplied timely irrigation played an important role in promoting food security within the state as rice self-sufficiency became a political concern. Under changing circumstances, paddy cultivation has seen a drastic downward trend in the last 30 years. One of the reasons for this trend is the irregularity in water supply through canals resulting from the flow fluctuations due to various hydroelectric projects that have come up in the upstream and inefficiencies arising out of low maintenance and performance management. At the same time, farmers in Kerala have largely shifted towards the cultivation of high valued cash crops. This paper presents a case study of the Chalakudy River Diversion Scheme which once served the irrigation requirements of paddy in the Chalakudy river basin. The paper tries to shed light on how farmers have adapted to the evolving nature of CRDS as they continually shift towards cash crops that require better water control. In this process, CRDS has ended up as an entity vastly different from the intent of its planners. The role of canal irrigation, changing from direct flow irrigation to complementing recharge or replenishment of groundwater and surface water storages, may point towards the imminent transformation of canal irrigation in the rest of India.

Keywords: Canal Irrigation, groundwater recharge, high value crop cultivation, conjunctive management, lift irrigation

1 Pre-Doctoral Fellow, IWMI-TATA Water Policy Program, International Water Management Institute (IWMI), Anand, Gujarat – 388001; Email: h.santhosh@cgiar.org

2 Student Intern, Institute of Rural Management Anand, Gujarat - 388001

EVALUATION OF WATER DEMAND SUPPLY ON TISZA RIVER BASIN

JánosTamás[1], Bernadett Gálya[1], Erika Buday Bódi[1], Tamás Magyar [1], and Attila Nagy[1]

ABSTRACT

Water scarcity and drought are becoming increasingly challenging for water management, in Europe including Hungary. According to the forecasts, the climate of our country is shifted to the Mediterranean, it becomes warmer and drier, which means that the drought and the water demand of agriculture can increase, impacting the usable water supply. The Great Hungarian Plain (and within this the Tisza-KőrösValley) is the most vulnerable area of the country from a hydrometeorological point of view. The number of drought years are becoming more frequent (2000, 2003, 2007, 2009, 2012, etc.) due to many reasons such as the soil conditions and uneven precipitation distribution. As a result, locally generated surface and ground water and their retention and preservation (storage, water retention, near-natural water management) becomes more important. At the same time, the role of water transfer to water scarcity areas is also increasing.

The Tisza-Körös Valley Co-operative Water Management System is one of the largest water management systems in Europe with the aim of replacing water resources in water-scarce areas and reducing the impact of hydrometeorological extremes. The project consists of two parts: the Tisza Lake and the Tisza-Körös Valley Co-operative Water Management project. The project covers all the areas concerned (agriculture, rural development, land use, water management, nature protection, etc.) and takes into account natural conditions and the effects of changes in them because of the climate. The water shortage remedies include the Kiskőre reservoir (the most significant), the main water supply and distribution network, main waterworks, backwaters and reservoirs. These allow the storage of a total of 201.1 million m^3 of dynamic water resources. The usable water supply for the normal summer water level of Lake Tisza is 155 million m^3. More than 10 million m^3 of water is retained in the main water irrigation works.

In the case of water works this value is 1.5 million m^3. In terms of surface water resources, the current irrigation water abstraction at the river basin level does not cause a deficit, however, it is difficult to estimate due to the lack of irrigation needs. In this study, we reviewed the current situation of drought prevention and water use in Hungary, including the development of water resources, water demand and the possibilities available to replace water shortages.

Keywords: water scarcity, water demand, water management, Tisza River, Hungary

1 University of Debrecen, Faculty of Agriculture and Food Sciences and Environmental Management, Institute of Water and Environmental Management; HU-4032, Debrecen, Böszörményi str. 138. E-mail: tamas@agr.unideb.hu

FUTURE PRECIPITATION PROJECTIONS AND ITS POTENTIALIMPACT FOR DEVELOPMENT AND MANAGEMENT OFIRRIGATION OVER INDONESIA

Radyan Putra Pradana[1], and Widya Utaminingsih[2]

ABSTRACT

Indonesia, as the largest archipelago country in the world, is one of the most vulnerable countries to climate change impacts. One of the impacts is expected to alter the precipitation pattern. The increase of extreme rainfall will increase the risk of flooding during the rainy season, while prolonged drought in the dry season will have a severe impact on agriculture activity. Future projections of precipitation at national scales are vital to informing climate change adaptation activities. Therefore, it is important to quantify projected changes and its associated uncertainty. This study aims to analyze future precipitation projections of near-term (2020-2035) periods on 7 spatial planning areas at the national level (Sumatera, Kalimantan, Jawa-Madura-Bali, Nusa Tenggara, Sulawesi, Maluku and Papua), by using outputs from 6 downscaled ensemble GCM of SEACLID/CORDEX-SEA project based on the RCP4.5 and 8.5 scenarios from phase 5 of the Coupled Model Intercomparison Project (CMIP5). Some result of this study may serve as a scientific basis to adaptation and mitigation for the irrigation sector impacted by climate change especially for national future development and management of irrigation.

Keywords: climate change, precipitation, projection, irrigation, food security.

1 Researcher, Climate and Air Quality Research Division, Center for Research and Development, Indonesian Agency for Meteorology Climatology and Geophysics (BMKG). Jl. Angkasa I No. 2 Kemayoran, Jakarta Pusat. 10720.); E-mail: radyan.putrapradana@bmkg.go.id

2 Researcher, Experimental Station for Irrigation, Center for Water Resources Ministry of Public Works and Housing. Jl. Cut Meutia PO. BOX 147, Bekasi 17113.); E-mail: widyautaminingsih0@gmail.com

CONJUNCTIVE EXPLOITATION OF SURFACE AND GROUNDWATER IN THE EASTERN OF NILE DELTA

Eman R. Nofal[1], and Ahmed M. Aly[2]

ABSTRACT

Egypt is one of the African countries that could be vulnerable to water stresses under climate change in the future. An array of serious threats resulting from climate change in Egypt, one of the most important matters is the rise in sea level that could affect the Nile Delta area. Irrigation in the Nile Delta depends on surface water. However, conjunctive exploitation of surface and groundwater is taking place, and unless carefully managed, it can result in saltwater intrusion and deterioration of groundwater and soil quality. This paper provides a comprehensive analysis for sustaining the irrigation systems to set suitable strategies and practices for enhancing crop water productivity at the irrigation canal levels, taking into consideration the problems of water supply performance and efficiencies, inequity of water distribution, and poor irrigation and drainage management/practices. The study area is located on east edge in the Nile Delta, Egypt. The study concluded that water is available in sufficient quantity throughout the year and the farmers at head of the branch canal in this area use more water than their needs; but the farmers in tail of irrigation canal tend to use groundwater to cover the shortage in surface water. The study results show seepage water from the canal to the ground water exists, especially at the end of the studied reach which may occur due to the recharge from the canal to groundwater at the wells located at the sides of the canal. The groundwater declines in the areas around the tail of canal as a result of the intensive random extraction rates for groundwater for irrigation purposes by the farmers;

Keywords: Water management, Groundwater, Surface water, Nile Delta, Conjunctive Use

1 Researcher (Civil Engineer), National Water Research Center, Delta Barrage, P.C 13621/5, Egypt, email: emanragab29@yahoo.com

2 E-mail: mando.ahmedmohsen@gmail.com

TRANSBOUNDARY RIVERS: WATER SAVING POLICY AND MUTUAL COMPENSATION FOR ENVIRONMENTAL DAMAGE

Yury Mazhayskiy[1], AliaksandrVolchak[2], AlehMeshyk[3], Lubov Hertman[4], and Inna Davydova[5]

ABSTRACT

The main task in the research of transboundary water resources at the present stage is a comprehensive assessment of their current state, taking into account the spatio-temporal fluctuations and changes in the main components of the water balance of riverwater-collecting header. At the same time, it is necessary to take into account the effects of various natural and anthropogenic factors on them, the forecast of changes in water resources under different scenarios of climate development. Based on the scientific results obtained, it is necessary to develop measures to minimize the possible negative consequences in case of a change in the regime of water resources.

The problem of adaptation of water resources to climate change is new and undefined. At the same time, as a result of climate change, some modern problems of the water management complex of Russia, Belarus and other states may be exacerbated, and new ones that are not typical for current conditions may appear. Therefore, the development of adaptation measures and their implementation is an urgent task.

The article deals with the major problem of water resources management in transboundary rivers. Wherein, the main management thesis is to ensure water saving policies and mutual compensation for environmental damage. The directions in which it is necessary to implementthe water-saving policy, among which the flood control, increasing drought resistance and improving the quality of natural waters are differentiated, are highlighted. The concrete measures to adapt water resources to climate change are proposed. In this regard, both engineering and economic and organizational methods are considered.

The problem of insufficient information support during the development of compensatory measures that reduce damages associated with the state and quality of water resources is noted.

The concept of management and rational use of water resources, which is based on an integrated approach that determines the priorities of water consumption and water use,is developed. The problems of transboundary rivers are proposed to be solved in close cooperation with partner countries, developing international cooperation. In this regard, the implementation of transboundary cooperation between Poland, Belarus, Ukraine in the management of water resources of the Zapadnyi Bug river basin is considered in detail.

1 Brest State Technical University, Moskovskaya str. 267, Brest, 224017, Belarus, omeshyk@gmail.com
2 Brest State Technical University, Moskovskaya str. 267, Brest, 224017, Belarus, volchak@tut.by
3 RUE “Central Research Institute for Complex Use of Water Resources” (CRICUWR), Slavinskogo str.
4 1/2, Minsk, 220086, Belarus, lubov.hertman@yandex.by

THE STUDY ON ARTIFICIAL RECHARGE OF GROUNDWATER FOR LAND SUBSIDENCEUSING EXISTING AGRICULTURAL PONDS

Ting Cheh-Shyh[1], Chuang Chi-Hung[2]

ABSTRACT

Taiwan is an oceanic nation with a combined area of approximately 36,000 km^2. The Central Mountain Range were formed by Eurasian and Philippine Plates and stretches along the entire island from north to south, along the entire island, thus forming a natural line of demarcation for rivers on the eastern and western sides of the island. The uncontrolled development of groundwater resources has led to undesirable effects, especially in the coastal area where aquaculture is concentrated. These effects are land subsidence, saline water intrusion, lowering of water tables. The purpose of this preliminary study is to evaluate the reclaimed water reuse via aquifers. The sewage waste water discharged from the surrounding settlements closed to the pathway of the Taiwan High Speed Rail located at the land subsidence area. Purification technology using existing agricultural ponds as constructed wetland is to recharge aquifer by ponds or wells and then to mitigate the land subsidence for railway safe. From the data collection, the evaluation and analysis will be simulated by numerical model for the next stage. The constructed wetland system can be achieved the required quality for recharge from the reclaimed water reuse. Based on the well results from preliminary study of artificial recharge of groundwater using existing agricultural ponds to alleviate the land subsidence, the planned projects will be promoted by the Council of Agriculture along the pathway of the Taiwan High Speed Rail located at the land subsidence area in the future.

Keywords: Artificial recharge of groundwater, constructed wetland, land subsidence

1 Distinguished Professor, Department of Civil Engineering, Director, Centre for Water Resources Educations and Studies, National Pingtung University of Science and Technology, Pingtung 912, Taiwan; E-mail: csting@mail.npust.edu.tw

2. Senior Manager, Pro. Vision Environmental Engineering Corporation (PVEEC), Taiwan; E-mail: chjuang@pcveec.com.tw

WATER CONSRVATION STRATEGIES FOR BEIJING CAPIATAL REGION, CHINA

Hubert Jenny[1],Mingyuan Fan[2], Yihong Wang[3], Paul Bulson[6]; Liu Peibin[6]; and Jelle Beekma[4]

ABSTRACT

Beijing's Capital Region (BCR) is home to over 23 million people (2017) and the World's second largest city after Shanghai. It still is a fast-growing mega city and one of the most water challenged cities. According to the World Health Organization, acute water scarcity occurs if water resources fall below 500 m3 per person per year and BCR residents do not reach 200 m3 per person per year. In 2016 the total annual water consumption in the BCR was 4 billion m3 and is expected to reach 4.5 billion m3 by 2020. Renewable fresh water resources are estimated to be within 3 to 5 billion m3 per year. Currently, about 55% of the water demand is met through underground water and 45% from surface water, including some recycling. With underground water potentials declining, the BCR has limited solutions and needs to either recharge the groundwater or build more surface impoundments: The only way(s) to sustainably meet the additional water demand by 2030 is through water conservation. Asian Development Bank (ADB) is assisting the Beijing Municipal Government (BMG) to meet the BCR's future water demand. ADB is currently reviewing and assessing specific BRC water conservation measures including tariffs, non-revenue water (NRW), increased water quality, water reuse (wastewater, storm water, industrial water), groundwater recharge (sponge city), water saving fixtures, urban forests/landscaping and education. In 2018, ADB prepared 'Guidelines and Good Practice for Managed Aquifer Recharge with Infiltration Basins', which outlined how infiltration basins could be constructed in the BCR.

In 2012, a Technical Assistance (TA) recommended investing in technology upgrades to both realize complete wastewater reuse and to reduce wastewater's large energy footprint. In the same year, a review concluded that NRW increases could be controlled by using four primary methods: (i) controlling gaps between recorded flows at the bulk meters and customer meters; (ii) improving flow measurement(s) throughout the system; (iii) installing more advanced pipes: and (iv) using new field methodologies to calculate NRW. Going forward there are several ADB initiatives that include implementing water conservation measures such as water reuse, groundwater recharge and residential water savings. One project expected in 2019 is an innovative approach for conserving and protecting water resources while increasing growth of urban forests as carbon sinks and supporting China's Intended Nationally Determined Contribution at the Paris Agreement. The proposed project involves using fecal sludge from septic tanks for their water content as a substitute for fresh water now used on BCR urban forests. Another project expected to move forward in 2019 is groundwater recharge using treated wastewater reuse through various techniques, including infiltration basins, re-design of existing waterways and modifications to the current building and landscaping codes. Under consideration is also a revolving fund that would provide partial water tariff rebates for the purchase of low water using fixtures and appliances under BMG's proposed water conservancy plan.

Keywords: Beijing, carbon storage, climate change, managed aquifer recharge, sponge city, urban forest, wastewater recycling, water conservation, water-food-energy nexus.

[1] Principal Infrastructure Finance Specialist, Asian Development Bank.Philippines. Email: hjenny@adb.org
[2] Senior Water Resources Specialist, Asian Development Bank. Philippines. Email: mfan@adb.org
[3] Senior Investment Officer, Asian Development Bank. Philippines. Email: wyihong@adb.org
[4] Senior Water Resources Specialist. Asian Development Bank, Philippines. Email: jbeekma@adb.org
[6] Consultants Asian Development Bank

GREEN AND BLUE WATER REQUIREMENTS FOR SUSTAINABLE PAKISTAN'S STAPLE CROP PRODUCTION UNDER FUTURE CLIMATE CONDITIONS

Mirza Junaid Ahmad[1], Gun-Ho Cho[1], Seulgi Lee[1] and Kyung-Sook Choi[2]

ABSTRACT

Sustainable wheat production is crucial for economic and food security of Pakistan; since wheat is a staple for masses and millions of agricultural workers rely on its production for employment and livelihood. In this work, green and blue water requirements were projected to sustain future wheat production in Punjab, Pakistan using the statically bias-corrected climate change projections from nine global circulation models by the end of 2080. Climate projections envisaged substantially hotter and drier future wheat growing season featuring significant yield losses. During the 2030s (2021 – 2050), the seasonal cumulative crop evapotranspiration (ET) and irrigation requirements declined due to growth span shortening induced by the moderate warming; whereas, during the 2060s (2051 – 2080), they both increased despite a significant growth span shortening caused by intense warming. The future wheat production was more irrigation-dependent since the green water contribution would be limited. Future wheat total water footprint (TWF) continuously increased; implying that the apparent ET decrease would not necessarily result inTWFs reduction. The projected green water footprints (GWF) declined and inclined during the 2030s and 2060s, respectively, indicating higher green water availability during 2nd half of the 21st century. During the 2030s, despite the limited green water availability, the blue water footprint (BWF) increments were marginal due to moderate warming. The BWF increments were higher during the 2060s compared to the 2030s; highlighting that higher green water contribution would not suffice warming driven 2060s-ET increments. The CO_2 enrichment effects showed promises to partially compensate for the detrimental climate change impacts over wheat yield and WFs; nevertheless, the reliability of such estimates demands a further in-depth examination of crop yield responses to climate change under field conditions.

Keywords: Climate change, Water footprint, Wheatyield, Aquacrop

1 Dept. of Agricultural Civil Engineering, Kyungpook National University, 80 Daehakro, Bukgu, Daegu, 702-701 Korea

2 Dept. of Agricultural Civil Engineering, Institute of Agricultural Science & Technology, Kyungpook National University, 80 Daehakro, Bukgu, Daegu, 702-701 Korea, Email: ks.choi@knu.ac.kr

DETERMINATION OF DEPENDABLE FLOW FOR MICROHYDRO POWER PLANT IN IRRIGATION NETWORK

Afida Zukhrufiyati[1], Joko Triyono[2], Segel Ginting[3] and Eko Winar Irianto[4]

ABSTRACT

Electrical energy at this time has become one of the basic needs of society. Along with economic growth, people's electricity needs have increased. This needs to be met by increasing capacity to provide electricity. One of the electricity sources that can be developed is microhydro power plant. Irrigation networks have the potential to develop microhydro power plants if they have water availability indicated by dependable flow in irrigation networks and have a minimum head of 2 meters in irrigation networks. Dependable flow in irrigation networks shows the availability of water supplies to irrigation channel. Calculation of dependable flow on irrigation networks is influenced by the schedule of water supply. This study explains some approaches that can be used in determining dependable flow. Determination of dependable flow in irrigation networks at this time is still constrained by data availability. The approach in determining dependable flow in irrigation networks is divided into two i.e. information on discharge data in irrigation buildings available and information on discharge data in irrigation weirs available. Dependable flow in the irrigation networks used to calculate the energy potential of microhydro power plant is determined using the flow duration curve method in the irrigation channel. The results of the study indicate that the most optimum probability of discharge for micro hydro potential applied in the Tajum Irrigation Area is 50% (Q50). Q50 can produce electrical power according to the micro hydro criteria based on water availability for 6 months.

Keywords : microhydro, electricity, dependable flow, irrigation networks, flow duration curve

1 Researcher, Experimental Station for Irrigation, Research Center for Water Resources,Research and Development Agency, Ministry of Public Works and Public Housing. Bekasi 11713, Indonesia; E-mail: afida164@gmail.com

2 Researcher, Experimental Station for Irrigation, Research Center for Water Resources,Research and Development Agency, Ministry of Public Works and Public Housing. Bekasi 11713, Indonesia; E-mail: joko3triyono@gmail.com

3 Researcher, Experimental Station for Irrigation, Research Center for Water Resources,Research and Development Agency, Ministry of Public Works and Public Housing. Bekasi 11713, Indonesia; E-mail: gintingsegel@gmail.com

4 Head of Water Resources Research and Development Center, Research and Development Agency, Ministry of Public Works and Public Housing, Bandung 40135, Indonesia; E-mail: ekowinar1966@gmail.com

REVALUATION OF LOCAL KNOWLEDGE AS A SUSTAINABLE DROUGHT ADAPTATION STRATEGY

Muhamad Khoiru Zaki[1], Keigo Noda[2], Kengo Ito[3] and Komariah[4]

ABSTRACT

Local knowledge can be defined as a person's ability to use his/her understanding and senses to respond to an event, object, or situation in the local environment. The aim of this study was to revaluate Pranata Mangsa as a form of local knowledge that can aid in adapting to drought. Pranata Mangsa is used on the Indonesian islands of Java and Bali, particularly by farmers, for managing agricultural activities in the fields and is based on Titen, or natural signs. The relationships between natural signs and farming activities are arranged in four primary and twelve secondary Mangsa, or seasons. Each Mangsa is characterized by activities such as Bero (maintaining fallow land) and burning rice straw, which reduce the loss of crops from meteorological drought and soil moisture deficits caused by agricultural drought. These practices suggest the potential for applying local knowledge to drought adaptation and indicate that a revaluation of the local knowledge of Pranata Mangsa with its specific characteristics could offer an effective strategy for adapting to drought and meeting the 2030 Sustainable Development Goals.

Keywords : Local knowledge, Drought, Soil moisture, Rain-fed farmland

1 The United Graduate School of Agricultural Sciences, Gifu University. Yanagido 1-1, Gifu, Japan. 501-1193. E-mail: zakimuhamad30@gmail.com

2 Faculty of Applied Biological Sciences, Gifu University. Yanagido 1-1, Gifu, Japan. 501-1193. E-mail: anod@gifu-u.ac.jp

3 Faculty of Applied Biological Sciences, Gifu University. Yanagido 1-1, Gifu, Japan. 501-1193. E-mail: joroken@gifu-u.ac.jp

4 Faculty of Agriculture, Sebelas Maret University. Jl. Ir. Sutami 36A, Surakarta, Indonesia. 57261. E-mail: komariah23@gmail.com

EVALUATION OF FARMING ACTIVITIES SUPPORTED BY CLIMATE SUB-LOANS IN TAJIKISTAN AND UZBEKISTAN

Dr. Shukhrat Mukhamedjanov[1], Dr. Sherzod Mominov [2], Rustam Sagdullaev [3], and Nazokat Khasanova[4]

ABSTRACT

Increased pressure on environment in combination with extreme weather events, such as droughts and floods, may lead to unsustainability of agriculture. Most probably, decreased crop yield may cause disproportion between production and population need for food.

In Uzbekistan and Tajikistan agrarian sector is the main consumer of water, which is used for irrigation. Climate change and its consequences (increased temperature, low precipitation and decreased area of glaciers) may lead to increased deficit of water availability and increased need for irrigation water in the future.

To improve sustainability of agriculture under climate change, investments will be required, firstly, for reorganization and improvement of irrigation and agriculture infrastructure. In addition, climate risks in agriculture and water sector will require separate investments. In this context, it should be clear, what specific problems need to be financed. It is also essential to understand that these investments should be targeted, with the use of existing high tech tools to solve specific tasks.

The paper presents the assessment of efficiency related climate investments in agriculture in Uzbekistan and Tajikistan. Basic criteria and indicators of assessment were developed. Climate anomalies and risks in agriculture production and adaptation measures were defined.

1 Scientific Information Center of the Interstate Commission for Water Coordination of Central Asi
2 Scientific Information Center of the Interstate Commission for Water Coordination of Central Asia
3 Scientific Information Center of the Interstate Commission for Water Coordination of Central Asia
4 Student

WATER RESOURCE AND FOOD SECURITY: A CASE STUDY OF HOUSEHOLDS IN GAUTENG PROVINCE, SOUTH AFRICA

Maponya Phokele[1]

ABSTRACT

South Africa is considered a 'food-secure' nation, producing enough calories to adequately feed every one of its 53 million people. However, the reality is that, despite some progress since the birth of democracy in 1994, one in four people currently suffers hunger on a regular basis and more than half of the population live in such precarious circumstances that they are at risk of going hungry. At national and country levels, South Africa exceeds most global benchmarks for amounts of food produced and exported. However, national figures hide the reality at the household level. Household survey was conducted in the Gauteng Province by the Agricultural Research Council (ARC) and Gauteng Department of Agriculture and Rural Development (GDARD) to establish the water resources and food security status. The following objectives were followed: (1) to identify and describe water resource availability in terms of wetness status and water sources. (2) to identify and describe food security status in terms of accessibility. A total of 1150 households' participated, quantitative, and qualitative designs were used as a questionnaire, stakeholder's discussion and field observations were part of the data collection. A purposive sampling technique was used and data was coded, captured and analysed using the Statistical Package for the Social Sciences (SPSS). Food security status was also in line with the fact that South Africa is food insecure at a household level in contradiction to the national level. At the same time, rainfall decreased significantly during the data collection period in Gauteng Province. The standardised precipitation index (SPI) showed that severe to extreme drought conditions were present over some parts of South Africa including Gauteng Province during data collection and currently the SPI showed the presence of mild to moderate drought conditions. 942/82% households had access to irrigation water with 208/18% households had no access to irrigation water. The large majority (881/77%) of households reported relying on municipal piped water for irrigating their gardens while few households reporting river or boreholes as sources of water. It was also emphasised by officials during focus groups discussions that households were encouraged to use rainwater harvesting and greywater. 876/76% Households across Gauteng Province indicated that water is available year round while 274/24% households did not receive water year round. This limited water resource had a negative impact on household food security as a whopping number of Gauteng Province households interviewed were food insecure (860/75%) as compared to households that are food secure (290/25%). This food security situation is worrying because 695/60% households go to sleep at night hungry because there was not enough food and about 395/34% households goes the whole day and night without eating anything. In terms of the impression of food availability across the Gauteng Province, most of the households (347/30% always, 159//14% often & 450/39% sometimes) indicated that their food runs out before they get money to buy more. Quite a number of households (371/32% never & 549/48% sometimes) cannot afford to eat enough food everyday. In terms of food accessibility, seven hundred and sixty seven (765/67%) households indicated that they lack resources for accessing food, while 385/33% households accessed food. The implications for this scenario can be that 765/67% households are food insecure due to lack of resources for accessing or producing food. This is because the households cannot afford to buy or produce preferred foods, thus they resorted to monotonous diets because it is all that they can afford.

1 Senior Researcher & Project Leader, Agriculture Research Council: Vegetables and Ornamental Plants, Pretoria, South Africa, E-mail: maponyap@arc.agric.za

For instances, 1002/87% households have to eat fewer meals in a day, 1001/87% households have to eat a smaller meal, 991/86% households eat some foods that really did not want to eat, 1000/87% households have to eat a limited variety of food, 964/84% households have not be able to eat the kinds of food they preferred. This food access situation is worrying because 695/60% households go to sleep at night hungry because there was not enough food and about 395/34% households goes the whole day and night without eating anything. However, in Gauteng Province the situation is different as even households with access to piped water complained that the municipality water bill is too high to engage in household food production. The drought situation also added burden to the households' food security status. Other households have emphasised that they find it difficult to access irrigation water as most of the household were residing in informal settlements or areas where there is no service delivery. It is thus concluded that there is a need to integrate surface water and groundwater to ensure water sustainability to support food security. The Agricultural Research Council is also involved in water related research in Gauteng Province to address the challenges of food security. The survey recommended that households should use grey water, groundwater and encouraged to harvest rainwater to engage in household food production.

Keywords: Water Resource, Food Security, Household Food Production, Gauteng Province and South Africa.

EFFECTS OF CLIMATE CHANGE ON WATER MANAGEMENT IN LOWER CHAO PHRAYA AND THA CHIN RIVERS, THAILAND

Sanit Wongsa[1] and Watchara Suiadee[2]

ABSTRACT

Climate change causes serious risks to the well-being of nature and people all over the world. These are expected to have significant effects on water resources planning and management, especially in estuary areas. The objective of this study is to evaluate the vulnerability and adaptability for water management in Thailand. A model is developed using MIKE11 software and was calibrated and validated by matching historical data for the period 2010-2012. The study covered the area from Chao Phraya Dam (barrage), Chai Nat Province and Pho Phraya Regulator, SuphanBuri Province and to the river estuary at the Gulf of Thailand for Chao Phraya and Tha Chin rivers, respectively. The model was divided into two parts, hydrodynamic (HD) module and advection-dispersion (AD) module. Calibration of each part was done by adjusting its important coefficients. It was observed that the Manning's coefficient (n) and coefficient of dispersion of mass were in the range of 0.025-0.040 and 800-1,600 m^2/s, respectively. The results of comparison between models and observed data revealed the order of forecasting error (R^2) in the range of 0.70-0.99 for water level and 0.73-0.86 for salinity. For model application, the RCP2.6 and 8.5 scenario from IPCC report were simulated, predicted sea water level rise were 0.76 and 1.06 m (in the year of 2100), respectively. Maximum salinity at Samlae pumping station were 0.63-0.67 g/l, exceeding the standard and the pointed tip of salinity at Ko rain sub-district by 0.25 g/l, Ayutthaya Province in Chao Phraya river. The increase of salinity also affects the growth of plants in the estuary areas. Results of this study can be used as guidelines for the management of water resources and agriculture of the Chao Phraya and Tha Chin Rivers.

Keywords: Global warming, Sea water level change, Chao Phraya River, Tha Chin River, MIKE11Model.

1 Department of Civil Technology Education, King Mongkut's University of Technology Thonburi (KMUTT), Bangkok, Thailand. CP. 10140.); E-mail: sanit.won@kmutt.ac.th
2 Information and Communication Technology Center, Royal Irrigation Department (RID), Bangkok, Thailand. CP. 10300.); E-mail: watchara_rid@hotmail.co.th

MODELLING OF MITIGATION STRATEGIES TO REDUCE NUTRIENT LOADS TO WATERWAYS UNDER CHANGING CLIMATE AND LAND USE

Richard G. Cresswell[1], Mark Walton and Andrew Herron

ABSTRACT

We have modelled the effectiveness of mitigation strategies to reduce soil nutrient leaching associated with selected agricultural land uses, particularly those associated with dairy farming. We used APSIM, a dynamic, mechanistic and stochastic platform for modelling biophysical processes in agricultural systems, to generate temporally and spatially explicit nitrate fluxes through soil profiles representative of paddocks under differing land use and management regimes. APSIM operates at a daily time step and allows the incorporation of actual and stochastic climate series, enabling assessment of leaching following discrete events; seasonal or decadal trends, or prediction of climate change impacts.

The modular, scriptable framework allows nutrient leaching associated with seasonal management regimes, or historical land use change, to be evaluated. In the same manner, mitigation strategies to reduce leaching can be assessed, examining dynamic trends in N leach, long term annual leach rates, and in respect to other soil properties or production targets affecting farm viability. Soil and climate parameters can be adjusted to represent the spatial variability of different paddocks, and paddock-scale results can be integrated across sub-catchments, providing sub-catchment scale outputs from farm and enterprise modelling that can be input to spatially constrained and temporally precise catchment models.

We will provide examples of where APSIM has been used to inform management decisions for dairy enterprises in New Zealand and also discuss the role of nitrate attenuation through denitrification via oxygen-poor groundwaters and riparian zones. We will outline the multiple lines of evidence that are required to evaluate the efficacy of denitrification impacts at any given site.

Keywords: APSIM, nitrogen leaching, land-use change impacts, denitrification, mechanistic models, nitrate attenuation.

1 Eco Logical Australia, Level 3, 101 Sussex Street, Sydney, NSW, 2000 Australia); E-mail: richardc@ecoaus.com.au

MEASUREMENT OF INFRASTRUCTURE PERFORMANCE IN LARGE IRRIGATION SCHEME AS A TOOL FOR ASSESSMENT OF IRRIGATION MODERNIZATION IN INDONESIA

Ansita Gupitakingkin Pradipta[1], Murtiningrum[1], Sigit Supadmo Arif[1], Eko Subekti[2], Mochammad Mazid[3], Nadiya Isnaeni[4], and Anditya Sridamar Pratyasta[4]

ABSTRACT

Irrigation modernization is a series of efforts to realize a participatory irrigation management system that is oriented in compliance the irrigation service level effectively, efficiently, and sustainably, in order to support food and water security. Irrigation modernization begins with the asessment of readiness index of irrigation modernization (IKMI), which consists of the assessment of 5 irrigation pillars: water availability, irrigation infrastructure, irrigation management system, irrigation institution, and human resources. This study discuss about the measurement of irrigation infrastructure of two large irrigation scheme in Indonesia, there are Serayu Irrigation Scheme (20,795 Ha) and Kedung Putri Irrigation Scheme (4,341 Ha). The assessment of infrastructure performance includes of 5 parts: main building, main network channel, main network building, drainage channel, and tertiary network. The assessment used the scale of 1 – 100, which includes irrigation network functions and conditions. The results showed that Serayu Irrigation Schemes and Kedung Putri Irrigation Schemes had the value of IKMI as 88.16 and 68.05 respectively. It means Serayu I.S included in the adequate predicate. Thus, the irrigation infrastructure of Serayu I.S. are ready to support the implementation of irrigation modernization. Meanwhile, Kedung Putri I.S included in the sufficient predicate. Then it is needed to improve the system for the 1 – 2 years on the irrigation infrastructure pillar.

Keywords: irrigation modernization, readiness index, irrigation pillars, infrastructure

1 Department of Agricultural and Biosystems Engineering, Universitas Gadjah Mada (UGM), Indonesia. E-mail: ansita.pradipta@ugm.ac.id.
2 Expert Team of Irrigation Modernization of Indonesia.
3 Directorate of Irrigation and Swamp, Directorate General of Water Resources, Ministry of Public Works and Housing, Indonesia.
4 Alumni of Department of Agricultural and Biosystems Engineering, Universitas Gadjah Mada, Indonesia.

CLIMATE CHANGE IMPACT ON IRRIGATION WATER REQUIREMENT FOR PADDY

Dissanayake Mudiyanselage Thushara Sanjeewa Dissanayake[1]

ABSTRACT

Anuradhapura district is one of the major low-land paddy cultivation areas in Sri Lanka fed by a large number of reservoirs. The cultivations are done according to traditional cultivation calendar, where Maha season starts on October 01, while Yala season starts on April 15. According to experts, climate change is causing changes in rainfall intensities and patterns and a considerable increase in average temperature. If rainfall and water evapotranspiration rate change, irrigation water requirement (IWR) from the reservoirs also change, resulting in either water shortage or surplus. Therefore, objective of this study is to see whether climate change has influenced IWR, so that measures can be taken to optimize the use of available water resources in the area. CROPWAT 8.0 software was used for calculating IWR using daily rainfall data of seven gauge stations and temperature data of Anuradhapura climatic station. Other unavailable climatic data were obtained from the CLIMWAT database for the nearest station. IWR for both Yala and Maha seasons were calculated, based on commonly cultivated paddy varieties and cultivation calendar, from 1980 to 2016. The spearman's rank correlation method was used to check possible trends in IWR for the study period. According to trend analysis the IWR for the Yala season showed neither an upward nor a downward trend. However, the same for the Maha season showed a considerable downward trend. Obviously, Maha season IWR has gradually been decreasing since 1980. Therefore, paddy cultivation in Anuradhapura district is positively impacted by climate change during the Maha season, while there is no impact during Yala season. It is suggested to increase cultivation extents during the Maha season to obtain maximum productivity from water resources. Additional extents have to be decided after carrying out new operation studies for each reservoir based irrigation scheme.

Keywords: Climate change, Paddy, Irrigation water requirement, Anuradhapura district.

1 Chief Engineer (Land), Irrigation Department, Colombo 07, 00700, Sri Lanka; E-mail: dmtsdissa@yahoo.com

RESEARCH ON DEVELOPING FARMLAND IRRIGATION WATER MANAGEMENT MODEL IN TAIWAN

Ray-Shyan Wu[1], Jih-Shun Liu[2] and Yi-Chen Ruan[3] , Hsiang-Chuan Wu[4]

ABSTRACT

The agricultural water usage accounts 70% of total nation's water consumption in Taiwan, which paddy field irrigation have the largest proportion. When the drought occurs, the allocation and utilization of water usage become an important issue, especially in agriculture, farmer pump ground water to supply the irrigation deficit from surface water which may impact regional groundwater level and cause more problem in strata subsidence. Generally, the irrigation water intake from channel and groundwater depends on the weather condition and the crop planting period, such as crops planting ratio and the growth stage of crops. Farmers choose to irrigate crops with water extracted from irrigation channel or pumped groundwater. To the need for calculating field water assumption and irrigation water, system dynamic model was used to establish irrigation water management model for mixed cropping fields. The second crop simulation in 2016 shows that when the ratio of water irrigated on paddy to upland is 0.5 to 0.5 (about 104.5 hectares for both paddy rice and upland crops), the ratio of total pumping volume to total channel water during simulated crop growth is about 46% and 54%; when the ratio of water irrigated on paddy to upland is 0.9 to 0.1 (about 188 hectares of paddy and about 21 hectares of upland crops), the ratio of total pumping to total channel water intake during simulated crop growth is about 51% and 49%. It can be understood that the ratio of rice to upland crops farming will significantly affect the irrigation water situation. When the rice area increases, the irrigation water demand will also increase. As the scenario simulated when paddy area increased 40%, the water demand increased 11%. Meanwhile, under insufficient canal water supply, the groundwater pumping will be increased up to 5%. Through the integrated irrigation system of surface water and groundwater to explore the situation of agricultural water use, the water source allocation efficiency of agricultural water can be upgraded, and the space for the allocation of water for people's livelihood and industrial water can be further improved.

Keywords: System dynamic model; Farmland irrigation; Mixed crop, Taiwan.

1 Taiwan Department of Civil Engineering, National Central University, Taiwan. E-mail: raywu@ncu.edu.tw
2 Taiwan Agricultural Engineering Research Center(AERC),Taiwan. E-mail: jsliu@aerc.org.tw
3 Taiwan Department of Civil Engg., National Central University, Taiwan. E-mail: kenny515ruan@gmail.com
4 Taiwan Agricultural Engineering Research Center(AERC),Taiwan. E-mail: hswu@aerc.org.tw

REVIEW OF HEAVY METAL CONTROL STANDARDS BASED ON THE UNCERTAINTY ANALYSIS OF HUMAN HEALTH AND SOIL SUSTAINABILITY

Dai-Ming Li[1],Pao-Hsuan Huang[2], Sheng-WeiWang[2], Ming-Der Hong[3], Sheng-Hsin Hsieh[3] and Chihhao Fan[1]

ABSTRACT

According to the past economic development policies in Taiwan, as years went by the lack of control, contributed to the situation of factories by the side of the farmlands. In order to establish a complete environmental safety regulation for agricultural production, the government authorities take scientific and technological study plan to integrate the principles and processes of the relevant regulatory standards of heavy metals in the agricultural safety management system. To view the standards in an appropriate light, we start from the perspective on human health risks and soil sustainability. While discussing human health, we also take environmental sustainability and the limits of establishing regulations into consideration. As this could be a scientific basis for evaluating the regulatory standards in the future, to reconfirm the accuracy of current heavy metal control standards. In this study, while estimating the allowable concentration of heavy metals in rice, the non-carcinogenic risk values are calculated with the local data and the regulations of the Ministry of Health and Welfare, and other parameters like the transportation rate of soil to crop, the heavy metal concentration of soil, soil weight, amount of irrigation water, and estimate of over-allowance time, are also calculated conservatively. . The allowable concentrations of heavy metals in irrigation water would be appropriate to ensure the safety of human health and the sustainability of soil.

However, the heavy metals control standards of irrigation water, soil, and agricultural products were established by the governing authorities, respectively. Due to the variety of the entering pathways of heavy metal from environmental media to food webs will eventually cause a health risk to human beings. It is necessary to consider the transport mechanisms of heavy metals in their pathways. In this study, to consider the variability of the influence of media in the agricultural production environment, the uncertain analysis is taken as a great part to meet multiple situations of the actual background value. The results from the regulations and reference show that the allowable concentrations of heavy metals in irrigation water are a lot lower than the current irrigation water quality control standards, and also lower than the actual concentration of heavy metals in the study area. The main reason is that parameter evaluation such as food intake, metabolism, and heavy metal degradation in the environment are not involved during the calculation. Therefore, it is appropriate to include complete health risk data to estimate the concentrations of heavy metals in irrigation water. On the other hand, the results calculated with the local data show that the allowable concentration of heavy metals, including copper, lead, nickel, zinc, and chromium, in irrigation water in the study area was estimated to be higher than the current irrigation water quality control standards, which means that there is no need to modify the standards, but the result of cadmium cannot be calculated due to its value of soil in the study area is too high. Nevertheless, the regulatory standards of Taiwan are strict enough as compared to other countries in the world.

Keywords: Heavy metals, Environmental safety regulation for agricultural production, Human health risks, Soil sustainability.

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1 Department of Bioenvironmental Systems Engineering, National Taiwan University, Taiwan(R.O.C)
2 Sinotech Environmental Technology, Ltd., Taiwan(R.O.C)
3 Council of Agriculture, Taiwan(R.O.C)

APPLICATION OF INTEGRATED AUTOMATIC MONITORING SYSTEM WITH WATER SIMULATION PLATFORM ON INCREASING EFFICIENCY OF IRRIGATION WATER QUALITY MANAGEMENT

Ning-Jin Kok[1],Shih-Chi Hsu[1],Ming-Der Hong[2], Sheng-Hsin Hsieh[2], Yu-Jung Hsu[3] and Chihhao Fan[3]

ABSTRACT

In Taiwan, irrigation water is polluted by the discharge of industrial and domestic wastewater into irrigation channels In Changhua County, the density of industrial area is relatively high, and surrounding the agricultural land making it difficult to identify the area of pollution. This study evaluates the integration of automatic monitoring systems (AMS) and water simulation platform on increasing management efficiency of the agricultural framework by ensuring the irrigation water was free from the risks of heavy metal pollution. In this study, a heavy metal-automatic monitoring system (AMS) was equipped at the drainage channels to record real-time water quality data and the data were retrieved via the cloud system. Data collected would be imported into a “water simulation platform” to indicate possible pollution receptor regions. In this study, statistical data from the past 15 years were collected via the AMS cloud system and data from Sept-Dec 2017 were applied for simulation.

It was discovered that most water quality anomalies occurred during evening and night-time. Meanwhile, in order to determine the diffusion area of pollution, simulation via the water simulation platform was used to increase the inspection efficiency. A water simulation platform transformed from the Water Quality Analysis Simulation Program (WASP) was visualized as a user-friendly web-based system with temporal-spatial data.

Users of the platform could assess the scenarios at the irrigation area, followed by customizing the parameters according to the data received from AMS. Simulation results of Hsinzhen channel were aggregated into a comprehensive table in a form of a conversion table containing parameters needed for simulations. Thus, while determining the region, processing via the platform or by referring to the conversion table were both feasible. Huge amount of time could be saved on the process as compared to conventional methods. The integration of AMS and water simulation platform are functional tools for irrigation associations while collaborating with the government’s environmental inspection units. Finally, amendments for water quality management measures could be improved and enhanced.

Keywords: Irrigation water, Automatic monitoring systems, Water simulation platform, Water Quality Analysis Simulation Program, Water quality management measures.

1 Sinotech Environmental Technology, Ltd., Taiwan(R.O.C)
2 Council of Agriculture, Taiwan(R.O.C)
3 Department of Bioenvironmental Systems Engineering, National Taiwan University, Taiwan(R.O.C)

WATER-ENERGY-FOOD RELATIONSHIP EVALUATION IN GREENHOUSE USING SYSTEM DYNAMICS AND SUSTAINABILITY INDEX

Pureun Yoon[1], Jin-Yong Choi[2], Kwihoon Kim[3], Yoonhee Lee[4], Seung Oh Hur[5] and Sang-hyun Lee[6]

ABSTRACT

Due to the population growth, food production demands and water use increase. There is a wide variety of global discussions on resource management in terms of securing resources such as water and food considering sustainability. The concept of “Water-Food-Energy Nexus” has emerged to interpret the linkage of water, energy and food resources and to suggest an integrated management plan. There is a trade-off relationship among input resources such as energy, water and cost, for increasing food productivity, therefore, it is necessary to analyze the relationships comprehensively rather than single resource analysis. This study was conducted to evaluate the relationship between water and food among the water-food-energy nexus of upland crops in the greenhouse. Because the greenhouse could control the environmental condition such as the temperature, humidity, and wind speed for growing the upland crops . Theanalysis based on the scenarios according to the environmental conditions could be conducted. Also, in the greenhouse, because the energy resources are put to provide an appropriate growth environment for crops, it is necessary to analyze the relationship between energy and other resources. Thus, this study included estimating the crop yield, irrigation water requirement and water productivity and simulating the response of crops to water stress, soil condition using AquaCrop model. Also, linking with energy resources such as heating, pumping energy, fertilizer, and calculating the equations between resources, Water-Energy-Food Nexus was constructed using System Dynamics. Assessment and comparison of scenarios can be accomplished through the calculation of a sustainability index to decide which scenario to choose and how much we can endure in terms of different resource requirement. Finally, the sustainability index for the scenario was calculated for decision-making and policy assessment.

Keywords: Water-Food-Energy Nexus, Greenhouse, AquaCrop, System dynamics, Sustainability index.

1 PhD student, Department of Rural System Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, E-mail: vnfms3259@snu.ac.kr
2 Professor, Department of Rural System Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, E-mail: iamchoi@snu.ac.kr
3 MS student, Department of Rural System Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, E-mail: kgh0330@snu.ac.kr
4 PhD student, Department of Rural System Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, E-mail: ukuleo@snu.ac.kr
5 Senior Research &Lab.Head, National Institute of Agricultural Sciences, Rural Development Administration, Jeonju 54875, Republic of Korea, E-mail: soilssohur@korea.kr
6 Research Institute of Humanity and Nature, 457-4 KamigamoMotoyama, Kita-ku, Kyoto, Japan. E-mail: sanghyunsnu@gmail.com

CLIMATE CHANGE IMPACT ON IRRIGATION WATER SECURITY IN WEST JAVA

Waluyo Hatmoko[1], Brigita Diaz[2] and Levina[3]

ABSTRACT

Climate change will change water availability characteristics in the future, and impact on irrigation water security. West Java contributes about 15% of national rice production from almost one million hectares of rice field. Irrigation water security in this region plays an important part in the national food security. This paper analyzes the climate change impact on irrigation water security in West Java. Climate change impact on rainfall in the future is projected using the worst scenario Representative Concentration Pathways (RCP) 8.5 that assumes high energy demand and greenhouse gas emissions in the absence of climate change policies, as mentioned in the latest IPCC report AR 5. The monthly rainfall is projected until the year of 2045 using ensemble of seven models CNRM CM5, CNRM RCA, CNRM v2 Reg CM, CSIRO MK3,6, EC EARTH, GFDL ESM, and IPSL. These models are bias-corrected with the CHIRPS rainfall data set that represents ground stations for the baseline period of 1981 to 2005. For the projection period from the year of 2006 to 2045, a statistical bias correction using quantile mapping methods is applied. Projected river discharge is calculated using a water balance equation, where discharge change is assumed to be influenced by changes in the rainfall and the evaporation. Irrigation water security index from Asian Water Development Outlook is reformulated to enable assessment of nature change, as well as human effort to control the water by means of reservoirs and weirs. The new irrigation water security index consists of: a) Natural hydrological condition represented by coefficient of variation of the monthly discharge within year and annual discharge; b) Competitive environment by water stress condition; and c) Infrastructures of reservoirs and irrigation weirs. It is concluded that the West Java irrigation water security in the future would be significantly reduced if no substantial effort is made to compensate the variability of water availability. All of the six river basins in West Java except Cilaki-Ciwulan are vulnerable to the climate change impact on irrigation water security.

Keywords: irrigation, water security, food security, climate change, discharge variability, water stress

1 Research Professor, Research Center for Water Resources, Ministry of Public Works and Housing, Jalan Ir. H. Juanda 193, Bandung; E-mail: whatmoko@yahoo.com

2 Climate Scientist, Research Center for Water Resources, Ministry of Public Works and Housing, Jalan Ir. H. Juanda 193, Bandung; E-mail: brigita.diaz@gmail.com

3 Researcher, Research Center for Water Resources, Ministry of Public Works and Housing, Jalan Ir. H. Juanda 193, Bandung; E-mail: ivepusair@gmail.com

A STUDY ON THE WATER RESOURCES ASSESSMENT FOR IRRIGATION SCHEME DEVELOPMENT IN MALAWI

SungSick, AHN[1,] RaeChul, LEE[2] and ChangHyun, CHOI[3]

ABSTRACT

In general, for the development or rehabilitation of irrigation scheme, the efficient water resource management that supplies the irrigation water considering the required time and accurate quantity for growing the crop should be conducted. Therefore, the water resource assessment that is composed of the water requirement analysis and water availability assessment should precede in order to supply the irrigation water efficiently, when the irrigation scheme is developed. In particular, since the African region of the tropical climate is weak in the climate exchange considering because of the high temperature and evaporation, etc., the water resource assessment should be reviewed more thoroughly. In this study, Matiti scheme in Blantyre District of the southern Malawi was selected as the study area. The meteorological data were collected from the meteorological station, where is located around the study area., The evapotranspiration was analysed estimated by the Penman-Monteith Method and the effective rainfall was analysed by the USDA Soil Conservation Service Method. This study displays the results that for study area, the evapotranspiration varies from 3.57 mm/day to 6.72 mm/day and the effective rainfall varied from 1.2 mm to 135.3 mm. The unit water requirement and water demand were estimated to be 0.0016 m^3/s/ha and 0.024 m^3/s respectively, based on the selected crops (Green Maize, Dry Maize) considering the irrigation efficiency, irrigation time and irrigation area. The water availability assessment reviewed revealed that whether the irrigation water can be supplied or not in accordance with the difference between the inflow at the intake and total water demand at the scheme. The inflow of Matiti scheme was estimated by the specific yield method, and the water availability was evaluated through reviewed differences of discharge between $Q80_{intake}$ and total water demand (Total WD). Because theTotal water demand and $Q80_{intake}$were calculated as 0.03071 m^3/s and 0.06711 m^3/s ($Q80_{intake}$> Total WD)., The irrigation water can be supplied to 15 ha of the existing area sufficiently. There fore, the Matiti scheme can be extended from 15 ha to 37 ha in the dry season considering the $Q80_{intake}$.

Keywords: Unit water requirement, Water availability assessment, Extensibilityof irrigable area

1 General Manager, Department of Water Resource & Agricultural Civil Engineering, Dasan Consultants Co., Ltd., Dasan B/D 15 Songi-ro 30 gilSongpa-gu Seoul 05800 Korea; E-mail: ssshce@gmail.com

2 General Manager, Department of Water Resource & Agricultural Civil Engineering, Dasan Consultants Co., Ltd., Dasan B/D 15 Songi-ro 30 gilSongpa-gu Seoul 05800 Korea; E-mail: leerc@dasan93.co.kr

3 Executive Manager, Department of Water Resource & Agricultural Civil Engineering, Dasan Consultants Co., Ltd., Dasan B/D 15 Songi-ro 30 gilSongpa-gu Seoul 05800 Korea; E-mail: choich@dasan93.co.kr

INTEGRATED RIVER BASIN PLANNING AND MANAGEMENT: A CASE STUDY OF THE SOUSS MASSA RIVER BASIN, MOROCCO

Karima SEBARI[1], Ikram Benchebani[2], Marouane Amili[1]

ABSTRACT

River basins are inherently complex systems with many interdependent components (streams, aquifers, reservoirs, cities, irrigation districts, etc.). The sustainability of future economic growth and environmental health in a basin depends on the rational allocation of water among the basin riparians and sectors. Efficient and comprehensive decision support systems have an important role to implement integrated water resources management and lead to sustainable water use strategies. The aim of this study is to present an implementation of integrated water resources management and evaluate alternative water resource development in Souss Massa basin in Morocco. The capacity of the water resource system to satisfy the water requirements of urban and agriculture uses is assessed over different horizons. Scenario analysis was carried out with the decision support system for integrated water resource planning and management RIBASIM. Sustainability criteria were defined.

The balance of Maximum Resources - Peak Needs showed that the resources allocated to the drinking water of Agadir city would be unable to cover future needs. Measures have to be undertaken to fill the deficits. The outputs showed serious deficits and therefore a strategy is proposed to overcome these impacts by the horizons 2030, 2040 and 2050. The result of decision making for the future was tested under climate change impacts. The selected planning strategy included the construction of a new dam (Tamri Dam) and the use of non-conventional water (desalination). Hydraulic simulations were carried out to determine optimal reservoir capacity and assess the hydraulic performances of the dam. The first scenario showed that conventional water resources will reach their full utilization by 2030.

This situation would become more critical if water resources are affected by climate change. A second scenario including climate change impacts were analyzed. It showed that the reservoirs system will go through several critical periods during which the average supply of water can decrease to -6.37Mm by 2050 and the reliability and resilience indexes of the system will decrease drastically. In order to alleviate the future deficits, the third scenario including sea water desalination plant is analyzed. Results showed that the use of non-conventional water resources will address the indexes to meet fully the drinking water and agricultural water needs of the Souss-Massa basin until 2050.

Keywords: Decision making, scenario analysis, basin simulation, climate change, Drinking water, deficit, reliability, resilience, vulnerability, RIBASIM, performance criteria, desalination, Souss Massa basin, Morocco.

1 Department of rural engineering, Hassan II Institute of Agronomy and Veterinary Medicine, BP. 6202. Rabat Instituts, Rabat, Morocco. E-mail: k.sebari@iav.ac.ma
2 Studies and planning division, Department of water, Ministry of Equipment, Transport, Logistics and Water, Hassan Benchekroun Street, Agdal, Rabat, Morocco.E-mail: ikrambenchbani@gmail.com

OPTIMIZATION OF SPATIAL PLANNING OF TIDAL SWAMP AREA TO SUPPORT THE COMMUNITY EVELOPMENT OF BUOL REGENCY, INDONESIA

Budi Santosa Wignyosukarto[1], Hadi Santoso[2]

ABSTRACT

The Government of Buol Regency intends to develop a lowland area of 4688 ha in the Biau, Bukat, Bukal and Momuno sub districts for agricultural, animal husbandry, fisheries and tourism purposes, in order to improve the community's economy. The area is close to the coast line and on the banks of the Buol river, which is affected by tidal movements and flows of several natural rivers. At present only around + 35% of the area is exploited for various purposes including rice fields 1.78%, coconut plantation 14.78%, sago/nipa 13.72%, fish pond 8.64%. Whereas the other areas are left as swamps and bushes. The land properties survey states that the majority of land in the S2 class order (Moderately Suitable) to S3 / N1 (Marginal Suitable / Currently Not Suitable), is quite appropriate and marginal to be developed as agricultural land, especially with restrictions on drainage problems. In a small spot, a small amount of sulfaquents is found. This type of soil has a high pyrite content which when oxidized will be harmful to plants. Most (93%) is the tropaguept soil type which is immature land, the water content is high and the drainage is very inhibited. The total P value and its high cation exchange capacity indicate that the land is potentially fertile. Considering the soil pH between 5.1-6.5 and 6.6-7.3, it can be concluded that the influence of pyrite is not visible, but the effect of saline water intrusion is quite significant, the existence of Nipaplants in several places can be notified.

Hydro-topography condition, the ratio of land elevation to tidal water level, states that almost all land is not flooded by tide, the upstream land elevation ranges between +2.8m ~ +3.0m, the land elevation in the downstream ranges between +1.1m ~ +1.5 m and tidal elevations fluctuate between -0.80m ~ +1.10m. Inundation that occurs is more due to poor natural drainage and flood water from surrounding river. Water governance is planned for the purposes of agriculture, fisheries and tourism taking into account the physical conditions of land and water, as well as external influences, such as tides, saline water intrusion and flooding. Considering hydro-topographic conditions, the irrigation water sources are rainwater, upstream river water and limited tidal overflows. The design of the drainage system is planned to remove excess rainwater and flooding from the surface and avoid the disposal of groundwater needed to maintain soil moisture for plants and avoid saline water intrusion. Flood risk management is one of the considerations in utilizing the floodplain. Cropping patterns are adjusted to the occurrence of floods, to minimize risk of flood. The results of land use planning propose the use of 3026 ha of rice fields, 693 ha of coconut plantations, 238 ha of perennials, 164 ha of sago, 435 ha of fishponds and 207 ha of conservation areas.

Keywords: Lowlands, réclamation, drainage, tidal

1 Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia. E-mail: budiws@ugm.ac.id

2 Engineer, PT. WEECON Bandung Indonesia

SUSTAINABLE DRAINAGE SYSTEM OF POPULATED SITEBA AREA, CITY OF PADANG, INDONESIA

Shafira Rahmadilla Hape[1], Budi Santoso Wignyosukarto[2], Istiarto[3]

ABSTRACT

High rainfall over a long period of time and the inability of the drainage network in the city of Padang to hold the overflow of the Batang Kuranji River, and dispose of rainwater within the area, are the main cause of flooding in the city of Padang. Based on flood event data in the city of Padang in 2016 and 2017, floods have occurred at least once a year, with varying depths of inundation between 0.5m and 1.0m. The worst flood recorded to date occurred on September 26th, 2018, with a depth of 1.5m. This flood caused damage to residential areas, agricultural land, irrigation channels and caused landslides on several hills in the city of Padang.

A sustainable drainage system is recommended to solve the flood problems of such area. Sustainable drainage systems encourage water infiltration; reduce runoff magnitude, thus helping preserve water resources and river flow for the dry season. In addition to reducing the peak of the flood, this drainage system also maintains the existence of wetlands in a wider scope as a flood retention area, protects and improves water quality and increases evapotranspiration and climate regulation in urban areas. Reduction of flood peaks could be done by building infiltration wells, allowing inundation for certain depth and duration in several low risk areas such as sports fields and parking lots. In addition to manage internal flooding, the drainage system also needs to be integrated with the flood prevention system.

Flood control simulations are carried out by utilizing the HEC-RAS mathematical model. The mathematical models integrate the internal drainage system and the external drainage system which is influenced by the Batang Kuranji River. The simulation begins with an evaluation of the capacity of the existing internal drainage channel network for the flood discharge and rainfall that have occurred and calibrated with flood water level data at the location. The simulation models were run for a 25-year return flood by increasing drainage channel capacity; increasing the infiltration rate with infiltration wells; allowing certain depth and duration of inundation in low risk areas.

Keywords : Flood, Urban Area, Sustainable Drainage System, Indonesia.

1 Master Student, Dept. Civil and Environmental Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia.; E-mail: shafirarahmadilla@gmail.com

2 Professors, Dept. Civil and Environmental Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia.E-mail: budiws@ugm.ac.id

3 Associate Professors, Dept. Civil and Environmental Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia.; E-mail: istiarto@ugm.ac.id

CLIMATE CHANGE IMPACT ASSESSMENT ON NUTRIENT LOADING FROM PADDY AREA USING APEX-BASED CLIMATE INDEX SENSITIVITY ANALYSIS

Jaepil Cho[1], Soongun Choi[2], Sewoon Hwang[3], and Chansung Oh[4]

ABSTRACT

The recent lack of water resources, including irrigation water, has led to relative consideration of water quality issue under the condition where water quantity is sufficient. During the last decade in Korea, the proportion of nonpoint source (NPS) pollution among the total pollutant load has been increased and became greater than the pollutant load from point source. In case of NPS pollution, it is recommended to reduce the pollutant load generated from source area rather than treat the collected pollutants. Irrigation managements are considered as best management practices (BMPs) for reducing pollutant loads such as nitrogen and phosphorus from paddy fields, which account for more than 50% of the total agricultural area in Korea. In this study, we propose a method to evaluate the change of nutrient load from paddy field during the future period according to climate change. Instead of using a direct approach to apply deterministic models to all paddy fields across the country, we used an indirect approach to estimate likely changes in nutrient loads over future periods based on climate indices that are likely sensitive to the nutrient outflows. The APEX-Paddy model was selected to consider the managements and mechanisms in paddy areas. Major indices for each nutrient were derived from 27 climate extreme indices using the model-based sensitivity analysis. Then, we analyzed the future changes in the selected climate extreme indices across the Korean peninsula using the downscaled data from 29 Global Climate Models (GCMs) at 3 km spatial resolutions. Finally, the changes in nutrient loads from paddy fields were estimated based on the changes in the climate indices.

Keywords: APEX, Paddy, Climate Change, Vulnerability, Irrigation Management, Non-point source pollution.

1 Research fellow, APEC Climate Center. Busan 48058; E-mail: jpcho89@gmail.com
2 Researcher, Department of Agricultural Environment, National Academy of Agricultural Science, Wanju 55365; E-mail: soonkun@korea.kr
3 Associate professor, Department of Agricultural Engineering (Institute of Agriculture and Life Science) Gyeongsang National University, Jinju 52828; E-mail: swhwang@gnu.ac.kr
4 Researcher, Future Policy Research Group, Rural Research Institute, Korea Rural Community Corporation, Ansan15634; E-mail: yes_csoh@ekr.or.kr

APPLYING KNOWLEDGE MANAGEMENT FOR IRRIGATION PERFORMANCE IMPROVEMENT IN LARGE IRRIGATION SYSTEM IN INDONESIA

Murtiningrum[1], Andri Prima Nugroho[2], SigitSupadmoArif[3], Djito[4], and Theresia Sri Sidharti[5]

ABSTRACT

Following the development of irrigation system infrastructures, the irrigation management becomes the next focus. The challenge irrigation management is related to human resources and their knowledge management. The problems occurred in human resources and knowledge management may threaten the sustainability of irrigation system. Some efforts to develop knowledge system in irrigation management system has started to develop. The objective of this paper was to analyse the development of knowledge management system in three different cases of irrigation management. This paper is based on irrigation from system approach and cycle of knowledge management implementation. The cases were Clean Irrigation Movement in Yogyakarta Province, Operation and Maintenance of Irrigation system of Lodoyo Irrigation System in East Java, and Irrigation Management Unit in Colo Irrigation System Central Java and East Java Provinces. From the cases, it was learnt that knowledge of individual in irrigation management determines the advancement of irrigation system and its sustainability. The success of institution is in management of its knowledge that influences the success of irrigation management.

Keywords: irrigation management, knowledge management, human resources, irrigation performance, operation and maintenance.

1 Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada. Jl. Flora 1, Bulaksumur, Yogyakarta, Indonesia. Email: tiningm@ugm.ac.id
2 Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada. Jl. Flora 1, Bulaksumur, Yogyakarta, Indonesia. Email: andrew@ugm.ac.id
3 Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada. Jl. Flora 1, Bulaksumur, Yogyakarta, Indonesia. Email: sigitsupadmoarif@ugm.ac.id
4 Individual Expert of Irrigation and Maintenance; E-mail: djitobrantas@yahoo.com
5 Individual Expert of Irrigation and Maintenance; E-mail: theresia_sri_sidharti@yahoo.com

INTEGRATED AGRICULTURE AND AQUACULTURE DEVELOPMENT IN BREBES COASTAL AREA, CENTRAL JAVA, INDONESIA

Moh. Ali Mashuri[1], F.X. Suryadi[2], Kittiwet Kuntiyawichai[3] and Haryo Istianto[4]

ASBTRACT

Rapid urbanization growth combined with the uncontrolled land use change and impacts of the changing climate pose one of the coastal areas in northern part of Central Java that will continue to result in coastal floods with overwhelming loss and damages to property, ecosystems and livelihoods. This paper presented the case study in Brebes, Central Java which experienced a serious flood in 2018 because of the combined effect of heavy rainfall and high water spring tides. Besides a hydrological analysis of the heavy rainfall, a hydrodynamic model was used to check the maximum capacity of the main urban drainage system in Brebes. Next to rice, Brebes is also well known as the largest producer of red onion in Indonesia. On the coastal area of Brebes, aquaculture development is also taking place.. Flood caused serious damages to agriculture, as well as aquaculture and urban area in Brebes. Based on the result of hydrodynamic model simulations, several possible measures have been evaluated.

It is concluded that next to the increase of the drainage capacity, polder system could be considered for Brebes area. Another important step to be taken is to reduce the extraction of groundwater in the coastal area of Brebes. The next step is to consider polder system is mainly to cope the flood problem especially due to the high rate of land subsidence. Polder system can be developed as a compartment system which will consider the natural drainage conditions and its boundaries. The polder system with a compartment system has to be operated and maintained in an integrated way in order to avoid any negative impact from one compartment to another because of improper operation and maintenance of the system.

Keywords: Integrated coastal zone management, Agriculture, Aquaculture, Land Use, Land Lost

1 Land and Irrigation Departement Head, Agricultural and Food Security Office, Brebes District, Central Java, Indonesia. Gadjah Mada Num 3 Street 52212; Email: mashurimohamadali@gmail.com

2 Senior Lecturer WSELWD, IHE, Delft. Netherlands; Email: f.suryadi@un-ihe.org

3 Associate Professor Khon Kaen University, Thailand; Email: kittiwet@gmail.com

4 Researc Center for Water Resources, Research and Development Agency, Ministry of Public Works and Housing; Email: haryoistianto@gmail.com

A PILOT STUDY ON USING PROBIOTICS TO REDUCE THE APPLICATION RATE OF NITROGEN FERTILIZER BASED ON ALTERNATE WETTING AND DRYING (AWD) IRRIGATION

Joon-Keat Lai[1], Kuan-Hui Lin[1],Jia-Qi Zuo[1],Ying-Tzy Jou[2], Yu-Min Wang[3],and Wen-Shin Lin[1]

ABSTRACT

Alternate wetting and drying (AWD) irrigation is an optimized agricultural water management practice with much less water than the usual system of continuously 'flooding' the field for planting rice. Long-term fertilizer application can cause the soil acidification and result in poor crop growth and significantly greater yield reductions. To reduce the application rate of fertilizer based on the AWD irrigation, the performance of probiotics that incorporated with the reduced fertilizer were investigated on the quantitative traits. The results indicated that the nitrogen fertilization rate could be reduced. Taking plant height as an example, there is no significant difference among the 25, 50 75 and 100% fertilization rates during the vegetative period, except the non-fertilized treatment. Moreover, the performance of rice growth status was consistent expressed in SPAD value among the 25, 50 75 and 100% fertilization rates. However, the performance of tillers number values is similar within fertilized groups, and is significantly higher than non-fertilized group. These methods reduce water and nitrogen fertilizer demand without reducing crop yields. In this study, plant height in fertilized groups showed two stunted interval, that are mostly related to maximum tillering and panicle initiation stages, but in the non-fertilized group it gently increased. SPAD values gradually decreased in fertilized groups, and were significantly higher than non-fertilized group upto 50 days. NDVI values showed complicated trends in all treatments, that means the interaction between beneficial microorganism and AWD irrigation approach probably existed. Accurate assessment of rice growth conditions in the entire season, especially the tipping point in panicle initiation stage, which affects yield potential, is essential for farmers and researchers to optimize field practices and further investigation is required for future industrial applications.

Keywords: alternate wetting and drying (AWD), probiotics, nitrogen fertilizer

1 Department of Plant Industry, National Pingtung University of Science and Technology. NO. 1, Shuefu Road, Neipu, Pingtung 91201, Taiwan (R.O.C.); E-mail: wslin@mail.npust.edu.tw

2 Department of Biological Science and Technology, National Pingtung University of Science and Technology. NO. 1, Shuefu Road, Neipu, Pingtung 91201, Taiwan (R.O.C.); E-mail: ytjou@mail.npust.edu.tw

3 Department of Civil Engineering, National Pingtung University of Science and Technology. NO. 1, Shuefu Road, Neipu, Pingtung 91201, Taiwan (R.O.C.); E-mail:wangym@mail.npust.edu.tw

WATER RETENTION MANAGEMENT IN LOWLANDS OF CHAO PHRAYA DELTA

Thanet Somboon[1]

ABSTARCT

The Chao Phraya Delta is one of the most important deltas in the central part of Thailand. Flooding in lowland is a common natural phenomenon in the Chao Phraya Delta typically occurring between August and December. Flood control is important in the lower part of the river basin because of the risk of largescale damage to public and private property. The Chao Phraya Delta, about 1.9 million hectares are natural lowland or floodplain. In rainy season or in flood period, there are 50 percent of natural lowland can become flooded. Other lowland areas are protected by dikes. The main natural causes of flood are heavy rainfalls, excess capacity of the river capacity and hightides. Lowland areas can reduce the impact of flooding and protect economic areas.

Most of natural lowland areas are paddy fields which often face flooding in the wet season, especially in the lower Chao Phraya Delta. Flooding in the Chao Phraya Delta causes most of paddy field in lowland areas to suffer damage before harvest. Frequently, farmers have no chance for income.

In 2017, The Ministry of Agriculture and Cooperatives has a policy to reduce the effects of flooding in both urban areas and agricultural areas. By arranging the planting system and using the lowland area as a temporary water storage area during the flood season. Royal Irrigation Department (RID) and related agencies have jointly implemented the Lowland water Management Project in the Chao Phraya Delta to solve this problem officially.

Step of work consisted of 1) Before wet season, RID will evaluate the water resources in order to best predict the flood period; 2) Set up a water management model that is consistent with the amount of water for flood mitigation; 3)The bringing forward the crop calendar by one month, the farmers can harvest their crops before flooded; 4) Prepare the lowland area for water retention after rice harvesting; 5) Most of the areas of water retention are lowland and agricultural in close proximity to the Chao Phraya River; 6) Deliver excess water from Chao Phraya River to lowland area using an irrigation system; and 7) Excess water will be retained in paddy field for one month to reduce peak of flood, after that a excess water will be released.

Success in operation in 2017; There were 12 selected lowland areas about 183,984 hectares in Chao Phraya Delta which is to be used for flood mitigation and there are 1,500 million cubic meters of water can be stored for 15 – 45 days before being drained through the irrigation system. Operation period from September 25, 2017 to December 15, 2017. Cultivation of rice in the next season in lowland area can start earlier than other areas. Farmers have more income from rice and fishing. All cultivated areas in this project are harvested before flood period.

Keywords: Lowland Management, arranging the planting system,water retention,Irrigation Syatem

1 Senior Expert on Hydrology, Royal Irrigation Department, 811 Samsan Road, Dusit District, Bangkok, Thailand, 10300.; E-mail: Thanet47@yahoo.com

A REVIEW OF CLIMATE CHANGE EFFECT ON GROUNDWATER IRRIGATION IN INDONESIA

Rahmad Dwi Putra[1], Andre Putra Arifin[1], Ahmad Taufiq[2], and Anggita Agustin[3]

ABSTRACT

Climate change is one of the biggest issues in the world and is stated as one of the United Nations Sustainable Development Goal the number 13. It has an impact on groundwater occurrence especially in groundwater use for irrigation. In some countries which use groundwater as source of irrigation, e.g. United States of America, Bangladesh, Bangkok, Pakistan, and Vietnam, the climate change has decreased the precipitation as well as the groundwater level. Groundwater for irrigation has been utilized in Indonesia since 1970. Until 2018, at least the total area of irrigated land by groundwater was 113,600 hectares in several provinces, i.e. West Java, Central Java, East Java, Yogyakarta, Bali, West Nusa Tenggara, South Sulawesi, and Central Sulawesi. Climate change has an impact on groundwater in terms of lowering of precipitation or rainfall which can affect the groundwater level declining. In Java itself, some rainfall analyses from Citarum, Cimanuk, Bengawan Solo, Progo, Serayu, and Citanduy watersheds indicate the declining trends, from -1.616 to -8.517 mm/year, and the turning point of climate change marked in the year 1960. Regionally, rainfall trends all over Indonesia are decreasing, except for the region of the Lesser Sunda Island and Eastern Java, whilst the highest decreasing of rainfall fall on Kalimantan and the less susceptible precipitation declining occurs in Java and Sulawesi. The declining sign of precipitation obviously threat the groundwater resources and food productivity from agriculture. To cope with this problem, the government should mitigate the probability of groundwater declining due to lack of rainfall. Some solutions are proposed: water harvesting to recharge back the aquifer, irrigation technology, and returning the irrigation flow back to the abstracted aquifer by installing artificial recharge wells or ponds.

Keywords: Climate change, groundwater, irrigation, recharge

1 Directorate General of Water Resources, Ministry of Public Works and Housing. Jl. Pattimura No 20, Selong, KebayoranBaru, South Jakarta, 12110; E-mail: rahmaddp@pu.go.id

2 Research and Development Center of Water Resources, Ministry of Public Works and Housing. Jl. Ir. H. Juanda No. 193, Dago, Coblong, Bandung; E-mail: ahmad.taufiq@pu.go.id

3 PT. ERM Indonesia. Centennial Tower, 40th Floor, Suite #B1, I. Gatot Subroto, Jl. PeltuRahmatSidupNo.Kav. 24-25, RT.2/RW.2, KaretSemanggi, Setiabudi, South Jakarta; E-mail: anggita.agustin@erm.com

PHOTOVOLTAIC PUMPING FOR DRIP IRRIGATION

Aleman, C.C.[1]; Paes, R.G.[2]; Ferreir A, T.S.[3]

ABSTRACT

The search for sustainable food production standards to meet the increasing demand of the population increase has led to discussions on the energy issue. The Brazil natural features are in favour of photovoltaic electricity generation. Solar radiation in Brazil varies from 8 to 24 MJ m^{-2} day^{-1}. In 2017, Brazil had 438.3 MW of installed capacity of solar generation. The installed power of approximately 9% is used by the rural sector. The State of Bahia stands out with the highest participation with 151 MW installed power, resulting from high values of solar radiation hitting 6.5 kWh m^{-2} day^{-1}. The objective of this work was to evaluate and compare the efficiency of drip irrigation operated by a photovoltaic system without energy storage (SB) and another that uses batteries to store energy (CB). The experiment was conducted in the Experimental area of Agricultural Engineering Department (DEA), the Federal University of Viçosa (UFV), Viçosa-MG, Brazil, during the period from October 24 to December 20, 2018. It used two sets of vibratory submerged pump photovoltaic solar-powered, Anauger model Solar spumping system, R100. The photovoltaic system without energy storage (SB) was used in accordance with the manufacturer's recommendations. The other system that uses batteries to store energy (CB) was adapted with three stationary batteries Heliar Freedom DF1000 70Ah 12V and a Viewstar VS3048AU 30A charge controller 36ValongwithAnauger model solar pumping system. There were two irrigation systems, a button-type emitters with Dripper iDrop Normal (Irritec), with flow rate of 4 L h^{-1} at 1 bar pressure. And another with button-type emitters Dripper iDrop PC (Irritec), 4 l/h flow, pressure-compensating, with approximately the same flow rate at 0.5 to 4.5 bar. The two irrigation systems were composed of seven laterals, spaced at 0.8 0.8 m. each Touchline with 22 issuers, spaced 0.5 in 0.5 m, totaling 154 transmitters per system. Irrigation systems, the assessment of uniformity of water distribution was conducted according to the methodology of DENÍCULI et al. (1980). In this way, the experiment was composed of 4 treatments, normal transmitter with pump without energy storage in batteries (NSB), self-compensating emitter with pump without energy storage in batteries (PCSB), normal transmitter with storage pump energy in batteries (NCB) and emitter self-compensating with pump with energy storage in batteries (PCCB). Photovoltaic drip irrigation systems with batteries were more effective due to greater uniformity of application of the irrigation with almost equal supply flow rate.

Keywords: Energy management; Sustainability; Water management; Water efficiency.

1 Universidade Federal de ViÃ§osa, Brazil, catariny@ufv.br
2 Universidade Federal de ViÃ§osa, Brazil, rafael.gpaes@gmail.com
3 Universidade Federal de ViÃ§osa, Brazil, thallita.ferreira@ufv.br

PROJECTED IMPACTS OF CLIMATE CHANGE ON MAJOR CROPS' VIRTUAL WATER IN SOUTHERN IRAN

Nozar Ghahreman[1], Mojdeh Mohammad Rezaei[2], and Iman Babaeian[3]

ABSTRACT

Global warming and climate change have caused major conflicts especially in agricultural water management. The aim of this research is investigation of climate change effects on virtual water of several crops i.e. Wheat, barley, potato and tomato in Kerman province, south of Iran. For projection of virtual water of selected crops under RCP4.5 and RCP8.5 climate change scenarios (IPCC Fifth Assessment Report) during period of 2010-2100 in three study stations, crop evapotranspiration were worked out using downscaled outputs of CNRM-C5 climate model. Also crops yield were simulated using Aqua Crop model. By choosing new date of sowing, temperature, rainfall and evapotranspiration during projected growing season were determined. Based on the maximum simulated yield for the study crops, the optimum date of sowing for future periods were chosen. Finally the crops virtual water (evapotranspiration divided by yield) was calculated.Besides, the trend analysis of temperature, rainfall and evapotranspiration variables during future periods were performed using Mann-Kendall and Sen's slope estimator test in three study stations . The results showed that there exist an increasing trend in air temperature time series, in all month. Also, the Maize crop yield would decrease in all three stations (with highest decrease in Jiroft station with 52 and 56 % under RCP 4.5 and RCP 8.5 in 2018-2039 period comparing to baseline period, respectively.) The virtual water of all selected crops is projected to increase, but this increase would be higher for wheat and barley crops. The lowest increase in virtual water was observed in tomato crop during the future period of 2018-2100.In Bam station, the highest amount of virtual water belongs to barley crop during the period of 2040-2069, i.e. 4853 and 5153 cubic meter per ton under two RCP scenarios, respectively. In Jiroft wheat crop has the highest virtual water during the period 2040-2069 projected to be 4984 cm^3/ton. In case of Kerman station, largest amount of virtual amount under RCP4.5 belongs to wheat during the period 2040-2069 and under RCP 8.5 corresponds to barley with amount of 4256 cm^3/ton. Further studies in other climatic regions of the country are recommended for more precise decisions in agricultural water management.

Keywords: Evapotranspiration, crop yield, Trend, Climate Change.Iran

1 University of Tehran,Irran, nghahreman@ut.ac.ir,
2 University of Tehran, Iran mozhdemohammadrezaii@gmail.com,
3 National Climatological Institute, Iran, i.babaeian@gmail.comm

NATIONAL SCHOOL OF PLOT IRRIGATION, ECUADOR

José MaríaGarcía-Asensio[1]

ABSTRACT

Within the framework of the Latin American Investment Fund of the European Union (LAIF), as a complementary contribution to the Technified Irrigation Project for small and medium producers in Ecuador, the Spanish Agency for International Development Cooperation (AECID) handed an assistance to the Ministry of Agriculture and Livestock of Ecuador, which is developed by its Under-Secretary of Technified Irrigation of Plots. The LAIF action includes the design and implementation of the National School of Plot Irrigation (ENIP) of Ecuador, commissioned by AECID to the spanish state company TRAGSA, during the period 2017-2021.

The specific objective of ENIP is to strengthen the national capacities in design and management of irrigation systems, through the consolidation of a critical mass of experts and professionals in irrigation, which contributes to the improvement of the productive systems, to the efficient management of irrigation water and to the resilience of ecuadorian territories to climate change. ENIP has constituted an Academic Coordination Committee and has three main components: training and technical assistance in irrigation, investments in Universities,and research & development & innovation.

Within the training, three academic levels have been designed. First one, for irrigation consultants aimed to irrigation specialists. A second level, aimed to managers and administrators of irrigation systems. And a third level, directly to the farmers. In the component of investments, demonstration plots of irrigation are being built and equipped with Universities in different parts of Ecuador, in order to have a network reference experiences, both in the coast and mountain regions, representative of territorial diversity.

At the same time, ENIP is creating a National Irrigation Observatory, with the development of forums, publication of irrigation technical books, Finally, the main lines of R&D&I in which progress is being made are resilience to climate change and agroecology and interculturality in plot irrigation.

Keywords: capacity building, irrigation systems, efficient water management, sustainable rural development, climate change, food security.

1 PhD Agricultural Engineer, Bachelor of Environmental Sciences and Diploma in Advanced Studies in Environmental Sciences.Tragsa Group International Expert.E-mail: jgarci36@tragsa.es

ANALYSIS OF LONG-TERM CHANGE IN THE DEGREE OF TIME-CONCENTRATION OF RAINFALL IN JAPAN

Kazumi Ikeyama[1], Takeo Yoshida[2] and Susumu Miyazu[3]

ABSTRACT

It has been suggested that torrential rainfall is likely to become more frequent due to the increasing severity of extreme weather events associated with climate change (IPCC, 2014).And tDue to global climate changes, extreme precipitation events are projected to be increased (IPCC, 2014). This trend may induce more frequent and intensive precipitation events, and thus the risks of flood inundation in low-lying agricultural areas may increase. he Japan Meteorological Agency (JMA) (2016)reported that the number of annual occurrences of short-term intense rainfall (for example, exceeding 50 mm/h) have increased in recent years.In Japan Automated Meteorological Data Acquisition System (hereafter AMeDAS; Meteorological Agency, Japan) started routine measurements of fundamental meteorological elements, including precipitation, from 1974 at approximately 1,300 observation stations throughout Japan. This report quantifies time-concentration of rainfall from hourly rainfall data collected by AMeDAS over 42 years in five areas of Japan, and analyzes the long-term changes. We collected hourly precipitation record from 80 stations that have more than a whole 40 years of record. Then we divided the record by a period without precipitation lasting at least 24 hours; and the divided precipitation series was defined as ‘rainfall event’. We evaluated temporal intensities of each event by Sherman equation: , where maximum *t*-hour rainfall intensity (), maximum t-hour rainfall, and a, c:empirical coefficients (). The coefficient *c* indicates the time-concentration of rainfall and can be easily understood by two extremes. If event rainfall fell in 1 hour within the event, c=1, while if event rainfall fell uniformly within 24 hours with hours, c=0. Overall, this study revealed that the increasing trend of rainfall intensity even for the same 24-hour cumulative rainfall in part of Japan that could influence the regional water management.

Keywords: Rainfall characteristics, Time-concentration of rainfall, Automated Meteorological Data Acquisition System

1 Institute for Rural Engineering, National Agriculture and Food Research Organization (NARO), Japan. 2-1-6 Kannondai, Tsukuba, Ibaraki, 305-8609 JAPAN; E-mail: ikeyamak970@affrc.go.jp

2 Institute for Rural Engineering, National Agriculture and Food Research Organization (NARO), Japan. 2-1-6 Kannondai, Tsukuba, Ibaraki, 305-8609 JAPAN; E-mail: takeoys@affrc.go.jp

3 Institute of Science and Technology (Faculty of Agriculture), Niigata University, 8050 2nocho, Ikarashi, Nishi-ku, Niigata-shi, Niigata, 950-2181 JAPAN; E-mail: smiyazu@agr.niigata-u.ac.jp

HISTORICAL SUSTAINABILITY OF GROUNDWATER IN INDUS BASIN OF PAKISTAN

Ghulam Zakir Hassan[1] Catherine Allan[2] and Faiz Raza Hassan[3]

ABSTRACT

Pakistan is bestowed with one of the world's largest contiguous irrigation canal network, major part of which lies in Punjab Province under Indus Basin. This network was started to be constructed by British during early nineteenth century. The continuous expansion of the irrigation system over the past century significantly altered the hydrological balance of the Indus River Basin (IRB) in Pakistan. During pre-irrigation era, water table in different doabs (the land between two rivers) in Punjab province was very deep but the system of canal irrigation was put in operation, the problems of waterlogging become the major challenge which led to the need of parallel system of drainage network. This situation created the need of drainage of agricultural lands in the country. Although some drainage was installed before World War II, little attention was paid to the growing waterlogging and salinity problems. To alleviate the twin menace of waterlogging and salinity, Water and Power Development Authority (WAPDA) was established in 1958 and Salinity Control and Reclamation Program was conceived, planned and implemented by adopting surface as well as subsurface drainage projects in the country. First Salinity Control and Reclamation Project (SCARP-I) was implemented in 1960-63. Currently, in Punjab which is the largest groundwater consumer amongst the provinces, groundwater is contributing about more than 45% towards irrigation requirements through pumping by approximate 1.2 million tubewells putting this natural gift beyond the limits of its consumers. The farmer's tubewells are pumping groundwater to meet 40 to 50 % of crop water requirements at farm-gate which has put the aquifer under stress especially in sweet groundwater zones consequently putting this natural gift beyond the limits of human utilization. To meet the ever increasing demand of food and fiber, cropping intensity has increased from 67% to 150% or even more in some areas which is a major driver for dependence on groundwater. Besides irrigation uses groundwater is the major source of drinking, industrial and commercial requirements in many areas the unplanned and over pumping has caused intrusion of saline water into fresh groundwater areas. Punjab Government, Irrigation Department has established a Groundwater Management Cell to carryout various research studies and to devise the management interventions in the Province. Research study carried out in Vehari district of Southern Punjab has indicated that by increase of depth to water table from 40 ft. to 70 ft. the cost of pumping per acre-feet has increased 125%. In urban areas, this threat is very severe for example in Lahore City, the annual average rate of fall is 2.5 ft. Its quality is also deteriorating at many places due to one or the other reasons. In this paper findings of various studies have been outlined to identify the critical areas and to suggest some management options for the replenishment of this fast depleting natural resource in Punjab. Potential site for artificial recharge of aquifer has been identified and possibility of aquifer recharging through flood water has been explored.

Keywords: Groundwater, Irrigation, Artificial Recharge, Punjab, Pakistan

1 PhD Scholar Charles Sturt University, Australia and Director and Irrigation Research Institute (IRI), Government of the Punjab, Irrigation Department, Library Road, Lahore 54500, Pakistan. * Correspondence author: zakirjg@gmail.com

2 Assistant Professor, School of Environmental Sciences, Charles Sturt University, NSW, Australia

3 Assistant Director, Irrigation Research Institute (IRI), Government of the Punjab, Irrigation Department, Library Road, Lahore 54500, Pakistan.

WATER-ENERGY-FOOD RELATIONSHIP EVALUATION IN GREENHOUSE USING SYSTEM DYNAMICS AND SUSTAINABILITY INDEX

Pureun Yoon[1], Jin-Yong Choi[2], Kwihoon Kim[3], Yoonhee Lee[4], Seung Oh Hur[5] and Sang-hyun Lee[6]

ABSTRACT

Due to the population growth, food production demands and water use increase. There is a wide variety of global discussions on resource management in terms of securing resources such as water and food considering sustainability. The concept of "Water-Food-Energy Nexus" has emerged to interpret the linkage of water, energy and food resources and to suggest an integrated management plan. There is a trade-off relationship among input resources such as energy, water and cost, for increasing food productivity, therefore, it is necessary to analyze the relationships comprehensively rather than single resource analysis. This study was conducted to evaluate the relationship between water and food among the water-food-energy nexus of upland crops in the greenhouse. Because the greenhouse could control the environmental condition such as the temperature, humidity, and wind speed for growing the upland crops . Theanalysis based on the scenarios according to the environmental conditions could be conducted. Also, in the greenhouse, because the energy resources are put to provide an appropriate growth environment for crops, it is necessary to analyze the relationship between energy and other resources. Thus, this study included estimating the crop yield, irrigation water requirement and water productivity and simulating the response of crops to water stress, soil condition using AquaCrop model. Also, linking with energy resources such as heating, pumping energy, fertilizer, and calculating the equations between resources, Water-Energy-Food Nexus was constructed using System Dynamics. Assessment and comparison of scenarios can be accomplished through the calculation of a sustainability index to decide which scenario to choose and how much we can endure in terms of different resource requirement. Finally, the sustainability index for the scenario was calculated for decision-making and policy assessment.

Keywords: Water-Food-Energy Nexus, Greenhouse, AquaCrop, System dynamics, Sustainability index.

1 PhD student, Department of Rural System Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, E-mail: vnfms3259@snu.ac.kr
2 Professor, Department of Rural System Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, E-mail: iamchoi@snu.ac.kr
3 MS student, Department of Rural System Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, E-mail: kgh0330@snu.ac.kr
4 PhD student, Department of Rural System Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, E-mail: ukuleo@snu.ac.kr
5 Senior Research &Lab.Head, National Institute of Agricultural Sciences, Rural Development Administration, Jeonju 54875, Republic of Korea, E-mail: soilssohur@korea.kr
6 Research Institute of Humanity and Nature, 457-4 KamigamoMotoyama, Kita-ku, Kyoto, Japan. E-mail: sanghyunsnu@gmail.com

FORESIGHTS -TECHNOLOGIES IN THE DEVELOPMENT OF LAND IMPROVEMENT PARKS IN THE COUNTRIES - PARTICIPANTS OF EURASEC

L.N. Medvedeva [1], D.V. Belykh [23], A.S. Vagner [2,3], A.V. Medvedev [4], P.D. Vaneeva [2,3], and I.G. Bondarik[5]

ABSTRACT

The article deals with the development of agricultural production in the EurAsEC countries. It is shown that the further development of agriculture should be based on the introduction of new lands improvement. One of the innovative infrastructure objects of further development of agriculture can be – Land improvement Parks, the concept of which is developed by scientists of research institutes of Russia.

Keyword: Land improvement Park, Management Company, innovation, public-private partnership, renewable energy, EurAsEC, convergent platform.

1 Federal State Budget Scientific Institution «All-Russian Scientific Research Institute of Irrigated Farming», Volgograd. Russia;
2 Federal State Budget Scientific Institution «Russian Research Institute of Land Improvement Problems», Novocherkassk, Russia;
3 Federal State Budget Educational Institution of Higher Education «South-Russian State Polytechnic University (NPI) named after M. I. Platov», Novocherkassk, Russia;
4 Federal State Budget Educational Institution of Higher Education «Volgograd State Agrarian University», Volgograd, Russia
5 Federal State Budget Scientific Institution «All-Russian Scientific institute for hydraulic engineering and Land reclamation», Moscow, Russia

REVIEW OF ALTERNATIVES FOR JAKARTA NCICD PROJECT USING NUMERICAL MODELING

Park Byong Jun[1] and Lee Jueng Chol[2]

ABSTRACT

A numerical simulation was conducted to compute changes in hydrodynamic characteristics that result from the installation of the outer sea dike in Jakarta Bay for NCICD Project. The tidal difference did not exceed 1.3m and the tidal current velocity did not exceed 0.5m/s. The tidal current consists of the flood current flowing from west to east and the ebb current flowing from east to west, with the flood current slightly stronger than the ebb current. The velocity of the tidal residual current was close to 0m/s in the planned area for the outer sea dike. The water mass near the coast moves slowly from west to east but cannot move out of the area near Jakarta Bay for a long time. Therefore, to implement for outer sea dike installation, it needs to take attentions in these simulation results of circulation and dilution of the water in the Jakarta Bay. In simulations to which reclamation of artificial islands and alternative routes for the outer sea dike were applied, it was confirmed that active flood response is possible with the exception of Alternative 1 and the preferred alternative (Phase 1). Alternative 4 and the preferred alternative can be good alternatives that block incoming waves and allow ocean circulation if accompanied by the reinforcement of coastal and river embankments. Alternative 1 allows flood control but its water quality problem should not be neglected. Alternative 2 allows flood control but an eddy occurs in front of the first sluice gate in the northwest area. Alternative 3 and the preferred alternative – Phase 2 allow active and elaborate flood control but an optimal operation method needs to be developed.

Keywords: NCICD, Numerical Simulation, Hydrodynamic Modeling, Sea Dike, Water Circulation.

1 [1]Manager, Overseas Project Office, Korea Rural Community Corporation, 20, Green-Ro, Naju-Si, Jeollanam-Do, 58217, South Korea, E-mail: jiwhaja1@ekr.or.kr, Tel: +82-61-338-6454

2 Director, Overseas Project Office, Korea Rural Community Corporation, 20, Green-Ro, Naju-Si, Jeollanam-Do, 58217, South Korea, E-mail: leejc321@ekr.or.kr, Tel: +82-61-338-6451

WATER TABLE VARIABILITY AND FLOW RESPONSE OF TROPICAL PEATLAND - A CASE STUDY

Nilna Amal[1], Joko Sujono[2] and Rachmad Jayadi[3]

ABSTRACT

Peatland is a type of soil that characterized by high water content. The use of peatlands, especially for agriculture and plantations is carried out by channel to control the water table level such that the water content in the root zone is in accordance by the variety of plant. Water table on drained peatlands will have a decline in groundwater level to a certain depth. Excessive continuous water table decreasing through below the surface of the land which occurs continuously can create irreversible dryness that causes land subsidence and increase the risk of fire (NOT CLEAR). The study aims to observe characteristics of water table level in the rainy season due to the construction of canal networks on peatlands.

The study was conducted in Pulau Padang Riau Province of Indonesia which is a drained peatland that has been developed for industrial crop cultivation. The land is managed by two different groups; those maintained by the local community and those by private companies. The analysis was carried out by using a balance of water budget on peatland specifically by calculating the dynamic interaction of the hydrological parameters of land and channels flow.

The results showed that the condition of water table elevation had changed during the period of data collection. The rainfall transformed quickly into overland flow and direct runoff. The decrease in the water table on local community management areas is higher than that occurring in companies land with a variety in the value of the up and down is greater.(NOT CLEAR) This phenomenon occurs because there are no canal blocks on the peatland, which is managed by the local community so that the rise and fall of the water surface occur naturally. In addition, since it is located in the downstream area, the state of the flow will be influenced by the flow in the upstream. When the upstream flow is retained, hence no current flows to the downstream, and as a result, the water table level continues to decrease.

Keywords : peatlands, water table depth, rainfall, direct runoff.

1 Ph.D student at Dept Civil and Environmental Engineering, Universitas Gadjah Mada; Email : nilna.amal@mailugm.ac.id
2 Department Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada; Email: jsujono@ugm.ac.id
3 Department Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada; Email: rjayadi@ugm.ac.id

AN IMPROVED APPROACH FOR ESTIMATING SOIL MOISTURE CONTENT TO IMPROVE IRRIGATION DECISIONS

Birendra KC[1], Henry Wai Chau[2], Magdy Mohssen[3], Keith Cameron[2,4] Majeed Safa[5],Ian McIndoe[6],Helen Rutter[7],Mina Lee[8], Vishnu Prasad Pandey[9], Bart Schultz[10], and Krishna Prasad[11]

ABSTRACT

Estimation of soil moisture (SM) is an essential component of effective agricultural water management practices. However, subtle spatial variations in SM across a farm are often overlooked as standard irrigation planning practices in New Zealand generally relyupon SMdata derived from a single monitoring location. The current study had two objectives:1) to understand spatio-temporal variability of SM measurements using multiple length Time Domain Reflectometry (TDR) probes and Aquaflex soil moisture sensors (Aquaflex); and (2) coupled TDR and Aquaflex SM readings to improve SM determination in non-weighing lysimeters for improving crop coefficient (K_c) estimation.

Twenty non-weighing lysimeters and an Aquaflex located within different soil types were utilized for the study. TDR probes with 200, 500 and 900 mm lengths were installed vertically adjacent to an Aquaflex and the lysimeters for monitoring SM contents. Both TDR and Aquaflex responded to wetting and drying events, with varying SM measurements both vertically and horizontally, due to variations in soil types at different locations. The amplitudes of the daily fluctuations in SM measurements were noticeably higher for the 200 mm TDR and the Aquaflex top sensor, with slightly lower fluctuation for the 500 mm TDR and the Aquaflex bottom sensors. However, the 900 mm TDR showed only minor fluctuations in average SM values indicating that pasture water uptake dominates in the top 500 mm soil profile.

These results indicate the importance of multiple lengths TDR to assess root water uptake for improving irrigation management. When the same Aquaflex soil moisture values were used in the water budget equations for data from all lysimeters, the coefficient of determination (R^2) for the K_c – h relationship was 0.43, which increased to 0.66 when Aquaflex SM values

1 Civil Engineer (irrigation & water resources), Aqualinc Research Limited, PO Box 8053, Christchurch, New Zealand; E: birendra@aqualinc.co.nz
2 Lecturer, Department of Soil and Physical Sciences, Lincoln University, PO Box 85084, Christchurch, New Zealand; E: Henry.Chau@lincoln.ac.nz
3 Senior Hydrologist, Otago Regional Council, PO Box 9054, Dunedin, New Zealand; E: Magdy.Mohssen@orc.govt.nz
4 Head, Centre for Soil and Environmental Research, Lincoln University, PO Box 85084, Christchurch, New Zealand; E: Keith.Cameron@lincoln.ac.nz
5 Lecturer, Department of Land Management and Systems, Lincoln University, PO Box 85084, Christchurch, New Zealand; E: Majeed.Safa@lincoln.ac.nz
6 Principal Water Resource Engineer, Aqualinc Research Limited, PO Box 8053, Christchurch, New Zealand; E: i.mcindoe@aqualinc.co.nz
7 Hydrogeological research scientist, Aqualinc Research Limited, PO Box 8053, Christchurch, New Zealand; E: h.rutter@aqualinc.co.nz
8 PhD Candidate, Department of Pest Management and Conservation, Lincoln University, PO Box 85084, Christchurch, New Zealand; E: Mina.Lee@lincolnuni.ac.nz
9 Researcher, International Water Management Institute, Nepal Office, PO Box 8975, Kathmandu, Nepal; E: V.Pandey@cgiar.org
10 Prof. em. Land and Water Development, IHE Delft, PO Box 3015, Delft, the Netherlands; E: schultz1@kpnmail.nl
11 Irrigation and Water Resources Management Consultant, Janakpur, Nepal; E: kcpsah@gmail.com

were adjusted for each lysimeter using corresponding TDR readings. This implies that SM monitoring at different locations in the farm is essential for improving water budget studies aimed at quantifying actual irrigation requirements.

Keywords: soil moisture, Time Domain Reflectometry, Aquaflex, lysimeter, crop coefficient.

USING SMART TECHNOLOGIES IN IRRIGATION MANAGEMENT

Gadzalo Ya., Romashchenko M., Kovalchuk V., Matiash T., Voitovich O. [1]

ABSTRACT

The proposed SMART-technology is an irrigation management technology that forecasts irrigation time and irrigation rate based on soil moisture prediction. The paper provides the basic principles of making and operating this system. The technology is based on the use of a multi-layer model of moisture transfer when using the Richards equation. The monitoring of field soil moisture is carried out by the automatic soil moisture sensors, while the monitoring of meteorological indicators is made by online weather stations. To determine the forecast indicators of weather conditions an automated data mining system for obtaining weather forecast data from weather forecasting web-services is used. The total evaporation is calculated by the Penman-Monteith, Shtoiko and Ivanov methods. Pre irrigation thresholds are determined for different crops depending on soil texture and their phenological phases according to the BBCHscale.

1 Institute of Water Problems and Land Reclamation of NAAS Ukraine, 37, Vasylkivskastreet, Kyiv, Ukraine, 03022 tel. +38044 257-40-30 Website: iwpim.org.ua, E-mail: iwpim.naan@gmail.com

WATER MARKET IN PAKISTAN A CASE FOR REVENUE GENERATION AND WATER SECURITY

Muhammad Nawaz[1]

ABSTRACT

"Pakistan is a water scarce country which could run out of water in 2025 or 2040," is one of the popular news widely under debate nowadays. Unchecked population growth, deteriorating water quality and climate change are said to be the major drivers of increasing water shortages. Water experts have been warning that water crises could strike anytime. In recent months, media raised water issues at such a scale that suddenly it emerged as a priority matter of public interest. These serious concerns have triggered a national debate loaded with many questions. Is Pakistan a water scarce country running out of water? If water is scarce then why it is allocated for wasteful and low value agriculture sector almost free (60,000 litres per 1 US cent)? Is water a public good or a private commodity? Should water be priced to encourage market based allocation towards high value end use or should it be supplied free because it is a basic human right? Is the government benevolent enough to continue provision of adequate, predictable, reliable and affordable water service to all sectors? Should the government act as a regulator or a service provider? Who will be the winners and losers if water is properly priced as a market commodity? How could water pricing contribute to economic growth and water security? This paper attempted to answer some of these questions in order to inform policy makers, water managers and general public to cope with water crises in Pakistan.

The paper suggests that water shortages are real, caused mainly by paucity of governance and economic disincentives. The good news is that there is an enormous potential for water reallocation to achieve long term security, higher productivity, equity and revenue generation. The paper recommends policy measures to promote private sector driven value added water economy.

Keywords: Water Scarcity, Allocation, Market, Pricing, Security, Irrigation, Value added water economy

1 Development Specialist (Irrigation), Office of the Economic Growth and Agriculture,, USAID, US Embassy Diplomatic Enclave Islamabad, Pakistan. E-mail: nawazyar@yahoo.com

IOT TECHNOLOGY BASED SMART WATER LEVEL PREDICTION SYSTEM IN TAIWAN TAO-YUAN MAIN CANAL

Jih-Shun Liu[1], Ray-Shyan Wu[2], Chien-Kuo Chen[3], Jihn-Sung Lai[4], Hung-Chih Lee[5], Fang-Lan Ko[6], and Chia-Yi Chien [7]

ABSTRACT

Taiwan is located in the subtropical zone and the Ring of Fire. It suffers from natural disasters such as typhoons, heavy rains, droughts and earthquakes every year. In order to solve the impact of extreme rainfall, the Irrigation Associations in Taiwan developed a hydrological automatic forecasting system in 2005, and then adopted the IoT (Internet of Things) technology to construct hydrological monitoring system for irrigation water management in 2018.

The spread all over of ponds for regional irrigation in the terrace-based terrain is the unique characteristic of Tao-Yuan Irrigation Association (TIA). 284 ponds with a total storage of 45 million m3 of water is used in response to insufficient water supply in Taoyuan main canal. Under the influence from climate change, the control of storage capacity in ponds need to be improved and effectively utilized. Therefore, the study uses the Internet of Things (IoT) technology to construct the dynamic management system that enhances the utilization efficiency of the ponds management for effectively allocating the water resources.

The study was carried out in 2018 through field investigation, monitoring station architecture planning, on-site contracting and construction, supplemented by hydraulic model and Back-Propagation Networks (BPN) to construct a canal water level prediction model and develop pond dynamic analysis management platform to present and predict the water level for allocation decision support to the manager. The system effectively achieves the goal of modernization of irrigation water allocation and pond management. In view of the impact of climate change and the more difficult agricultural water environment, this study can be used as a reference for countries that are also facing similar water management challenges.

Keywords : Internet of Things; Irrigation Pond management; Tao-Yuan main canal, Taiwan.

1 Agricultural Engineering Research Center(AERC), Taiwan, jsliu@aerc.org.tw
2 Department of Civil Engineering, National Central University, Taiwan, raywu@cc.ncu.edu.tw
3 Head of Information Division, Taiwan Tao-Yuan Irrigation Association. Taiwan, tia.a109@gmail.com
4 National Taiwan University, Taiwan, jslai525@ntu.edu.tw
5 Taiwan Tao-Yuan Irrigation Association.Taiwan, powell1090@yahoo.com.tw
6 Agricultural Engineering Research Center(AERC), Taiwan, amelia@aerc.org.tw
7 Agricultural Engineering Research Center(AERC),Taiwan, chiayi.chien@aerc.org.tw

WATER PRODUCTIVITY OF POTATO UNDER IMPROVED IRRIGATION TECHNIQUES IN UZBEKISTAN

Kakhramon Djumaboev[1], J. Mohan Reddy[2],Carlo Carli[3], TulkunYuldashev[4], Oyture Anarbekov[5] and Davron Eshmuratov[6]

ABSTRACT

Potato is a very important cash crop in Uzbekistan as the government has implemented several measures to increase its production to meet food security as well as to improve its export potential. However, irrigation water demand of potato is much higher than for other crops such as sorghum and maize, which normally consume less water and generate more income. Furrow irrigation is the main irrigation method used to grow potato in Uzbekistan. Introduction of improved irrigation methods could reduce the water used for potato production and provide alternative solutions to improving potato production and income security under water scarce conditions. There are few comparative studies on conventional furrow versus improved irrigation methods for potato production.

This paper explores water productivity of two varieties of potato under four irrigation treatments in Andijan and Ferghana regions of Uzbekistan. At each location, four different irrigation treatments were evaluated. These four treatments were: conventional furrow irrigation (CFI), high frequency furrow irrigation (HFI), partial root zone drying irrigation (PRD), and drip irrigation (DrI). The experimental sites in each study area were established in 2012 on farmer fields. Data on water used and agronomic performance were collected from both study sites to calculate water productivity for each treatment. Analysis of Variance (ANOVA) was used to identify differences in treatments. The results indicate that, overall, high frequency furrow irrigation and drip irrigation treatments performed better than conventional furrow irrigation and partial root drying treatments.

Research findings from this paper are useful for relevant stakeholders in Uzbekistan whose population is highly dependent on irrigated agriculture. Existing water use policies in Uzbekistan do not provide water users incentives for water saving as water delivery for agriculture is highly subsidized by the government resulting in excessive water use. These findings may help reduce unsustainable water use by increasing knowledge of relevant stakeholders including decision makers in order to improve water policies in the region.

Keywords: Irrigation of potato; Conventional furrow irrigation; Improved irrigation methods; Uzbekistan; Crop water productivity; Water policy.

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1 Researcher/Water Resources Management, Water Management, International Water Management Institute (IWMI). Central Asia Office, Flat No.120, Building No.6,Osiyo Street, Tashkent, 100000, Uzbekistan. E-mail: k.djumaboev@cgiar.org.

2 Professor (Affiliate Faculty) - Irrigation, Department of Civil & Environmental Engineering, Colorado State University, Fort Colins, Colorado, USA. E-mail: mohanreddyi@hotmail.com

3 Manager, Agriculture Division@ SNF-Floerger, France, Former Program Leader International Potato Centre (CIP), Central Asia Office; E-mail: ccarli@snf.fr

4 Consultant, Water Management, International Water Management Institute (IWMI). Central Asia Office, Flat No.120, Building No.6, Osiyo Street, Tashkent, 100000, Uzbekistan. E-mail: tulkun_yuldashev@mail.ru

5 Researcher/ Economist-Social Scientist, International Water Management Institute (IWMI). Central Asia Office, Flat No.120, Building No.6, Osiyo Street, Tashkent, 100000, Uzbekistan. E-mail: o.anarbekov@cgiar.org

6 PhD student, Hydro meteorological Research Institute, 1stBodomzorYuli Street 72, Tashkent, 100052, Uzbekistan.E-mail: eshmuratov_d@mail.ru

THE EFFECTS OF MEASURING IRRIGATION WATER USING PREPAID WATER METER ON WATER SAVING AND ENVIRONMENT: A CASE STUDY FROM TURKEY

Mevlüt Aydın[1], Mehmet Uğur Yıldırım[2], Aynur Fayrap[3] and Hakan Özdal[4]

ABSTRACT

Many countries in the world are facing problems regarding irrigation operation, maintenance and management activities, over use of water, illegal use of water and pricing of water. The volumetric pricing in irrigation is becoming an important implementation method in resolving this problem. In order to accurately measure irrigation water, it is necessary to have a water meter (counter) in each parcel of land to record the amount of water. Pre-paid meters provide accuracy in measuring water and to collect in full. In this study, performance indicators of irrigation system including water distribution, financial, and production of Kayacık irrigation before and after usage of prepaid water meters were examined. It has been determined that there was a significant reduction in the amount of water usage in per the irrigation area after usage of prepaid water meters. While the amount of water usage in the irrigated area was 7 414 m3/ha in 2012, became 3.617 m3/ha in 2017. A savings of approximately 51% in the amount of water usage in the area was attained. As a result, significant amount of increase was realized in the production value for the amount of irrigation water usage in the area. The cost recovery ratio was calculated as 0,76 in 2013 and 1.07 in 2017. In summary, by using prepaid water meters for water distribution excess water usage in irrigation has been avoided and high water usage collection ratio has been carried out without problems. Furthermore, the amount of water evacuating to drainage canal has significantly been reduced.

Keywords: Water saving in agriculture, Reducing excessive water consumption in irrigation.

1 General Director, General Directorate of State Hydraulic Works. Yücetepe, Çankaya, Ankara-Turkey; E-mail: mevlutaydin@dsi.gov.tr
2 Head of Department, General Directorate of State Hydraulic Works. Yücetepe, Çankaya, Ankara-Turkey; E-mail: muyildirim@dsi.gov.tr
3 Engineer, General Directorate of State Hydraulic Works. Yücetepe, Çankaya, Ankara-Turkey; E-mail: aynurf@dsi.gov.tr
4 Director of Kayacık Water User Association, Oğuzeli, Gaziantep-Türkiye, E-mail: hakanozdal@hotmail.com

ANALYSIS OF VEGETATION INDICES FOR ESTIMATING RICE LODGING UNDER AWD IRRIGATION

Tzu-Hsuan Wen[1], Wen-Shin Lin[2] and Yu-Min Wang[3]

ABSTRACT

Lodging incidence of paddy rice depends upon crop management and environmental conditions. The objective of this study was to investigate the effects of alternate wetting and drying (AWD) method with probiotics applied at tillering and panicle initiation stages on paddy lodging. To study the effects of AWD, spectral crop detection techniques were explored by using vegetation indices (VIs) derived from multispectral remote sensing images. The normalized difference vegetation indexes (NDVI), green normalized difference vegetation index (GNDVI) and simple ratio index (SRI) were calculated from unmanned aerial vehicle (UAV) imagery. T-test was used to study the potential effects of each of these indices. After applying probiotics and nitrogen fertilizer at the panicle initiation stage, three VIs (NDVI, GNDVI and SRI) were not significantly different between lodging and non-lodging areas. For a few days, three of the VIs for the lodging area was significantly different from those of the non-lodging areas. However, in the lodging area, three VIs were not significantly different between two measurement dates. On the other hand, GNDVI and SRI were significantly different in the non-lodging area. The study results indicate that the VIs of GNDVI and SRI were sensitive between lodging and non-lodging areas. Therefore, to monitor the state of rice plants to predict the incidence of rice lodging, GNDVI and SRI can be used in the rice cultivation method proposed in this study.

Keywords: Alternate wetting and drying (AWD), Vegetation indices (VIs), rice lodging

1 Irrigation Engineering Department Head, InstitutoMexicano de Tecnología del Agua (IMTA). PaseoCuauhnáhuac 8532, Jiutepec, Mor. México. CP. 62550.); E-mail: wojeda@tlaloc.imta.mx

2 Irrigation & Drainage Coordinator, InstitutoMexicano de Tecnología del Agua (IMTA). PaseoCuauhnáhuac 8532, Jiutepec, Mor. México. CP. 62550.); E-mail: nahung@tlaloc.imta.mx

3 Researcher, InstitutoMexicano de Tecnología del Agua (IMTA). PaseoCuauhnáhuac 8532, Jiutepec, Mor. México. CP. 62550.); E-mail: mic@tlaloc.imta.mx

MULTI CRITERIA IRRIGATION WATER ALLOCATION FOR OPTIMIZING PANDANDURI RESERVOIR OPERATION

Rachmad Jayadi[1], FatchanNurrochmad[2], Abdul Azis[3], Ratih Kusuma Hartini[4]

ABSTRACT

Water utilization for irrigation purpose through reservoir operation often faces problems in the form of uncertainty in water potential either in the amount or in the distribution pattern of flow from water sources. This issue is found in Pandanduri Reservoir, West Nusantara Province, Indonesia, where a unique mechanism of water reuse persists in which the return flow from drainage system and pond is used for irrigation water supply in the downstream cultivated area. Ddetermination of water allocation based on the water availability according to time and space distribution should be considered in formulating an optimal reservoir operating rule. In this research, a multi-criteria water allocation model was developed to optimize the performance of the reservoir operation in fulfilling irrigation water demand. Standard operating rule method of reservoir simulation was applied in combination with a deterministic linear programming model to control release from the reservoir. The criteria used to measure the performance of water allocation are annual cropping intensity, *k* factor as the ratio between actual release and target release according to water demand, and the reliability of reservoir operation. The result shows that the distribution of return flow discharge can be estimated with a simple Tank model. The optimum reservoir operation concludes that irrigation water supply capacity is characterized by average ***k*** factor of 0.87 and the reservoir operation reliability is 83%. Moreover, the consistency of the performance of water allocation model was verified using reservoir operation simulation model with input of the generated synthetic stream flows.

Keywords: Return flow, Standard operating rule, Linear programming, Operation reliability.

1 Department of Civil and Environmental Engineering, Universitas Gadjah Mada (UGM). Jl. Grafika No. 2 Kampus UGM, Yogyakarta, Indonesia. CP. 55281.); E-mail: rjayadi@ugm.ac.id

2 Department of Civil and Environmental Engineering, Universitas Gadjah Mada (UGM). Jl. Grafika No. 2 Kampus UGM, Yogyakarta, Indonesia. CP. 55281.); E-mail: fatchan-nurr@ugm.ac.id

3 Public Works Office of West Nusa Tenggara Province. Jl. Majapahit No. 8, Mataram, Indonesia. CP. 83114; E-mail: abdoelazis.makawaru@yahoo.com

4 Directorate General of Water Resources, Ministry of Public Works and Housing. Jl. Pattimura No. 20, KebayoranBaru, Jakarta, Indonesia. CP. 12110; Email: ratihkusumahartini@gmail.com

IMPROVING THE WATER DISTRIBUTION UNIFORMITY BY INVESTIGATING THE HYDRAULIC PERFORMANCE OF BIG GUN SPRINKLER

Tang Pan[1] and Li Hong[2]

ABSTRACT

The hydraulic performance of sprinkler equipment largely determines the quality of the irrigation. Big gun sprinklers are one of the most useful rotating sprinklers, and the most widely used globally. The large areas covered by big gun sprinklers result in fewer sprinklers and less pipes required per unit area. Relevant factors of big gun sprinkler affecting the irrigation performance are the nozzle diameter, operating pressure, layout form, and overlapping distance which were studied under no wind condition. The discharge coefficient ranged from 0.96 to 0.99. A mathematical model of radius of throw was also regressed and the coefficient of determination was found as 0.9765. The application rate was lower near the sprinkler, and a peak value occurred under the radius of throw from 4 to 6 m for each water distribution pattern. The average application rate decreased with increase of operating pressure. The average application rate increased with the increase of nozzle diameter. The increase or decrease in magnitude of average application rate under small nozzle diameter was larger than large nozzle diameter sprinklers within the same range of variation in operating pressure. The maximum Christiansen's uniformity (CU) values increased with the increase in operating pressure under different nozzle diameter or different layout. Equilateral triangle layout achieved higher uniformity compared with square layout. The optimal CU values and spacing coefficients of the big gun sprinkler with different layout forms, operating pressure and nozzle diameter were proposed.

Keywords: Sprinkler irrigation, Hydraulic performance ,Water distribution uniformity, layout.

1 Research Center of Fluid Machinery & Engineering, Jiangsu University, 301 Xuefu Road, Zhenjiang, Jiangsu, China, 212013; E-mail: tangpan19@163.com

2 Research Center of Fluid Machinery & Engineering, Jiangsu University, 301 Xuefu Road, Zhenjiang, Jiangsu, China, 212013; E-mail: hli@ujs.edu.cn

SUSTAINABLE SUBSURFACE IRRIGATION WITH A RING-SHAPED EMITTER FOR SMALL-SCALE FARMS IN ARID REGIONS

Reskiana Saefuddin[1], Hirotaka Saito[2], and Jiří Šimůnek[3]

ABSTRACT

Introducing an irrigation technique based on indigenous materials and skills to small-scale farmers in rural areas is crucial to support food security in highly populated regions of developing countries. A simple-design affordable emitter is vital for small scale farmers. Subsurface irrigation with a ring-shaped emitter is one of the low-cost irrigation techniques that have been developed and introduced in arid regions of Indonesia for cultivating horticulture crops. The original emitter was made from a water rubber hose, which was bent into a ring-shape emitter with a 20-cm diameter. After five small holes were drilled at equal distances, the ring-shaped hose was covered entirely with a permeable textile to ensure uniform water distribution around the emitter. Our previous study investigated whether the number of holes and the covering method can be modified. As a result, an emitter partially covered by permeable textile with a reduced number of holes was proposed. In addition, proper water and nutrient management during subsurface irrigation of cultivated crops is very important to obtain sustainable yields, to save precious water, and to prevent nitrate pollution of groundwater due to deep percolation. Understanding the relationship between applications of water and nutrients, plant root water uptake, and leaching risk can be helpful in designing better irrigation practices and management. The present study was undertaken to assess long-term effects of using subsurface fertigation with a ring-shaped emitter on the subsurface environment. Two different emitter designs were used: the original fully-covered emitter with 5 holes (emitter 5F) and an alternative design of an emitter with 2 holes, which was partially covered with permeable textile (emitter 2P). The fully three-dimensional numerical model HYDRUS was used to simulate soil water movement and solute and nutrient distribution and leaching under different emitter designs. The numerical analysis extended for 10 years. The simulation results showed that by applying water and nutrients using emitter 2P, the amount of nutrient leaching can be minimized and root nutrient uptake can be increased by up to 94 %.

1 Tokyo University of Agriculture and Technology, Japan, E-mail rezqchan@gmail.com
2 Tokyo University of Agriculture and Technology Japan, hiros@cc.tuat.ac.jp
3 University of California Riverside, United States, E-mail: jsimunek@ucr.edu

DRIP IRRIGATION TECHNOLOGY FOR RICE CULTIVATION FOR ENHANCING RICE PRODUCTIVITY AND REDUCING WATER CONSUMPTION

Soman Padmanabhan [1]

ABSTRACT

The future of rice production which consumes a lion's share of water (85% in India) used in irrigated agriculture will therefore depend heavily on developing and adopting technologies and practices which will use less water with highest use efficiency. Rice is cultivated usually in a puddled soil condition with large volumes of water and grown in standing water. The water productivity is hardly 0.15 kg/m3 of water which is very low. Way back in 2008 we began introducing drip irrigation (both surface drip and sub surface drip systems) and fertigation for rice cultivation. During the last 10 years, this input management method is tried over several rice ecologies in India and over several rice varieties spanning both Dry seeded (DSR) and Transplanted rice (TPR) growing systems (sole rice or rotation with other crops).

Under drip –fertigation, the water productivity rose to 0.46 to 0.67 kg/m3 across varieties and locations. Rice yields were higher (13-28%) across varieties compared to the yields recorded in the respective conventional methods. Panicle number, grain number and test weights (grain) were found to be superior under water and fertilizer management through drip systems. Similarly, higher N, P and K efficiencies were also recorded under drip –fertigation. A standard rice growing package with drip fertigation is made available to farmers.

Keywords: drip irrigation, fertigation, water productivity, farmer field, yield

1 Chief Agronomist, Jain Irrigation systems Ltd. Jalgaon, 425001 Maharashtra, India., E-mail: dr.soman@jains.com

IMPACT OF THE CHANGE OF SOIL TEXTURE ON THE INFILTRATION BEHAVIOR OF SOILS IN THE EARTHEN IRRIGATION CANALS OF LGDIMA AND HANABOU

M. Bakache[1], A. Hammani[1], M Kuper[1], and E. Bartali[1]

ABSTRACT

This work was devoted to the study of the infiltration at the laboratory on samples of soil taken from the irrigation channels Lgdima and Hanabou located in the irrigated area of Jorf which belongs to the province of Errachidia (Morocco). The experimental device is composed of glass test-tubes containing the samples to be tested. The test-tubes were subjected to a constant water head during all the tests, which consisted of the recording of the infiltration time versus the advance of the humidification front in the test-tubes. All the samples underwent the same energy of dry compaction. In all the experiments, the infiltration measurements concerned the samples from origin soils not compacted, then compacted and finally mixed with fractions of clay according to percentages from 5 to 25%. The two parameters analyzed in the experiments are the water infiltration time necessary to cross entirely the soil column and the infiltration rate. The objective of this paper is to test the impact of change in the soil characteristics on the infiltration behavior, while keeping constant the other parameters such as the initial water content and the compaction degree.

The results showed in a first stage of the experimentation, that the comparison between infiltration times in the same sample not compacted then compacted, allows us to get a ratio between the two times higher than 2.This shows the effect of the compaction on the deceleration of the humidification front and thus on that of the infiltration. In one second stage, the infiltration time was measured in a case where the two samples of origin soil were compacted then mixed with clay. The results of these tests indicated that the variation of the infiltration time is an increasing function of the clay fraction brought and it is that this variation is better represented by a second order parabolic law with determination coefficients (R^2) of 0,972 and 0,983, respectively, for Lgdima and Hanabou samples. The study of the variation of the infiltration rate *I(t)* versus the time *t*, made it possible to get in the case of the two samples, curves whose the best fit is a power function with a coefficient of determination R^2 ranging between 0,909 and 0,995. The equation of the infiltration rate was found to be as:

$I(t) = \alpha t^{-\beta}$, α and β are coefficients which vary from a sample to another and from one test to another.

Keywords: Infiltration, Humidification front, Clay fraction, Infiltration rate, Compaction.

1 Departement of Water, Environement and Infrastructures, Agronomic and Veterinary Institute Hassan II

WATER-LIVELIHOOD-SUSTAINABLE AGRICULTURE APPROACH FOR ENHANCING ADAPTIVE CAPACITY TO CLIMATE CHALLENGES IN URMIA BASIN

Hossain Dehghanisanij[1], Nastaran Moosavi[2]Seyed Babak Moosavi Nejad[3], Afrooz Taghizadehghasab[4], Neda Asadfalsafizadeh[5], Hamid Soltani[6,]Abolfazl Abesht[7]

ABSTRACT

In the Urmia basin, vulnerability context is depicted in water resources of this area as the starting component for policy process analysis through the sustainable livelihood and agriculture approach. The main reason for the focus on 3 elements (water, livelihood and sustainable agriculture) in this study was climate change which contributed to greater water stress and making people more vulnerable in the Urmia basin. The interactions of water, livelihoods and sustainable agriculture have shown that factors such as migration, social capital, business, development, existence level, food supply, health, minor industry, agriculture and services, income variation, variety of crops and horticulture, sustainability of agriculture, livestock, fisheries, crops and horticulture, livelihood security for poor farmers, cover crops, stability of quality, quality of water and soil resources, participation in planning, reduction of water and irrigation losses, reduction of evaporation losses (mulch), pastures regeneration, market security, access to food, environmental sustainability (quantitative and qualitative resources), sustainable livelihoods (sustainable production), development of technology and service activities, compatibility with changing market conditions, reduction of poverty, labor force diversity, job creation, equipping infrastructure, responsibility, investment development, insurance, allocation of resources, improving nutrition, water rights, water use culture are effective on water-livelihood-sustainable agriculture nexus.

Also interdepartmental cooperation in the Urmia Lake basin (Environment, Ministry of Agriculture Jihad, Regional Water Company, Non-Governmental Organizations and Private Sector) with the aim of social participation and responsibility among all stakeholders, especially local communities to revitalize the Urmia Lake and carry out activities in three sectors of water, livelihoods and sustainable agriculture led to job creation, reduction of chemical inputs, and water savings in the field. As a result of training programs and capacity development on water-livelihood-sustainable agriculture nexus project, more than 80% of farmers had used the capacity development techniques. In East Azerbaijan, yield and water productivity were increased by 27.8% and 48.9%, and water consumption decreased by 25.3%.Also, in West Azerbaijan, water productivity increased 46.7% and water consumption indicator decreased by 29.2%. The yield decreased by 12.3%and 60% farmers in the whole of the basin were satisfied with their income received from their agricultural activities.

Keywords: Urmia Lake, Drought, Water resource, Ecosystems, Agriculture, Climate change

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1 Associate Professor, Agricultural Engineering Research Institute, Agricultural Research Education, and Extension Organization, Karaj, Iran. Water-Sustainable Agriculture-Livelihood Nexus Consultant, The Conservation of Iranian Wetlands Project, Email:h.dehghansanij@areeo.ac.ir

2 Socio-economic Consultant for the Conservation of Iranian Wetlands Project, Tehran, Iran.

3 Capacity Development Advisor for the Conservation of Iranian Wetlands Project, Tehran, Iran.

4 Water-Sustainable Agriculture-Livelihood Nexus Consultant, the Conservation of Iranian Wetlands Project, Tehran, Iran.

5 Project Coordinator, the Conservation of Iranian Wetlands Project, Tehran, Iran.

6 Technical Expert, the Conservation of Iranian Wetlands Project, Tehran, Iran.

7 National Project Manager, the Conservation of Iranian Wetlands Project, Tehran, Iran.

DEVELOPMENT OF OPTIMAL WATER MANAGEMENT SYSTEM FOR CULTIVATION OF HIGHCOST CROPS IN RECLAIMED FARMLAND

Si Hoon Kim[1], Young Jun Park[2] and Han Yong Um[3]

ABSTRACT

The purpose of this study is to present optimal environmental conditions in terms of the irrigation method and the quantity required for the cultivation of high value crops in order to increase the farm income and utilize the reclamedfarmland according to the changes in agricultural environment. Due to the opening of rice imports, the continuous increase of rice production, and the decrease of rice consumption, various other crops have been cultivated recently for the reclamation of reclaimed land. It is necessary to establish the basis of high value crops cultivation through the improvement of reclamedfarmland due to changes in agricultural environment. Tthe irrigation system is constructed according to the irrigation method, the water plan, and the water source plan and the installation location.The format, major specifications and approximate project costs for the last irrigation facility, adjustment facility, water supply facility were also reviewed. In addition, we established smart land reclamation water management measurement technology by integrating soil moisture measurement method applicable to salt concentration of reclaimed land, weather environmental factor and groundwater level fluctuation.

Keyword: Reclamation farmland, High value crops, Irrigation system.

1 Researcher, Rural Research Institute. #870 haean-ro, Sangrok-gu, Ansan-si, Gyeonggi-do, 15634, Korea E-mail :jjangminha@ekr.or.kr

2 Associate Researcher, Rural Research Institute. #870 haean-ro, Sangrok-gu, Ansan-si, Gyeonggi-do, 15634, Korea E-mail :ramses11@ekr.or.kr

3 Principle Researcher, Rural Research Institute. #870 haean-ro, Sangrok-gu, Ansan-si, Gyeonggi-do, 15634, Korea E-mail :umhy@ekr.or.kr

COUNT AND ACCOUNT WATER FOR AGRICULTURAL SUSTAINABILITY AND SUSTAINABLE DEVELOPMENTIN THE NENA REGION

Jiro Ariyama[1], Charles Batchelor[2], Amgad El Mahdi[3], Robina Wahaj[4], and Domitille Vallee[5]

ABSTRACT

The Near East and North Africa (NENA) region experiences severe scarcity, and there is a need to understand the fate of water to sustainably manage water. Well-adapted and well-implemented water accounting (WA) provides countries and/or regions that face increasing water scarcity a sound and transparent basis for managing the scarce water resources and inform management to achieve relevant goals and targets. WA differentiates consumptive and non-consumptive water uses in space and time. The latter is a crucial element of monitoring systems, for example, to evaluate and quantify benefits and potential trade-offs that result from policies and practices aimed at improving water efficiency, productivity and sustainability. Well-adapted and well-implemented WA also provides detailed information at different scales and institutional levels needed by potential users. To use water accounting properly for decision making, uncertainty in water accounting should be managed and communicated so that users of outputs know the level of confidence they can have in these outputs.

Better information, facts and evidence from water accounting alone may not deliver a quick fix to the complex challenges in the areas experiencing increasing water scarcity. Meeting these challenges will depend also on: better governance of water resources; investments in infrastructure; adoption of new technologies and better co-operation including data sharing and dialogue between key stakeholders within and across institutions and sectors. In this regard, water auditing can add value to water accounting by placing trends in water supply, demand, accessibility and use in the broader context of governance, institutions, public and private expenditure, legislation and the wider political economy.

This paper highlights the benefits of using water accounting that is multi-scalar, problem-focused and based on active stakeholder engagement in the NENA region. Typical challenges of institutionalising, operationalising and upscaling water accounting and water auditing are also highlighted alongside practical approaches to addressing and overcoming these challenges. The paper also describes the capacity development strategy and innovations that are being piloted in the NENA region. Finally, the paper lists recommended standard features of international standard water accounting systems.

Keywords: water accounting, water auditing, water scarcity, Near East and North Africa, capacity building,

1 Food and Agriculture Organization (FAO), Near East and North Africa Office; Email jiro.ariyama@fao.org
2 FAO, Near East and North Africa Office; Email batchelorch@gmail.com
3 International Water Management Institute, Middle East and North Africa Office; Email a.elmahdi@cgiar.org
4 FAO, Pakistan Office; Email Robina.Wahaj@fao.org
5 FAO, Near East and North Africa Office; Email domitille.vallee@fao.org

SENSITIVITY ANALYSIS OF FARMERS' DEGREE OF FREEDOM (E) ON CANAL CAPACITY IN SECOND CLEMENT'S MODEL

Shadi Ghafouri Bidgoli[1], Mohammad Javad Monem[2]

ABSTRACT

The on-demand delivery method, gives a considerable flexibility to farmers that can manage water in the best way and according to their needs. When the irrigation networks are designed On-demand, one of the proper tools for flow determination is Clement's model which has two sub models, namely First and Second, Clement's model(Monserrat et al. 2004). The latter is based on the Markovian stochastic theory of birth and death processes. In this paper, the impacts of variation of the parameter E on canal capacity were investigated. to this end, the real data of East-Aghili canal was studied and the Second Clement's model was applied. The results have shown that in general, the canal capacity increases by increasing E. Additionally, for higher values of E, in spite of the high discharge variations, its rate of change is constant. On the contrary, for lower values of E, the flow variations are less, and its rate of change vary for different E. Moreover, for high values of E and high values of irrigation time (T'), the canal capacity has the same sensitivity to both E and T'. Furthermore, it could be stated that the Clement's model can be used for On-systems by considering some limitation on input parameters of the model. It should be noted that in this paper the "On-request" method, is considered as a synonym of "Arranged" method.

Keywords: Second Clement's model, On-demandmethod,Farmerdgree of freedom, Water distribution networks.

1 MSc. Student of Hydarulic Structure Engineering, Department of Hydraulic Structures, TarbiatModares University.E-mail: Shadigh72@yahoo.com

2 Professor, Department of Hydraulic Structures, TarbiatModares University. E-mail: Javadmonem@gmail.com

TRANSFORMATION OF AUSTRALIAN IRRIGATION WATER MANAGEMENT UNDER CHANGING CLIMATE

Mohsin Hafeez[1], Ahsan Tayyab[2], Muhammad Kaleem Ullah[3]

ABSTRACT

In Australia, extended recent drought conditions and climate change concerns have highlighted the need to manage water resources more sustainably. Assessing water resources and accounting for their availability and use at a regional and continental scale requires comprehensive and consistent information on water distribution, storage, availability, and use across Australia. This information needs to be accurate, up-to-date and take account of local climatic and hydrological conditions. It also needs to be produced in a robust, transparent and repeatable manner. This has also highlighted the need to manage agricultural water resources more sustainably especially in the Murray Darling Basin (MDB) which utilizes more than 70% of water for food production. In 2004, the Australian Government started the National Water Initiative (NWI) which is a policy blueprint to transform and improve the way Australia manages its water resources. Under this NWI program, Australian Government has invested in modernising irrigation sector to improve the water productivity of irrigation system across all scales (on—farm and off-farm) so that more water is available for the environment sector.

This paper provides a major review of recent water policies, structural and non-structural changes implemented as well as technological innovations (non-traditional including application of information technology, satellite remote sensing) coupled with hydrology-hydraulic models across multiple scales ranging from continental, catchment and irrigation systems in Australia. Typically, improving water management in irrigated areas require the analysis of real time water demand in order to determine the possibilities in which it may be modified and rationalised. Real time water demand information in irrigated areas is a key for planning about sustainable use of irrigation water. These activities are needed not only to improve water productivity, but also to increase the sustainability of irrigated agriculture by saving irrigation water. This presentation will provide in-depth analysis on managing water resources in Murrumbidgee river basin, a major food bowl in the MDB, by providing examples from the project including Australian Water Resources Assessment (AWRA), Computer Aided River Management (CARM) and Coleambally Irrigation Demand management (first world irrigation system with 95% delivery efficiency). Examples of innovative projects will also include development of decision support systems using Information and Communication Technology (ICT) and remote sensing to monitor and predict yield and water supply-demand balance in a near real-time environment for irrigation areas.

Second half of the paper is mainly focussing on major technical and non-technical issues for a poor performance of irrigation system in many Asian countries where more than 80% of freshwater is diverted for food production. However, the irrigation efficiency is very low ranging from 30-50% meaning a large part of the water devour for irrigation is wasted due to poor management of irrigation systems. The author presents the current challenges faced in

1 Principal Researcher and Country Representative, International Water Management Institute (IWMI)12 Km Multan Road, Lahore, Pakistan 53700; E-mail: m.hafeez@cgiar.org

2 Principal Agricultural Economist, Asian Development Bank, Manila, the Philippines, Email: atayyab@adb.org

3 Assistant Professor, College of Civil Engineering, University of Lahore, Lahore, Pakistan; E-mail: kalimull23@yahoo.com

many irrigation systems located in Yellow and Yangtze River Basin (China), Indus River Basin (Pakistan), Pampanga River Basin (the Philippines), Mekong River Basin (Lao PDR), and Amu Darya River Basin (Uzbekistan). Based on practical insights and in-depth rich knowledge, the author will discuss pathways and opportunities to improve water and food security through enhancing water use efficiency and water productivity of irrigation sector across the Asian countries.

Keywords: Irrigation Water Management, Decision Support System, Murray Darling Basin, Water Productivity, Australia and Asian Irrigation System.

WATER USE EFFICIENCY OF UNDULATED COMMAND ENHANCED BY INTEGRATION OF TANKS: CASE STUDY

Bishnu Prasad Das[1]

ABSTRACT

Odisha a coastal State in east India having geographical area of 15.5 Million hectare (MHa) comprises of a western region, almost 500 Km. long and 250 Km. wide having undulated, hilly degraded terrain with large forest cover. The geographical area of this region is 11.3 MHa having arable land 3.5 MHa and irrigation coverage 1.4 MHa served by a few major and large number of medium and minor projects. The characteristics topographical feature of all irrigation projects is existence of large patches measuring 500 to 1000 hectare out of command upland within the command (GCA) and adjacent to the designated command, these lands are marginally above the command level (maximum 1 Mtr.) of the project.

Although the area receives an average of 1200 mm. of monsoon rain fall, the variability is in a range of 600 to 1700 mm. Invariably three to four dry years occur out of a ten year stretch, when no rain fall occurs continuously even up to fifteen days during the monsoon. The consequence is serious shortage to meet crop water demand as the reservoir/ pond as head works do not have enough storage. However, three to four storm spells in the monsoon precipitating to a maximum of 300 mm in three days is a regular pattern. At least two spells in July and August occur in dry years.

The project spills even up to 50% of the yield in above average years with nominal spill in dry years. To meet the deficiency of the evapo-transpiratory crop need during dry spells innovative interventions have been made by lining the main channels to increase their conveyance capacity. Further a large part of the spill during storms is conveyed to a series of new tanks built on valleys. These tanks essentially stabilise the designated command during dry spells and in addition provide deficit irrigation to specific out of command patches brought down to the command level by minimal cutting and levelling. In three typical projects Sunder, Saipala and Dumarbahal in Mahanadi basin, the modality of augmenting irrigation supplementation through identification and integration old/new tanks has led to increase of command area up to 23%.The consequential Water Use Efficiency (WUE) has increased from 32% to 43%.

The annual income of beneficiaries has significantly increased from Rs. 16000 per Ha to Rs. 28000 per Ha availing both monsoon and non-monsoon irrigation particularly adopting winter cash crops and horticulture in the tank command. The modalities of hydrological interventions and structural addition/ alteration to the conveyance system with tanks are detailed. Appropriate management technique for deficit irrigation are described for the three medium irrigation projects having designated command area of 4400 ha, 2752 ha and 2800 ha, which are now getting additional benefit 400, 700 and 850 ha respectively in both Kharif and Rabi season.

Keywords; Water use Efficiency, Undulated Command, Tank Integration, Management by Beneficiaries.

[1] Former Engineer-in-Chief and Chief Advisor, projects of Department of Water Resources, Govt. Of Odisha, Chairman of Environment Monitoring Committee for River Valley Projects, Ministry of Environment, Forest & Climate Change, Govt. of India.

CONVERSION OF CANAL BASED IRRIGATION NETWORK SYSTEM TO PRESSURIZED PIPE BASED NETWORK SYSTEM INTEGRATED WITH SOLAR PLANT A CASE STUDY IN UTTAR PRADESH, INDIA

Sabarna Roy [1], Rajat Chowdhury [2]

ABSTRACT

Badaun irrigation project was designed many years back by the Government of Uttar Pradesh on Canal Based Irrigation Network. The project could not be completed in so many years. Only the major part of the Main Canal was completed that too at substantially escalated project cost and after long delays, but none of the branch canals and the distributaries could be completed.

The Champatpur Branch Canal with its distributaries as such was taken up on Pressurized Piped Irrigation Network basis, considering the advantages as mentioned in the Central Water Commission PIN Manual of Government of India of July 2017. The project has been designed as per the instructions of the UP government, adopting modern irrigation system is proposed to be brought under sprinkler irrigation integrated with Solar Plants of the Champatpur branch system, by which irrigation can be done in more areas with less water.

The paper discusses design aspects, all costs and comparative costs in detail, which will help engineers at the threshold of converting Canal Based Irrigation Network to Pressurized Pipe Based Irrigation Network.

1 Senior Vice President (Business Development), Electrosteel Castings Limited, (G. K. Tower, 19, Camac Street, Kolkata – 700017); Email: sabarnaroy@electrosteel.com
2 Senior Executive (Business Development), Electrosteel Castings Limited, (G. K. Tower, 19, Camac Street, Kolkata – 700017); Email: rajat.chowdhury@electrosteel.com

DEVELOPMENT OF PERFORMANCE EVALUATION MODEL FOR OLD AGRICULTURE INFRASTRUCTURE (FOCUS ON PUMPING AND DRAINAGE STATION)

Joongu Lee[1], Won Choi[2], Sung Su Yoon[3] and Jin Sun Park[4]

ABSTRACT

The purpose of this study is to analyse the reason of performance degradation and suggest their countermeasures through field survey. Onthis study the performance evaluation model was developed using the factors related to performance degradation of pumping and drainage facilities. We focused on the pumping and drainage stations belonging to each climatic zone separated by the Korea geographical climatic classification system. The performance evaluation model was developed using three different statistical models of POLS, RE, and LASSO.

Keywords: Agricultural infrastructure, Degradation factor, Performance evaluation model, LASSO, Performance prediction.

1 Corresponding author, Senior Researcher, Rural Research Institute, Korea Rural Community Corporation.#870 Haean-ro, Sangnok-gu, Ansan-si, Gyeonggi-do, Korea. 15634; E-mail: leejk@ekr.or.kr
2 Professor, Rural Systems Engineering Department, Seoul National University.#1 Gwanak-ro, Gwanak-gu, Seoul, Korea. 08826; E-mail: fembem@snu.ac.kr
3 Professor, Rural System Engineering Department, Chungbuk National University.#1Chungdae-ro, Seowon-Gu, Cheongju, ChungbukProvince,Korea. 28644; E-mail: yss@chungbuk.ac.kr
4 Researcher, Rural System Engineering Department, Chungbuk National University.#1Chungdae-ro, Seowon-Gu, Cheongju, ChungbukProvince,Korea. 28644; E-mail: icarus@chungbuk.ac.kr

ASSESSING THE IMPACT OF IRRIGATION IMPROVEMENT PROJECTS ON WATER-ENERGY-FOOD NEXUS - CASE STUDY : AL-ATF CANAL, EGYPT

Talaat El Gamal[1] andHanan Farg[2]

ABSTRACT

Egypt is an arid country with limited water resources. There were also some problems regarding energy resources during last few years. In Egypt, both water and energy are closely connected to food production, as agriculture depends totally on irrigation, and the Egyptian irrigation system restricts lifting the water from canals to the surrounding fields. With the rapid population growth in Egypt, there is a necessity to produce more food, and this requires optimizing the use of limited water and energy resources. Irrigation Improvement Projects (IIPs) were among the solutions to improve Water-Energy-Food nexus. The projects were conducted to improve water productivity by improving water use efficiency and crops yield. Another important objective for IIPs was to decrease the irrigation cost through the optimal use of the energy. After the actual implementation, the evaluation of IIPs referred to difficulties in the achievement of some objectives, while other objectives were achieved successfully. The current study assess the Water-Energy-Food nexus in traditional situation in Egypt, the expected impact from IIPs on this nexus, and the actual impact of IIPs after the implementation. An improved canal in the Middle Delta (Al-Atf canal) was selected for such assessment. The measurements were conducted in the first reach of the canal. Measurements on the canal did not refer to real change in water use efficiency, mainly due to the unsuitable operation of the irrigation system and the lack of coordination between farmers. Regarding the energy, the single-point lifting and the dependence on the electric power had a significant impact of reducing the irrigation cost. The study discusses the reason for low water use efficiency, and it suggested developing an operation model that calculates actual water requirements based on remote sensing information to propose the optimal operation scenario for the improved Mesqas. Such model could improve water management, which should have positive impact on water use efficiency, and which could minimize the adverse impacts of Water-Energy-Food nexus in the improved areas in Egypt

Keywords: Water-Energy-Food nexus, Irrigation Improvement Projects, Water Management, Water Use Efficiency

1 Water Management Research Institute (WMRI), National Water Research Center (NWRI), Ministry of Water Resources and Irrigation (MWRI). El-Kanater El-Khariya, CP ; E-Mail: elgamalt@gmail.com

2 National Water Research Center (NWRI), Ministry of Water Resources and Irrigation (MWRI). El-Kanater El-Khariya, CP ;E-Mail: hananfarag71@gmail.com

ASSESSING CAPACITY DEVELOPMENT NEED FOR SUSTAINABLE IRRIGATION DEVELOPMENT IN CAMBODIA

Sytharith Pen[1], Ketya Hun[2], PinnaraKet[3], Bin Dong[4], Garry Ellem[5] and Sarann Ly[6]

ABSTRACT

Cambodia's economic performance in recent years has been impressive, evidenced by high economic growth rates compared to global averages. However, significant challenges remain, including among other, low levels of technology adoption and the human capital to utilise such technology to improve productivity and lack of information. Cambodia has invested and plan to invest hundreds of millions of dollars in irrigation and drainage infrastructure. Despite these investments, the irrigation schemes are not as successful as was hoped for.This paper discusses the outcomes of the multi-stakeholder and expert assessment of the capacity needs for ensuring sustainable irrigation and drainage systems. The assessment reveals that the unsuccessful story is due to several factors. First, most investments have not yet sufficiently factored in the user needs and operation and maintenance (O&M) requirements of irrigation schemes including resource mobilization (i.e., human, technical and financial) to support long-term sustainability of the irrigation schemes. Both resources for the professional management of primary and secondary main structures are significantly absent as currently there are only about 630permanent staffs in the provincial water resources departments all over the country to manage over 700,000 hectares of irrigated area. In addition, the functional FWUCs and Agricultural Cooperatives for managing small scale irrigation system or field level irrigation schemes are small in number. The current US$ 2.6 billion Irrigation and Water Resources Investment Program (2019-2033) envisages for developing further irrigation schemes, knowledge management system and human capital to provide reliable irrigation to over 1,375,000 ha irrigated areas. Successfully operating and managing these irrigation schemes, Cambodia would need additional skilled staff between 1,600 to 2,200 (1 skilled staff per 600 to 900 ha)irrigation engineers, planner, and technicians to professionally plan for water allocation, conduct O&M of major and medium systems, and run the main components – reservoirs, main canals and secondary canals of the medium to large schemes. At the same time at least 250 self-sustaining and functional Water User Communities will be required to operate sustainable O&M at the water distribution canals level to reduce pressure on Government Budget and human capacity. Cambodia needs a well-funded and resourced capacity development program, for short, medium and long term.

Keywords: Adaptation strategies, Irrigation schemes, Climate change, Regional Climate Models, Crop water requirement.

1 Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia; E-mail: sytharithpen@yahoo.com
2 Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia; E-mail: ketyah@live.com
3 Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia; E-mail: ketyah@live.com
4 School of Water Resources and Hydropower Engineering, Wuhan University; E-mail: dongbin@whu.edu.cn
5 Cambodia Agricultural Value Chain Program; E-mail: garyellem@cavackh.org
6 Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia; E-mail: ketyah@live.com

ENABLING POLICY ENVIRONMENT: IMPROVING THE IRRIGATION WATER PRODUCTIVITY THROUGH NEW IRRIGATION POLICY IN AFGHANISTAN

Suman Sijapati [1], Masoom Hamdard [2] and Hashmatullah Ghafoori [3]

ABSTRACT

The National Irrigation Policy 2018 is the first documented policy for irrigation in Afghanistan since 1978. Several consultative workshops were conducted with the stakeholders related to the irrigation sector at the regional and central level, and consensus were reached at technical forums such as inter-ministry coordination groups, and technical secretariat of Supreme Council for Land, Water and Environment, before final approval from Cabinet of Ministers in November 2018.

The fact that Afghanistan now has a documented policy is a significant milestone as irrigation remains a priority area with livelihood source of over 80% population depending on agriculture. This policy seeks to (a) fill the policy gap, (b) facilitate and guide interventions in the irrigation sector, and (c) contribute to sustainability and more equitable distribution of benefits across irrigation systems and across agro-environments. It clarifies programmatic priorities of the country's irrigation sector that includes increasing the productive area under irrigation, triggering job creation, increasing domestic agricultural production, reducing food-insecurity, and addressing water shortage as well as problems of salinity and drainage. It is expected to particularly contribute to achieving the SDGs indicators tailored for Afghanistan.

This paper explores the key features of the policy and tries to investigate the extent to which they provide an enabling environment for the water, food and energy nexus in Afghanistan. It analyses the status of the nexus as well as the potential improvements in water productivity due to the prevailing policy measures. It also analyses the arrangements for participation of the stakeholders and resilience against destructive forces of nature. The paper also discusses on the various policy measures put in place and their merits and demerits particularly from the perspective of making a difference at the ground level by enhancing irrigation water productivity.

The paper concludes stating that this policy is well positioned for the current context of Afghanistan. It has filled in the policy gap and well identified the programmatic priorities of the country's irrigation sector. Its implementation,even though moving in the right direction, needs some refinements and coordinated efforts from all stakeholders. Otherwise the set objective cannot be met within the stipulated period. The policy direction of increasing the productivity of irrigated agriculture and the measures proposed for enhancing water productivity are appropriate and have even started to show some positive indications. However, measures must be in place for sustaining the achievements which can be done through local scale institutional arrangements and proper engagement of the concerned Irrigation Associations in the planning, implementation, as well as operation and maintenance of the irrigation schemes. Finally, the paper also provides specific pointers for next most logical steps to materialize the essence of the policy considering the prevailing challenges like poor infrastructure, institutional structure, financing and capacity at different tiers.

1 Chief Technical Advisor in FAO Afghanistan, Nepal, sumansij@yahoo.com
2 Senior Irrigation Advisor to the Office of the Deputy Minister of Irrigation and Natural Resources, Afghanistan, masoom.hamdard@gmail.com
3 Deputy Minister of Irrigation and Natural Resources of the Ministry of Agriculture, Irrigation and Livestock of the Islamic Republic of Afghanistan, Afghanistan, h.ghafoori@mail.gov.af

ESTIMATION OF DAILY RUNOFF USING WATER LEVEL DATA AND OBSERVED FLOWRATE DATA

Maga Kim[1], Jin-Yong Choi[2] and Jehong Bang[3]

ABSTRACT

Runoff is a vital factor in water resource planning and water quality management. Rainfall-runoff processes are affected by the complex relation of watershed factors such as geographical features, vegetation distribution, land use, soil properties, and weather conditions. These relationships make the rainfall-runoff processes nonlinear. Artificial Neural Network (ANN) model is the computational model created by simplifying the brain structure of a human. ANN models have been applied to modeling and recreating non-linear natural phenomena such as weather or hydrological data. Once an ANN model has been trained it can be utilized to predict the outcome of a process. In Korea, the Korea Rural Community Corporation (KRC) has been collecting the reservoir water level data every 10 minutes, and a flow observation net has been created to collect runoff flow data. Knowing the volume of runoff from a watershed means that the inflow into the reservoir can be estimated using the reservoir water level and evaporation data in the non-irrigated period via a water balance method. Observed flow data can be used as runoff from a watershed at the observation point. Therefore in this study, the ANN model was utilized to predict daily runoff. Reservoir water level data and observed flow data were used for training the ANN model. The ANN model consists of three layers including input, hidden, and output layer. Runoff data obtained from reservoir water level, the observed flow, weather data, watershed characteristics, and others applied as input data to the ANN model. This dataset was divided into training dataset and test dataset. These two sub-sets of the data were used to train and verify the ANN model. The sigmoid function, which is commonly used for the ANN models, was applied as the activation function of the hidden nodes. The softplus function, which gives only positive results, was applied as the activation function of the output nodes. The results of each model run were evaluated by comparing with the target data. They were also compared with the results of the TANK model which can estimate the runoff of the watershed with input data of the ANN model. This study is useful for estimating and predicting the daily inflow to the reservoir. It is also helpful for managing water resources and operating the reservoirs.

Keywords: Runoff, Artificial neural network model, TANK model.

1 Ph.D. Course in Department of Rural Systems Engineering, Agriculture and Life Sciences, Seooul National University, Seoul 08826, Republic of Korea, E-mail: mnkm53@snu.ac.kr

2 Professor in Department of Rural Systems Engineering, Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of Korea, Email: iamchoi@snu.ac.kr

3 Ph.D. Course in Department of Rural Systems Engineering, Agriculture and Life Sciences, Seooul National University, Seoul 08826, Republic of Korea, E-mail: jaehong999@snu.ac.kr

IRRIGATION DEVELOPMENT IN INDIA - A FIRM STEP TOWARDS FOOD SECURITY

Manoj Kumar Sinha1

ABSTRACT

Since independence India has remained agriculture based country. At the time of independence about 80% of the population was dependent on agriculture. With the urbanization and industrialization in post independence era, the Indian population's dependency on agriculture has gradually reduced from 80% to 50%. However the growth of population is yet to stabilize. It is expected that the population of India will stabilize around the year 2050 and the projected population of the country would be around 165 crore. This shows that our demand for foodgrain production will continue to rise till 2050. Keeping the above fact in view, India embarked on a large program of water resources development, soon after its independence in 1947. Variation in rainfall with respect to space and time and dependency of famers on rainfed irrigation led to frequent droughts in the country in pre and post independence till 1960s. As such there was shortage of food in general and the Government had to import foodgrain from other countries. That is why the general shortage of food became the main drivers of water planning. The multipurpose river valley development was the chosen vehicle of change. Providing assured irrigation to farmers for increased foodgrain production became the main objective of the Government and this was followed by flood control and hydro-electric power generation. A large number of water projects, including large storage and diversion projects were implemented. As a result, the irrigation potential of about 127 million hectare is reported to have been created by March, 2018 against ultimate irrigation potential of 140 million hectare (This includes irrigation potential of all Major Medium and Minor Irrigation Projects.). During the course of above achievement, some major corrective measures like Command Area Development (CAD) Programme, Participatory Irrigation Management (PIM) approach, Accelerated Irrigation Benefit Programme (AIBP) and Pradhan Mantri Krishi Sinchai Yojna (PMSKY), etc were taken. Further it is expected that additional irrigation potential of about 5 million hectare alone would be created through 45 projects under PMSKY targeted to be completed by December, 2019, thus taking the irrigation potential achieved upto 132 million hectare. This shows that in another 3-4 years we are likely to achieve ultimate irrigation potential if same pace of irrigation development is maintained. As a result, Country's foodgrain production touched the figure of 290 million tonnes in the year 2017 and country is now not only self sufficient in foodgrains but it is exporting foodgrains also. However now question arises as to would this irrigation development be sufficient to grow foodgrain requirement for the year 2050.

In this context it is stated that as per an earlier estimate the present foodgrain requirement for the year 2050 for an estimated increased population has been assessed as about 450 million tones. However a mid-term assessment indicated that India requires an irrigation potential of atleast 160 million hectare to grow the foodgrains and meet the increased demand of population of India in the year 2050. National Perspective Plan prepared by Government of India suggested that if nation goes for long distance inter basin water transfer or water transfers between important sub-basins of a basin, an additional area of 35 million hectare can be brought under irrigation raising the ultimate irrigation potential from 140 million ha to 175 million ha. So Government of India has already initiated action for implementation of long distance inter-basin water transfer. This shows that irrigation development in India is a firm step towards food security.

1 Former Executive Member, Narmada Control Authority and Chief Engineer, Central Water Commission (presently working as Assessor, Krishna Water Dispute Tribunal, Govt. of India, New Delhi) Email-mksinhacwc@yahoo.co.in

COMPARISON OF YIELDS ATTRIBUTES AND WATER PRODUCTIVITY UNDER THE SYSTEM OF RICE INTENSIFICATION (SRI) IN SOUTHERN TAIWAN

S. Jean Paul Zoundou[1], Shiang-Min Chen[2] and Yu-Min Wang[2]*

ABSTRACT

Rice (Oryza sativa L.) is the staple food for more than half the world population. With the world population continuously growing, rice production is compelled to grow as well. Unfortunately, due to water scarcity driven by climate change continuous flooding is no longer a reliable option for sustainable water management to meet the food needs of our growing population while at the same time mitigating water scarcity. The System of Rice Intensification with its efficient management of production inputs, especially water, seems to be a possible solution to meet the growing food demand. From December 2017 to April 2018 a field experiment was conducted at the National Pingtung University of Science and Technology (NPUST) to compare water use efficiency and rice yields from the System of Rice Intensification (SRI). The experiment involved using the following four (4) water depths: 2cm water depth (SRI2); 3cm water depth (SRI3); 4cm water depth (SRI4); and 5 cm (SRI5) under intermittent irrigation based on visual observations by estimating soil hairline cracks. The yields of these four water depths were compared to the control plot irrigated at 3cm every week (SRI3/week).

The results of this study revealed that yield attributes like number of spikelets per meter square and percentage of filled spikelets were determinant for the grain yield. SRI3 yielded better with 4,072kg/ha compared to SRI2 (3,448kg/ha), SRI4 (3,081kg/ha and SRI5 (2,604kg/ha). The highest water productivity was recorded in SRI3 at soil hairline cracks (0.19kg/m^3) whereas SRI2 obtained 0.18kg/m^3.

Keywords: System of Rice Intensification (SRI), Yield, Water Productivity, soil hairline cracks

1 International Master Program in Soil and Water Engineering, NPUST (1 Shuefu Rd., Neipu, Pingtung 912, Taiwan); E-mail: wojeda@tlaloc.imta.mx

2 Department of Civil Engineering, NPUST(1 Shuefu Rd., Neipu, Pingtung 912, Taiwan); * E-mail: wangym@mail.npust.edu.tw; hsiang.min2114@gmail.com

INCREASING WATER PRODUCTIVITY AND SAVING ENERGY BY HIGH YIELD RICE RATOONING IN MYANMAR

Kazumi Yamaoka[1], Khin Mar Htay[2], Resfa Fitri[3] and Erdiman[4]

ABSTRACT

There are over one hundred countries globally in which rice is cultivated. Annual production of paddy rice is above 750 million tons (FAO, 2019) and 3.5 billion people who consume rice worldwide (IRRI, 2013). Rice is one of three major grain crops that act as the staple food for people all over the world, especially, the importance of rice in Asia, which contains 60% of the world's population cannot be understated, and recent increases in rice consumption in Sub-Saharan Africa are also noteworthy. However, rice needs more water for its cultivation; it is said that the water productivity of rice is about half of that of other two major grain crops i.e. wheat and maize. Tropical Perennial Rice (ToPRice) farming systems (SALIBU technology) originating from West Sumatra, Indonesia allow for harvesting rice grain up to 3.5-4 times annually and produce a yield for each ratoon crop at the same level as that of the main crop. ToPRice farming systems should revolutionarily increase water productivity because farmers can reduce the amount of irrigation water drastically by shortening cultivation periods and omitting seedling raising, puddling and transplanting. The systems also effective to save energies and input resources for such various activities above-mentioned. It is useful for adaptation against climate change and promotion of low input rice cultivation. Authors conducted trials on continuous cultivation of rice ratooning for nine generations including main crop in Myanmar.

The trials were done in large concrete pots (1.8m x 2.4m each) out door. While the yield of main crop was 5.3 t/ha, that of its subsequent SALIBU ratoon crop from the 1st to 8th generation were 9.1, 6.9, 11.5, 6.9, 11.0, 9.6, 5.7, 3.9 t/ha respectively. Authors also conducted other trials in test fields (3.5m x 9.3m each) in Myanmar. They were on continuous cultivation of rice ratooning for three or four generations including main crop to compare water productivity. Three rice cultivars were tested. Thee Htat Yin variety scored 4.5 t/ha in yield of main crop while it did 4.7, 5.4, 5.1 t/ha in that of its subsequent SALIBU ratoon crop from the 1st to 3rd generation respectively. It also scored 0.61 g/l in water productivity of main crop while it did 1.44, 0.89, 1.07 g/l in that of its subsequent SALIBU ratoon crop from the 1st to 3rd generation respectively. Water productivity of the same variety cultivated in conventional practice (transplanting) in parallel with the ratoon crop from the 1st to 3rd generation were 0.61, 0.57, 0.87 respectively. The average of them is 0.68 while that of SALIBU ratoon crop is 1.13 which is higher than the former by 66%. It means that farmers can produce by 66% more rice under SALIBU technology than conventional practice within the same amount of water available annually in certain area.

Keywords: Tropical Perennial Rice, high water productivity, continuous cultivation of rice ratooning, save energy

1 Senior researcher, Japan International Research Center for Agricultural Sciences (JIRCAS). 1-1 Ohwashi, Tsukuba, Ibaraki Prefecture, Japan; E-mail: kyamaoka@affrc.go.jp

2 Deputy Director, Department of Agricultural Research (DAR), Ministry of Agriculture, Livestock and Irrigation (MOALI). Yezin, Nay Pyi Taw, Myanmar; E-mail: khinmarhtay2007@gmail.com

3 Lecturer, Bogor Agricultural University. Bogor, Indonesia; E-mail: rfitri2@gmail.com

4 Reserch Fellow, Bogor Agricultural University. Bogor, Indonesia; E-mail: erdimantanjung@gmail.com

CAPTURING THE IRRIGATION DYNAMICS AT FIELD SCALE IN A RICE DOMINATED BASIN USING SATELLITE REMOTE SENSING

Kirthiga S.M[1], Narasimhan B[2] and C.Balaji[3]

ABSTRACT

Monitoring the dynamics of Indian agriculture is challenging due to small field sizes and heterogeneity in management practices. The global availability of high resolution remote sensing data at multi-spectral and multi-temporal ranges have helped in increasing its usage for monitoring of natural resources in developing nations. This study explores the possibility of using an integrated approach combining high resolution images from Sentinel and Landsat missions to capture the irrigation dynamics at field scale. A part of the rice paddy dominated Tamirabharani basin (southern parts of south India), which was considered for the study is posed with serious challenges from cloud cover throughout the year. Thus, integrated use of optical and microwave remote sensing was attempted in the study. The irrigated rice paddy fields were classified at high resolution (20m) using a cloud free Sentinel-2 image with ancillary information from Sentinel-1 time series, Landsat-8 time series and ALOS Global Digital Surface Model data. Supervised classification using Random forest classifier was performed for the identified 10 land-use classes. The classification procedure was validated against ground truth data and gave an overall accuracy of 79.6%. The classification accuracy for rice paddy was relatively higher with producer's accuracy of 88% (F score of 86%).The field scale variability has been adequately captured. About 94% of the classified rice paddy matched with irrigated land cover from the Global irrigated area map (GIAM) datasets which confirm the spatial consistency of the method. The whole algorithm was implemented in Google Earth Engine (GEE) cloud computing platform reducing the processing time and local storage needs. The results are promising and in view of above the use of the procedure at regional level is suggested. An attempt to further capture the irrigation dynamics at 12-day interval for the classified rice paddy fields was attempted with the backscatter values from Sentinel-1 time series data and field collected irrigation frequency data.

Keywords: Irrigated crop mapping, Google Earth Engine, Sentinel -1, Sentinel-2, Landsat-8.

1 PhD Research Scholar, Indian Institute of Technology, Madras (IITM). Chennai 600036, India; E-mail: smkirthiga@gmail.com

2 Professor, Envi. and Water Res. Engg. Division, Indian Institute of Technology, Madras (IITM). Chennai 600036, India; E-mail: nbalaji@iitm.ac.in

3 Professor, Mechanical Engineering, Indian Institute of Technology, Madras (IITM). Chennai 600036, India; E-mail: balaji@iitm.ac.in

NEW GEOSYNTHETIC CEMENTITIOUS CONCRETE MAT (GCCM) LINER FOR REDUCING IRRIGATION CANAL LOSSES

William Crawford[1] and Lee Church[2]

ABSTRACT

A new class of geosynthetic has recently emerged known as GCCMs (Geosynthetic Cementitious Composite Mats) defined by the ASTM D-35 committee in 2017 as ‘a factory-assembled geosynthetic composite consisting of a cementitious layer contained within a layer or layers of geosynthetic materials that becomes hardened’.

GCCMs consist of a three-dimensional fibre structure filled with a dry cement/concrete mix, overlain by a hydrophilic filter layer and underlain by a watertight membrane, which is typically a PVC or LDPE film. The material is delivered in its dry format and unrolled into place using similar installation techniques to traditional geosynthetics. Once in place, it is hydrated by spraying with water and the cement/concrete mix hardens. The result is a watertight polymeric film which is overlain by a protective fibre-reinforced concrete layer, with a thickness typically between 5 and 13mm and an equivalent coefficient of permeability in the region of 10^{-9}m/s.

GCCMs have been in use since 2009 and are predominantly used for the lining of water channels for small scale drainage. This paper explores their use as a potential lining solution for large scale irrigation canal structures by examining selected case studies from around the world.

Keywords: Canal liner, GeosyntheticBarrier, Geomembrane, Concrete, GCCM, GCCB, Concrete Canvas.

1 Director, Concrete Canvas Ltd. Block A22, Severn Road, Treforest Industrial Estate, Pontypridd. UK. CF37 5SP; E-mail: will.crawford@concretecanvas.com

2 Technical Manager, Concrete Canvas Ltd. Block A22, Severn Road, Treforest Industrial Estate, Pontypridd. UK. CF37 5SP; E-mail: lee.church@concretecanvas.com

PRODUCING MORE WITH LESS WATER: FROM CONCEPT TO REALIZATION BY GREEN MOROCCO PLAN

Ahmed El Bouari[1], and Zakariae El Yacoubi[2]

ABSTRACT

In Morocco, irrigated agriculture is increasingly confronted with a scarcity of water resources under the combined effects of successive and prolonged droughts and increased demand for water from economic sectors. Since 2008, the Government has launched a voluntarist and ambitious program to modernize irrigated agriculture to convert 550,000 ha of irrigated land into drip irrigation, in order to save about 1.4 billion m3 of irrigation water and double the added value per cubic meter of water. This program, which mobilizes nearly 4 billion USD, is based on a systemic and participative approach for : i modernisation of collective irrigation systems in order to provide a water service to farmers that satisfies drip irrigation requirements at farm level ; ii equipment of agricultural farms with drip irrigation system by means of government subsidies that cover up to 100% of the investment cost, iii support to farmers for a better control and valuation of the irrigation water. Since the program's launch in 2008, an additional 400,000 ha of irrigated land have been converted to drip irrigation, bringing the total area equipped with this irrigation technique to 35% of the irrigated area at national level, as well as comprehensive modernization of collective irrigation systems.

1 Director of Irrigation and Agricultural land development, Ministry of Agriculture – Morocco (bouariahmed@gmail.com)
2 Head of Division of Hydro Agricultural Resources, Ministry of Agriculture – Morocco (zakariadiaea2@gmail.com)

SUSTAINABLE WATER SAVING AND WATER PRODUCTIVITY USING DIFFERENT IRRIGATION SYSTEMS FOR COTTON PRODUCTION

Oner Cetin[1]

ABSTRACT

In this article, different irrigation systems/methods (furrow, sprinkler, surface drip irrigation (SDI) and subsurface drip irrigation (SSDI) used for cotton irrigation in South-eastern Region of Turkey were evaluated on water use efficiency, water and yield relationships and water productivity. According to a study carried out in this region, the sprinkler irrigation method resulted in a lower yield than that of both the drip and furrow method. Considering the optimum yields, SDI resulted in 21 % more seed-cotton yield than yield obtained by the furrow irrigation, and 30 % more than the sprinkler irrigation. Irrigation water use efficiency (IWUE) or water physical productivity (WPP) proved to be 0.49, 0.39 and 0.24 kg/m^3 for SDI, furrow and sprinkler, respectively. The net return of US$989 /ha per land area could be obtained using 10000 m^3/ha of irrigation water for the furrow irrigation method. Whereas the same net return was obtained using 8000 m^3/ha of irrigation water for the SDI. The water economic productivity (WEP) for furrow irrigation and SDI were US$0.099 /m^3 and US$0.124 /m^3, respectively. According to another study, the maximum WPP (0.84 kg/m^3) occurred in the SSDI system at a soil depth of 40 cm. The net return was US$1109.9 /ha at the same treatment using irrigation water of 551 mm. The reason of differences on WPP for two different studies of SDI could be attributed to different irrigation scheduling based on different methods and cotton variety. The use of the SDI technique in arid and semi-arid areas and the evaporation rate from the soil surface increased considerably due to high air temperature and low relative humidity, as in those study areas. Having higher water use efficiency and saving water are dependent on decreasing the evaporation from the soil and an appropriate irrigation management. Thus, the use of SSDI is one of the main methods of saving water. Water productivity can vary according to the crop, climate conditions, agronomic practices and agricultural technologies. Better agronomic practices and water management can, thus, improve the yield and water productivity of irrigated crops.

Keywords: Water productivity, water saving, cotton, surface and subsurface drip irrigation.

1 Department of Agricultural Structures and Irrigation, Agricultural Faculty, Dicle University, Diyarbakır, Turkey; E-mail. onercetin@dicle.edu.tr, oner_cetin@yahoo.com

Papers Presented Under

SUB-THEME 2
Role of Civil Society and Non-state Actors with Focus on Farmers and Extension Facilities

Topics

2.1 Performance of public irrigation extension services in strengthening the irrigation management institutions

2.2 The potential roles of non-government organizations, including private sector (NGOs) and civil societies in irrigated agriculture extension and advisory services including improvement of farmers livelihood (i.e. agricultural input, post-harvest technology, market chain, agro-based industry)

2.3 Promoting public-private-partnership and participation of WUA in the irrigation development and management for irrigation sustainability (i.e. to improve water efficiency and to reduce water conflict).

REFORMS IN THE IRRIGATION SECTOR OF INDIA

K. Vohra[1] and M. L. Franklin[2]

ABSTRACT

India has taken up an ambitious goal to double the average income of agricultural households from 2015 to 2022. This mammoth task requiring a sharp accelerated annual growth of over 10 per cent would have to harness all possible sources of growth in farmers' income within as well as outside agriculture sector and will need strong inclusive measures in the irrigation sector such as water use efficiency, Participatory Irrigation Management (PIM), Water Conservation, Agricultural Productivity, etc.

Traditionally, execution of irrigation projects has been known to be very complex process which results in long gestation periods. Further, improper water management at the farm level leads to inefficient use of water and non-equitable distribution with the tail-end farmer often not getting water. Though an irrigation potential of 112 Million Hectare (MHa) has been created against an ultimate potential of 140 MHa, the utilization is only 93MHa (Gross cropped area). Moreover, efficiency of water use in irrigation in India is about 30% to 40%. Keeping in view the limitations in the overall potential that can be created, emphasis has to shift to resourceful management of water to meet the future requirement of food grains which is estimated to be about 450 Million tonnes (MT) by 2050 against the present food grain production of 277.7 MT.

Central and State Governments have come up with various initiatives in the supply and demand side management. Few of them are as under:

- Increasing area under irrigation by accelerating ongoing projects.
- Encouragement to adopt efficient canal automation systems.
- Extensive use of micro irrigation across all varieties of crops.
- Watershed Management approach in rainfed areas.
- Pari-passu implementation of Command Area Development and Water Management (CADWM) works
- Participatory Irrigation Management.

This paper highlights the various steps taken by Government of India (GoI), various State Governments, Non-Governmental Organizations (NGOs) etc. in reforming the irrigation sector and also explores the prospects of scaling up the same to other projects.

Keywords: IPC – Irrigation Potential Created; IPU – Irrigation Potential Utilized; PDN - Piped distribution Network; MI - Micro Irrigation; Canal Automation; Solar Panels; Water Use Efficiency.

1 Commissioner (SPR), Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India. Email: kush.vohra@gov.in

2 Dy. Director (SPR), Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India. Email: mlfranklin-cwc@gov.in

The views expressed in this paper are strictly personal of the authors

SENSITIVITY ANALYSIS OF IRRRGATION CANAL CAPACITY WITH RESPECT TO FARMERS' DEGREE OF FREEDOM

R. Naghaee[1], M. J. Monem[2]

ABSTRACT

One of the reasons for poor performance of irrigation networks is the problem of water distribution and delivery methods. Among different delivery methods, on request system has higher flexibility than rotational delivery, and doesn't need high cost automatic systems of on-demand methods. On request system could be applied on existing manually operated irrigation networks with minor changes. Implementation of this method in existing networks increases the flexibility. Some effective factor in canal capacity are: Farmers' Degree Of Freedom (E), the operating time of the network (t), cumulative probability (Pq) of simultaneous operation of intakes. The main objective of this paper is sensitivity analysis of canal capacity with respect to farmer's degree of freedom to be used for on request system. For this purpose, the First Clement's model was used. For the present study, the East Aghili canal was evaluated. The First Clements' model was implemented for the wide range of variation of effective factors. For degree of freedom, the range of 1 to 8, and for duration of irrigation, the range of 2 to 24 hours was examined. According to the results the degree of freedom could be divided to 4 intervals, which have sharp different impacts on canal capacity. As the degree of freedom is increased, the irrigation could be completed in a shorte time. For higher degree of freedom (6-8) irrigation duration could be completed in 4 hours, while for low degree of freedom (1-2) the minimum irrigation time is 16 hours. The sensitivity of canal capacity for longer irrigation time is, higher. According to these results, the most suitable degree of freedom for Aghili canal is 1 to 2.

Keywords: Sensitivity Analysis, Farmers' Degree of Freedom, Irrigation canal capacity, on request method, First Clements' Model

1 PhD Student of Water Structure Engineering, Department of Water Structures, the University of TarbiatModares,
2 Full Professor, Department of Water Structures, The University of TarbiatModares,

EFFECTS OF TRAINING DURATION AND THE ROLE OF GENDER ON FARM PARTICIPATION IN WATER USER ASSOCIATIONS IN SOUTHERN TAJIKISTAN

Soumya Balasubramanya[1]

ABSTRACT

This paper examines whether longer training increases farm participation in community-managed water user associations, in a context where assignment to training duration was not randomized and none of these institutions existed before training began. We also examine whether participation is affected when farm managers migrate and leave farm operations to other workers, in a context where only managers have been directly trained, almost all managers are male, and females are increasingly operating farms. We collected microdata from 1,855 farms in Southern Tajikistan, where farm managers in 40 sub districts received longer training, while those in the other 40 received shorter training. These 'treatment' and 'control' sub districts were selected by constructing propensity scores and matching without replacement to address observable selection effects that may affect assignment to training duration. Farms were then selected from a census using a stratified random sampling process. A difference-in-difference technique with right-hand-side covariates is employed, where both sets of data were collected after training was completed. Longer training has a causal effect on increasing participation in WUAs. Results also demonstrate that when male workers not directly trained operate farms, participation is not affected; however, participation is negatively affected when female workers operate farms. These results provide evidence for designing irrigation management programs to target female workers directly, in order to strengthen institutions whose success depends on active farm participation.

Keywords: participation, training, gender, difference-in-difference; propensity-scores; Tajikistan

1 International Water Management Institute, 127 Sunil Mawatha, Pelawatte, Sri Lanka, E-mail: s.balasubramanya@cgiar.org

EVALUATION OF HAPPY SEEDER AS RESOURCE CONSERVATION TECHNIQUE IN LUDHIANA DISTRICT OF PUNJAB, INDIA

Devinder Tiwari, Harshneet Singh Sran[1], Karun Sharma, S C Sharma and Rajbir Singh[a2]

ABSTRACT

Declining water table in the Punjab State demands for development of new technologies and agronomic practices in order to enhance the water use efficiency for cultivation of different crops. Wheat being major cereal *Rabi* crop grown in more than 80 per cent of the cultivable area and require 4-5 irrigations. The first irrigation is generally applied at 20-25 days after sowing and subsequent irrigations are applied at 30-35 days interval. The requirement of water for the wheat crop varies from 210-350 mm depending upon the soil type, date and method of sowing ‘rainfall etc. After harvesting paddy, wheat crop is needed to be sown in window of 15-20 days. Due to this shorter span of wheat sowing majority of the farmers in the state resort to burn paddy straw for early clearance of the fields. To tackle the issue of stubble burning a technology was required for in-situ residue management and timely sowing of the crop. Among various *in-situ* residue management technologies, Happy Seeder technology had a major breakthrough due to its rapid expansion in the past two years. Present study was conducted in four adjoining villages of Ludhiana district of Punjab *viz* Begowal, Lall Kalan, Mallipur and Araichan, where the technology was rapidly adopted in recent years. The aim of the study was to assess the economic viability, conservation soil and water resources, impact and prospects of Happy seeder technology in the state. The responses of 150 farmers showed that this technology was easy to operate, environment friendly and economical (saving Rupees 3500/- per ha). Majority of the farmers (65%) also acclaimed that there was saving of one irrigation (70 mm) under this technology in comparison to conventional sowing. Thus average water requirement for wheat crop under this technology was lesser i.e. 215 mm as compared 285 mm required in conventional sowing. It was also found that sowing of wheat with Happy Seeder resulted in rejuvenation of soil micro-flora and fauna, reduction of weeds especially the obnoxious *Phalaris minor* to an extent of 62 percent and better crop health as compared to conventionally sown ones. However, the long-term impacts of this technology on conservation of natural resources (water and soil), flora and fauna, role of civil society in rapid adoption of technology, technology contribution towards poverty alleviation etc. needs to be further explored.

Keywords: Natural Resource Conservation, Happy Seeder Technology, Crop Residue Management

1 [*]Krishi Vigyan Kendra Ludhiana
2 [a]ICAR-Agricultural Technology Application Research Institute, Ludhiana

ENHANCING PRODUCTION EFFICIENCY AND FARM PROFITABILITY THROUGH INNOVATIVE ENGAGEMENT PROGRAMMING

Matt C. Stockton[1], Daran R. Rudnick[2], and Chuck A. Burr[3]

ABSTRACT

An innovative Nebraska Extension program titled “University of Nebraska-Lincoln Testing Ag Performance Solutions” (TAPS, www.TAPS.unl.edu) was developed in 2016 at the West Central Research and Extension Center (WCREC) in North Platte, NE, USA. This program was developed to enhance the engagement of agricultural producers in the areas of input use efficiency and profitability by providing a common platform for experiential and peer-to-peer learning with participation by University researchers, extension specialist, and industry personnel. The program hosts annual farm management competitions, where producers are introduced to and are able to use new and developing technologies, tools, methods and other resources without exposing themselves to financial risks. The TAPS Farm Management Competitions allow producers to evaluate many input and management choices, including crop insurance selection, planting density and hybrid selection, marketing strategy, irrigation scheduling and quantity, and fertilizer timing, amount, and method. This article presents the conceptual underpinnings, operational components, and outcomes of the program.

Keywords: Compétition, expérientiel learning, Extension, Peer-to-peer learning

1 Agricultural Economist;University of Nebraska-Lincoln West Central Research and Extension Center Department of Agricultural Economics;402 W State Farm Rd. North Platte, NE, USA; E-mail: matt.stockton@unl.edu

2 Irrigation Management Specialist; University of Nebraska-Lincoln, West Central Research and Extension Center, Dept. of Biological Systems Engg; 402 W State Farm Rd. North Platte, NE, USA; E-mail: daran.rudnick@unl.edu

3 Extension Educator; University of Nebraska-Lincoln, West Central Research and Extension Center; 402 W State Farm Rd. North Platte, NE, USA; E-mail: chuck.burr@unl.edu

ASSESSING CONJUNCTIVE WATER MANAGEMENT THROUGH COUPLING HUMAN AND NATURAL SYSTEM IN PAKISTAN: AN AGENT BASED MODELLING APPROACH

Mamona Sadaf[1], Abdul Jabbar[2] & Asad Zaman[3] Jelle Beekma[4]

ABSTRACT

Agriculture water demand is expected not to decline in foreseeable future. But pattern of water demand and supply are changing. These patterns present threats and opportunity in them. Initially Pakistan subsidized installation and operation of tube wells to complement surface water. Extensive groundwater development and use resulted in groundwater depletion and degradation. Farmers which have surface water available more than water demand don't use groundwater irrespective of the fact that conjunctive water use yield more output. Further, due to less or no use of groundwater causes logging in the area. Due to excessive surface water use farmer farther from canals exclusively use groundwater of poor quality with higher energy cost and hence experience loss of benefits associated with irrigation and face issue of secondary salinization. Therefore, conjunctive water management and regulation is becoming an unprecedented challenge for planners and policy makers. Current management practices ignored complexity of conjunctive ground and surface water management. Since pure analytical methods and models have been used which failed to provide sufficient explanation for individuals' decisionin irrigation water management. This study put forth the theoretical framework and conceptual for analysing the water management potential in Indus Basin through agent based modelling for farmers' behaviour under different water management strategies. Model is developed to see different type of farmer's behaviour from random to cooperative in order to assess possible outcomes of government intervention and resultant emergence of behaviour for socially optimal outcomes in water management.

Keywords: Common Pool, Agent based modelling, conjunctive water management

1 Corresponding Author: PhD Scholar, IIIE, International Islamic University, Islamabad, 44000, Pakistan Email: mamonasadaf@gmail.com

2 Assistant Professor IIIE, International Islamic University, Islamabad, 44000, Pakistan

3 Vice Chancellor, Pakistan Institute of Development Economics, Islamabad, 44000. Pakistan

4 Senior Water Resources Specialist (food security). Water Sector Group. Sustainable Development and Climate Change Department. Asian Development Bank, Manila

OASIS OF CONSERVATION AGRICULTURE IN PUNJAB, INDIA: A CASE STUDY OF HAPPY SEEDER TECHNOLOGY

Devinder Tiwari, Karun Sharma[1], Harshneet Singh, S C Sharma[2], Rajbir Singh and J S Mahal[3]

ABSTRACT

Punjab has 1.5 percent of the total land area of India and the state produces 20 and 12 percent of country's wheat and rice respectively. The state alone contributes 60 percent of wheat and 40 per cent of rice to central food grains reserves. Paddy is grown on 2.6 million ha (75% cultivable area) in the state. Out of the 20 million tonnes of paddy straw left in the fields after mechanical paddy harvesting, 15 million tonnes is burnt annually by farmers for timely and convenient sowing of subsequent sowing crop, largely the wheat. Due to such burning enormous quantity of particulate matter (especially PM 2.5) and other noxious gases are released in the atmosphere. The presence of fog during winters further escalates the problem by trapping pollutants and hampering their dispersal. In order to curb this menace the central government sanctioned Rupees 6950 million to the Punjab for the awareness drive and subsidized purchase of in-situ residue management machinery.

Among various in-situ residue management technologies, Happy Seeder technology had a major breakthrough due to its exponential expansion in the past two years. Present study was conducted in cluster of four villages viz Jatana, Katani, Mehdoodan and Begowal in Ludhiana district of Punjab where the technology was rapidly adopted. The aim of this study was to explore factors affecting adoption, impact and prospects of the technology in rice wheat cropping system. Single intervention of Happy Seeder last year in a small area of 18 ha at one location increased to 800 ha in the adjoining areas during current year i.e. 2018-19.

The lower cost of cultivation, zero burning of paddy straw, significant control of Phalaris minor etc. were the major motivational factors for the farmers to adopt this technology. Mr. Harjeet Singh, a progressive farmer and opinion leader of the area, has also played key role in ensuring rapid adoption of the technology. He not only motivated fellow farmers to gain technical assistance from the KVK but also assisted them in purchasing 26 Happy Seeders. Responses of 100 farmers showed that this technology was easy to operate, environment friendly and economical (saving Rupees 3500/- per ha) due to saving of labour and fuel, along with very low mechanical breakdown etc. It was also found that sowing of wheat with Happy Seeder resulted in rejuvenation of soil micro-flora and fauna, reduction of weeds especially the obnoxious Phalaris minor to an extent of 65 percent and better crop health as compared to conventionally sown ones. However, the long-term impacts of this technology on soil flora & fauna, natural resources (land and water), role of opinion leaders in rapid diffusion of technology and its contribution towards poverty alleviation needs to be explored further.

Keywords: Conservation Agriculture, Happy Seeder Technology, Crop Residue Management

1 Krishi Vigyan Kendra Ludhiana, PAU Ludhiana
2 ATARI, Zone-I, ICAR, PAU Campus Ludhiana
3 Directorate of Extension Education, PAU, Ludhiana

WATER SCARCITY PROBLEM TREATMENT USING PRECISION IRRIGATION TECHNIQUES ON TISZA-RIVER BASIN

János Tamás[1], Bernadett Gálya, Florent Demelezi and Attila Nagy

ABSTRACT

Over the past decades, - as in other parts of the world - the variability of the climate has increased, which has also affected the Tisza River Basin (Ukraine, Romania, Slovakia, Serbia and Hungary). Most of the climate scenarios predict an increase in water scarcity in arid areas, such as Hungary. However, the trend of annual precipitation is still very uncertain in this region. The frequency of drought has already increased significantly due to the rising temperatures, and decrease precipitation in the vegetation periods. Beside water retention measures, one of the main trends in water management is precision irrigation. However, the irrigation area is 200,000 hectares in Hungary covering approximately 2% of agricultural land, mostly with outdated irrigation technology. The task of precision water management is to optimally satisfy the current demand for water in cultivation technology. It uses automated real-time data collection and evaluation systems in the observed crop systems. It continuously processes the 2-3-dimensional hydrological water balance elements in time and controls the technical equipment for water supply or drainage. In moving systems, in addition to GPS control, sprinkler irrigation systems are able to adapt to the continuous changes in soil and plant water balance.

The aim of the research was to develop an alternative water source based water-saving precision sprinkler irrigation system on an arable land (85 ha), which is located in the reference area of the Tisza River Basin. During the research we developed a real-time eco-potential measurement methodology for water management by processing real-time remote sensed data series. Real-time water balance calculations were made and the irrigation water requirements were determined for different soil and plant conditions. Finally, we developed a real time correction based control technology of the linear irrigation systems, taking into account the agro-ecological properties of the cultivating area, where the amount of the supplied nutrient solution can be regulated at the nozzle level according to the user requirements (flow-level control l / s, speed and zone control). In this research, high precision soil maps and 3-D DEM are presented which were created to support establishing the water saving variable rate irrigation system by selecting and identifying sites for different agro technical implementations and precision management zones.

Keywords: precision irrigation system, LiDAR, water scarsity, alternative water resource

1 [1] University of Debrecen, Faculty of Agriculture and Food Sciences and Environmental Management, Institute of Water and Environmental Management; HU-4032, Debrecen, Böszörményi str. 138. E-mail: tamas@agr.unideb.hu

RESEARCH, EXTENSION SERVICES AND TRAINING AS KEY DRIVERS TO AGROFORESTRY ADOPTION IN LIMPOPO PROVINCE, SOUTH AFRICA.

Maponya P[1], Venter SL[2], Du Plooy CP[3], Backeberg GR[4], Mpandeli SN[5] and Nesamvuni AE[6]

ABSTRACT

Agroforestry is a land use system that includes the use of woody perennial, agricultural crops and animals in combination to achieve beneficial ecological and economical interactions for food, fiber and livestock production.South Africa is considered a semi–arid country, vulnerable to water stress, particularly drought, and it falls amongst the 30 driest countries in the world. The Limpopo Province's average annual rainfall is 600 mm and the threshold for rainfall agriculture is averaged at 250 mm annually. In terms of forestry, the forest plantations in South Africa use just 3% of the country's total water resources and rainfall needs to be higher than 750 mm per annum to sustain commercial forestry. However limited understanding, incorrect information and a negative mindset could hinder the adoption of agroforestry.A survey was conducted in Limpopo Province by the Agricultural Research Council (ARC), University of Venda (Univen) and Water Research Commission (WRC). The aim of the survey was to identify and describe the key drivers to agroforestry adoption in Limpopo Province. The following objectives were followed:(a) To identify and describe the characteristics of selected timber based mixed farming/agro forestry farms in Limpopo Province. (b) To identify and describe the socio-economic characteristics of selected farmers in Limpopo Province. A total of 65 smallholder farmers, spread in districts as follows, participated in the study: Vhembe (62%)40/65, Capricorn 32%(21/65) and Mopani 6%(4/65).Quantitative and qualitative designs were used as a questionnaire, stakeholder's discussion and field observations were part of the data collection. A purposive sampling technique was used to select 65 potential agroforestry farmers from the list provided by the Department of Agriculture, Forestry and Fisheries (DAFF), Forestry South Africa. Data was coded, captured, and analyzed using SPSS.The results indicated that the majority of farmers 71%(46/65)in different potential agroforestry systems in Limpopo Province had no access to research information.

The results also indicated that less than 45% (29/65) of farmers received extension services, mainly through formal extension service i.e. National, Provincial and Municipal Departments of Agriculture. This situation need improvement especially for those who are not accessing extension service. It is well known that extension service has an important role in assisting farmers to acquire new technology, skills, innovation and production advice. As part of training, demonstration trials were conducted, monitored and harvested. The areas for demonstration trials were selected based on the survey situational analysis findings, especially water, soil and climate conditions. It is therefore concluded and recommended that with good research, extension services and training, farmers have opportunities to improve their livelihoods and generate income if they could adopt agroforestry in Limpopo Province.

Keywords: Agroforestry, Adoption, Research, Extension Services, Training, Limpopo Province and South Africa.

1 Senior Researcher & Project Leader, Agriculture Research Council: Vegetables and Ornamental Plants, Pretoria, South Africa

2 Senior Manager, Agriculture Research Council: Vegetables and Ornamental Plants, Pretoria, SouthAfrica

3 Research Team Manager, Agriculture Research Council: Vegetables and Ornamental Plants, Pretoria, South Africa

4 Retired Executive Manager, Water Research Commission, Pretoria, South Africa.

5 Executive Manager, Water Research Commission, Pretoria, South Africa & Professor, University of Venda, Department of Geography and Geo –Information, SA.

6 University Registrar and Professor, University of Venda, SA.

MANAGEMENT MODEL OF MICRO IRRIGATION NETWORK BASED ON FARMER BUSINESS GROUPS

Susi Hidayah[1] And Santi Lestari[2]

ABSTRACT

The success rate application of micro-irrigation technology in Indonesia cannot be seen widely. The current application of this irrigation method in Indonesia is still very limited because there are several obstacles. Micro-irrigation requires a large initial investment as compared to other irrigation systems. The implementation of micro irrigation requires the readiness of farmers from the start of technology acceptance, the selection of plant commodities, the implementation of irrigation operations and maintenance, until the marketing of crops. This study produced a model of the farmer group business based micro irrigation network management system. The study was carried out by observing the application of micro irrigation in the established farming groups. The research step was to compile instruments for evaluating various types of farming based on the parameter group (i) land resources, (ii) human resources, and (iii) technological resources. The assessment instrument contains the weighting of these parameters to the maximum function of production. An assessment was carried out in four locations that had applied micro-irrigation in West and Central Java. The adoption of micro-irrigation technology by four groups was dominated by the introduction of micro-irrigation technology by the Government. There are groups that have mature age, stable organizations, have other business fields, so they are able to implement and develop micro-irrigation. The model of the micro irrigation network management system based on the farmer group which is organized shows the type of farm management with maximum benefits, namely the family farming business group management model.

Keywords: Management model, Farmer business group, Micro-irrigation.

1 Researcher, Exerimental Station for Irrigation, Research Center for Water Resources, Ministry of Public Works and Housing; E-mail:hidayahsusi@gmail.com

2 Exerimental Station for Irrigation, Research Center for Water Resources, Ministry of Public Works and Housing; E-mail:hidayahsusi@gmail.com

TOWARDS IMPROVED WATER USE EFFICIENCY AND PRODUCTIVITY IN COMMAND AREAS THROUGH PUBLIC PRIVATE PARTNERSHIPS – CASE OF MAHARASHTRA, INDIA

Sanjay Belsare[1], J.V.R. Murty[2] and Ajith Radhakrishnan[3]

ABSTRACT

Maharashtra has about 22.5 million hectares of cultivable area. Out of this, about 22% (5 million hectares) is irrigated through surface water, tapped and distributed through 3,700 major, medium and minor irrigation projects across the state. The average landholding of farmers in Maharashtra is approximately 1.4 hectares, with varying degrees of use efficiency and productivity.

The Water Resources Department (WRD) is responsible for developing irrigation projects and supplying bulk water up to a common point for each cluster of farms, called Chaks, covering roughly 20 to 50 hectares. In order to promote efficient water management on the farms, the Government of Maharashtra (GoM) enacted the Maharashtra Management of Irrigation Systems by Farmers Act (MMISF) in 2005. The MMISF empowers farmers within an area to form Water User Association (WUA) and manage the distribution of water in an equitable and efficient manner in their areas and also fix and collect water user tariffs. Each WUA covers an area of about 400 hectares. Earlier to adoption of MMISF, WUAs were promoted under Maharashtra Cooperative Society Act, 1960. As of date, about 5221 WUAs have been established, under both the Acts, and are functioning with varying degrees of effectiveness. Several initiatives like affordable tariffs, capacity building support, performance incentives have been designed and executed to strengthen Participatory Irrigation Management, through WUAS.

2030 Water Resources Group (2030 WRG), a technical assistance unit hosted by the World Bank, has collaborated with GoM to facilitate multi stakeholder participation in ensuring water security in the state, through Maharashtra Water Multi Stakeholder Platform (MSP). On-farm and off-farm water use efficiency and productivity, capacity of WUAs and market linkages for their produce have been identified as key areas of concern with respect to the irrigation sector. Initial efforts of the MSP started yielding results and led to participation of private sector organizations and also not-for -profit philanthropy organizations in piloting innovative models to address above issues in a few command areas. This process of attracting private sector participation in strengthening of WUAs is narrated in this paper.

Keywords: Water use efficiency, Water user associations, private sector participation, multi stakeholder platform, Maharashtra

1 Deputy Secretary, Water Resources Department (WRD), Government of maharashtra, 03rd Floor, Mantralaya, Mumbai, E-mail: belsare.sanjay@gmail.com
2 Short Term Consultant, 2030 Water Resources Group, the World Bank, Mumbai. e-mail: jmurty@worldbank.org
3 India Country Coordinator, 2030 Water Resources Group, the World Bank, New Delhi. E-mail: aradhakrishnan3@worldbank.org

ENHANCING IRRIGATION AGENCY AND WATER USERS PARTNERSHIP FOR THE REALIZATION OF A MODERN IRRIGATION SERVICE IN THE PHILIPPINES

Mona Liza F. Delos Reyes[1] and Bart Schultz [2]

ABSTRACT

Irrigation development in the Philippines is a primary mandate of the National Irrigation Administration (NIA). Participatory approaches to irrigation system management and improvements have been adopted by the NIA with farmers since the 1980s. Almost all national irrigation systems (NIS) are under joint management contracts between NIA and the respective irrigators associations (IA). Efforts to improve performance of NIS include implementation of various improvement projects on systems' physical structures and their operation and maintenance, as well as regular programs on organization strengthening and capacity building for members of IAs. These efforts left quite something to be desired as there is in several NIS still a gap between irrigation service area and the actual irrigated areas, vandalism of structures, unauthorized diversions, conflicts over water distribution, and non-adoption of field-demonstrated water-saving techniques.

To help gain understanding on causes of and identify solutions to the gap and social disharmony, sets of data on desired system features and visions of modern irrigation service, which were gathered through consultation-workshops of IA representatives of sample NIS and interviews with concerned personnel of the NIA, were analysed and compared for level of consistency and agreements.

The results of the analysis showed inconsistency of some preferred system features and the aspired quality of irrigation service both within the individual personnel and irrigation agency. Also, there were differences in the visions of and selected options for irrigation system modernization between the concerned NIA and IA representatives. The findings revealed a need to enhance appreciation of the required coherence among the desired irrigation service, system operations and flow control structures so that consensus on logical and unified methods of realizing a common vision of quality irrigation service may be reached. Also the findings are instructive of the nature and focus of capacity development programs that would foster productive NIA and IA partnerships and enhance participation of water users in irrigation system modernization, operation and maintenance.

Keywords: national irrigation system; modernisation; participatory approach; capacity development; Philippines.

1 University Researcher in Land and Water Development, IAE-CEAT University of the Philippines Los Baños, College Los Baños, Laguna, Philippines; E-mail: mfdelosreyes@up.edu.ph.
2 Prof. em. Land and Water Development IHE Delft, Delft, the Netherlands. E-mail: schultz1@kpnmail.nl

IRRIGATION ASSOCIATIONS AND PUBLIC-PRIVATE-PARTNERSHIP IN IRRIGATION DEVELOPMENT AND MANAGEMENT IN TURKEY

Aysegul Kibaroglu[1]

ABSTRACT

Turkey has been one of the pioneers in irrigation sector reform. The almost full transfer of irrigation systems to the irrigation associations (IAs) has helped to overcome some of the problems such as collection of irrigation fees. However, an increase in water use efficiency remains a challenge. Moreover, the outcomes of irrigation management decentralization particularly in terms of participatory performances of IAs display mixed results. In the early periods of devolution, IAs were established by reference to various local government laws. IAs finally gained clear legal status with the adoption of the Irrigation Associations Law which brought many facets to the decentralized structure and functioning of the IAs. However, recently, major amendments to the Irrigation Associations Law were made, which brought back significant government role and control in the administration of the IAs. On the other hand, privatization through service procurement and Build-Operate-Transfer (BOT) models was also tried to be applied in irrigation management. Yet, despite the enabling legal environment, so far, these models could not be implemented in the irrigation sector in Turkey mainly due to a lack of consensus among stakeholders.

Keywords : Irrigation Associations, Irrigation management, Irrigation development, Public-Private-Partnership, Turkey.

1 Head of Department of Political Science and International Relations, Faculty of Economics, Administrative and Social Sciences, MEF University, Ayazaga Cad. No.4 Maslak, Sariyer, 34396, Istanbul, Turkey. Email: aysegul.kibaroglu@mef.edu.tr

FARM-LEVEL PARTICIPATION OF A NOVEL WATER SAVING EDUCATION MODEL TO IMPROVE WATER USE EFFICIENCY AND IRRIGATION SUSTAINABILITY

Seul Gi Lee[1], Bashir adelodun[1], Kyung Sook Choi[2]*, Jong Won Do[3],Gwang Ya lee[3]

ABSTRACT

The behavioral and attitudinal change towards sustainable resources utilization is a daunting challenge to the management of agricultural water conservation. The free-of-charge policy on agricultural water use in Korea hinders the farmers' perception of water saving despite the prevailing scarcity of water resources and incessant drought periods. This study addresses farmers' behavioral water conservation attitude using a novel participatory farm level-based water saving education (WSE) model on agricultural water management techniques and the need to conserve finite water resources in the fields. The developed model was based on farmers' participation in agricultural water use and irrigation management at the farm level, which consists of three stages: understanding, application, and practice. The model was applied in eight selected agriculture-based villages in Korea after which a follow-up survey was conducted on participating farmers to investigate their behavior and attitude regarding water saving and the willingness to replicate water saving practices in the fields.

The findings showed that prior to model implementation, a significant lack of water saving attitude was reported among 51.1% of the paricipating farmers. However, 91% of the farmers had changed their perception on the need for watersaving after the WSE, of which 75% reportedly experienced water shortage, and 62% experienced water conflict due to water scarcity and droughts in the past. Moreover, 97% of the water resources managers agreed to the necessity for WSE training. This study shows that WSE model could be a valuable tool for policy implementation concerning the effective agricultural water conservation, precisely at the farm level to improve water use efficiency and prevent impending water conflict among the water users.

Keywords: Farmers' education, water use efficiency, water conservation, irrigation sustainability

1 Land & Water Engineering Lab., Department of Agricultural Civil Engineering, Kyungpook National University, Daehak-ro 80, Buk-gu, Daegu, 702-701 Republic of Korea Email: leesg91@knu.ac.kr;adbash2008@gmail.com

2 * Department of Agricultural Civil Engineering, Institute of Agricultural Science & Technology, Kyungpook National University, Daehak-ro 80, Buk-gu, Daegu, 702-701, Republic of Korea. Email: ks.choi@knu.ac.kr

3 Korea Rural Community Corporation, Green-ro 20, Naju-si, Jeollanam-do, Republic of Korea

DEFICIT IRRIGATION CONTRIBUTION TO IMPROVE WATER USE EFFICIENCY IN WATER SUPPLY AND UTILIZATION CHAIN

Ali Akbarzadeh[1] and Ali Shahnazari[2]

ABSTRACT

One of the main requisite for having sustainable agriculture is establishing equilibrium between resources which are consumed in crop production procedure. Water is always the primary limiting element in crop production cycle in most of the regions in the world where rainfall amount is not enough to supply plant water requirement. In this research, the effect of deficit irrigation on total water use efficiency in water supply and utilization chain has been computed. A systematic and quantitative approach was applied to determine water use efficiency. Water supply system for crop production could start with pumping from deep well, Or taking water from diversion channel from irrigation network canal. How to distribute water to the field is important practice to determine total water use efficiency in field system. Deficit irrigation strategies are used when farmers have less water than the maximum evapotranspiration (ET), and have to irrigate their fields at levels below full ET. At first glance, we just use less water than usual, so the application efficiency would be increased because most or all of the applied water remains in the root zone. But in fact, we also altered some inherent behaviors of plant compared to normal condition. Studies showed that the final product specification and quality indices are improved by applying deficit irrigation strategies.

This fact relies on the role of deficit irrigation in changing the resource partitioning pattern in photosynthesis and plant metabolism. Total water use efficiency is calculated as final product mass divided by total volume of water delivered to the field. Due to the multiplying feature of improvement in efficiencies chain in each step for calculating the overall efficiency, it is important to know how improvements in the efficiency of the steps affect the overall efficiency. For example it is demonstrated in studies that deficit irrigation during specific growth period of plants could control the excessive vegetative growth in some plants. And consequently yield efficiency would be increased. Also in plants that secondary metabolites such as essential oils are used as final product, it is proved that deficit irrigation can alter the metabolism to produce more essential oil.

In this study, the peppermint plants were subjected to regulated deficit irrigation and partial root-zone drying. Peppermint was cultivated under full irrigation (FI, control) and regulated deficit irrigation treatments including RDI85, RDI70, RDI55 and RDI40 receiving 85, 70, 55 and 40% of FI treatment, respectively; Partial root zone drying techniques including PRD70, PRD55 and PRD40 receiving 70, 55 and 40% of FI treatment in one side of root zone at each irrigation event, respectively. Four components of total wet biomass, dried biomass, leave weight and essential oil as final product were investigated. Improvements in efficiency of each step were calculated. The highest improvement in efficiency in wet biomass stage, which has not significant difference with highest yield, was corresponded to PRD70 treatment (18.6% improvement). In dried biomass section, the highest improvement in the section

1 PhD student, Irrigation and Drainage, Sari Agriculture Sciences and Natural Resources University (alipirans23@gmail.com)
2 Associate Professor, Water engineering Department, Sari Agriculture Sciences and Natural Resources University (aliponh@yahoo.com)

considering not having significant difference with highest yield was made by PRD40 treatment (27.7% improvement). The highest improvement in efficiency in leaves weight, which has not significant difference with highest yield, was found in case of RDI55 treatment (9.94% improvement). In essential oil yield step, as final procedure, highest improvements observed in PRD55 treatment with 91.95% improvement in efficiency compared to control treatment. According to the results and calculating overall efficiency, PRD55 treatment improved water use efficiency by 173% compared to the control treatment. By applying such investigations, weaknesses and strengths of deficit irrigation strategies could be revealed and actions and measures could be implemented to improve water use efficiency as much as possible.

Keywords: drought, food security, water productivity, irrigation management.

PIPED DISTRIBUTION OF IRRIGATION IN SSP: MAKING SENSE OF THE CHAOS

Kuhelika Ghosh[1]; Gyan P. Rai[2]

ABSTRACT

Piped distribution of irrigation water has helped in faster expansion of sub-minor distribution network of the *Sardar Sarovar* Project (SSP). An ITP study across six minor canal commands though shows that majority of the intended beneficiaries continue to depend on surface-lift or ground water sources for irrigation. The defunct status of WUAs, responsible for managing operation and maintenance at sub-minor level, in most of these locations raises question on the efficacy of the present participatory model. Farmers are however arranging for irrigation through private initiatives and are able to access assured irrigation using the same canal water. Is it time we provide legitimacy to these initiatives to enhance utilization of the SSP water?

1 WMI Tata Water Policy Program, Anand, India. E-mail: k.ghosh@cgiar.org

PARTICIPATORY IRRIGATION MANAGEMENT FOR WATER CONSERVATION PROJECTS IN MAHARASHTRA, INDIA

Rajesh Puranik[1] and Mohan Narkhede[2]

ABSTRACT

Maharashtra is a state located in western and central part of Republic of India, and is having six major River Basins where agriculture is practiced in 22.86 million ha area of which only about 12.5 million ha can be brought under irrigation from all sources. Both State Government and farmers have realized that irrigation assurance is the only way to save the crop failures and combat drought situation in Maharashtra. State Government has taken decisions to develop Water Users Association (WUAs) in minor irrigation schemes, Kolhapur type weirs, storage tanks etc. ensuring participatory irrigation management (PIM). Water potential developed under minor projects and other is of 1.79 million ha. from 90455 schemes. However, a bigger challenge of management and maintenance of these schemes is now realized. Farmers can ensure their participation through their legitimate and registered organizations. Water user's involvement has gain momentum through Participatory Irrigation Management and WUAs. Hence, there is a fertile time to work on public private partnership model in water resources schemes to reap mutual benefits.

This paper elaborates the efforts of public and private entities to develop and manage state water resources in participatory manner and highlight the issues of community mobilization and PIM in flagship programmes like SWC, watershed management water rich farms (Jalyukta Shivar), silt free Dams (Galmukta Dharan) and silt rich farms (Galyukta Shivar) of State Government which provides direct as well as indirect means of irrigation to farmers.

Keywords: PIM, WUAs, WRD, SWCD, WCD, PPP, MMISF-2005, MWRRA-2005, MI 1976, SWC

1 Professor and Head, Social Science Faculty, Water and Land Management Institute, WALMI Aurangabd Maharashtra State India. e mail: rajeshpuranik@gmail.com

2 Assistant Professor, Social Science Faculty, Water and Land Management Institute, WALMI Aurangabd Maharashtra State India. e mail: mohanbn23@gmail.com

IMPLEMENTATION OF PARTICIPATORY IRRIGATION MANAGEMENT AND ITS ROLE IN IMPROVING THE CEREAL WATER PRODUCTIVITY – A CASE STUDY

Reza Taghdisi Haydarian[1], and Soheila Pour Resane Manesh[2]

ABSTRACT

Active participation of farmers in operation and maintenance of irrigation and drainage networks plays an important role in improving irrigation management and sustainable agricultural production. In this regard, the project of establishing the participatory Irrigation management system in the Gareh Sou- Zarringol irrigation and drainage network in Gharebolag village in Golestan province of Iran was started in early 2017. The client of project was the regional water company of Golestan. The meta-facilitation technique based on fact-finding inquiries was used to engage the farmers. In order to implement the participatory irrigation management (PIM), measures have been taken with central role of water users association (WUA) and with the support of governmental and local organization. These actions consist of three parts: 1-Extension training on agriculture and irrigation practices 2- Regulating the system of operation 3-Empowering the existing organization (Lale kesht production cooperative). The result of the project and active participation of farmers in the participatory irrigation management was the increase in water productivity of wheat from an average of about 0.98 kg per 1 cubic meter of water to about 1.15 kg/m3 per year.

Keywords: Participatory irrigation management, Meta-facilitation technique, Water productivity

1 Project Manager of establishing the PIM system in the GarehSou- Zarringol irrigation and drainage network, Toossab Consulting Engineers Company, Mashhad, IRAN
2 Head of Irrigation&Drainage Group, Toossab Consulting Engineers Company, Mashhad, IRAN

PROMOTING PARTICIPATION FROM BENEFICIARIES IN IRRIGATION MANAGEMENT- THE CASE OF THE DAPINGDING AREA IN NANTOU COUNTY, TAIWAN

Hsieh, Sheng-Hsin[1]Chiu,Feng-Chen[2]

ABSTRACT

Irrigation and drainage facilities are the foundation of agricultural development, such systems if well planned and maintained play an important role in achieving high crop yields. Nevertheless, implementing such systems is as important as integrating agricultural technologies with production-marketing systems, setting up distribution systems, and establishing brand image for each dedicated agriculture industry zonewhich are all important policy directions for future agricultural development.

A testament to the aforementioned policy is a new irrigation expansion program initiated by Nantou Irrigation Association for the Dapingding area in Nantou County. The irrigation and water storage system for the area was first established with subsidies from Taiwan's central government. A water use group was formed within the irrigation association, in which farmers who receive water participate in water allotment practices. The government also helped the Association by setting up a monitoring and management system for flows of irrigation water. In the past two years the program has achieved its key objectives. In addition to stabilizing local irrigation water delivery, the program which resulted in income increases in the area has also attracted many younger expatriates to move back. The program has become an important case for evolution of agriculture and irrigation in Taiwan.

Keywords: Beneficiary Participation, Public Pipeline Irrigation System, Irrigation Monitoring System.

1 Director of Department of Irrigation and Engineering, Council of Agriculture, Executive Yuan. 37 Nanhai Road, TaipeiCity 10014, Taiwan;E-mail:ctcid@triwra.org.tw

2 Research fellow in Taiwan Research Institute on Water Resources and Agricultural. 19F, No. 27-10, Sec. 2, Zhongzheng E. Rd., Tamsui Dist., New Taipei 251, Taiwan; E-mail: kite6tw@triwra.org.tw

WATER USER ASSOCIATION AND SCHEME MANAGEMENT DEVELOPMENT UNDER THE TRANSFORMING IRRIGATION MANAGEMENT IN NIGERIA (TRIMING) PROJECT

Abdullahi Abdulrahman O.[1]

ABSTRACT

The paper is intended to present efforts deployed to critically reform and strengthen the Participatory Irrigation Management (PIM) in public irrigation schemes under TRIMING project (pilot) intervention in Nigeria. This is done through a technical assistance program for the Water User Association and Scheme Management Development to ensure sustainability of Operation, Maintenance, and Management (OMM) of large scale Public Irrigation Schemes that are currently performing far below expected efficiencies. The paper is a response to sub-theme 2.3 “Promoting public-private-partnership and participation of WUA in the irrigation development and management for irrigation sustainability (i.e to improve water efficiency and to reduce water conflict)” in the 3rd World Irrigation Forum (WIF3). The TRIMING Project is a seven year collaborative effort of the Federal Government of Nigeria with the World Bank to diversify the economy and create significant welfare improvements for the Nigerian citizens; the Federal Government of Nigeria (FGN) desires to achieve sustainable growth in agricultural production and productivity. Amongst TRIMING Project Development Objectives is to strengthen institutional arrangements for integrated water resources management.

Keywords: Strengthened Participatory Irrigation Management, Water User Association and Scheme Management

1 Senior Irrigation Engineer, Department of Irrigation & Drainage, Federal Ministry of Water Resources, Abuja, Nigeria, E-mail: abdulsqr@yahoo.com; engrabdulsqr@gmail.com

BIHAR MODEL OF PIM IN INDIA – SOME ISSUES

L. B. Roy[1]

ABSTRACT

Like other countries of the world, e.g. China, Sri Lanka, Philippines etc., Indian states have also developed Participatory Irrigation Management System as per their respective ground conditions. Bihar, an eastern state of India, has also developed a PIM model, as per its needs and ground conditions, which is popularly known as "Participatory Irrigation Management – Bihar Model". In Bihar against 25.74 lakh ha created irrigation potential, management of nearly 1.67 lakh ha has been transferred to respective FOs under PIM programme. Farmers have appreciated the efforts of WALMI and think that much can be achieved if Water Resource Department officers also respond adequately. FOs at channel level are formally constituted less than 20 years back except for Paliganj distributary in Sone system, and most of them have conducted adequate meetings indicating that they are active and formed their village level committees also. In terms of water distribution, farmers have reported that irrigated area has also increased. Tail end areas now receive a significantly higher fraction of water. The tail-end section of the Paliganj distributary canal serves 30.7% of the irrigable area. Before the action research, this portion of the canal received only 10 to 12% of the water diverted into the canal. It has helped in enhancing the economic return of small farmers of the area. Therefore, in the present paper Bihar PIM model with special focus on the Paliganj distributary of the Sone irrigation system in south Bihar has been described and discussed.

Keywords : Participatory Irrigation Management, Water Users' Association, Farmers' Participation.

1 Professor, Civil Engineering Department, NIT Patna. Patna – 800005, India.; E-Mail: Lbroy@Nitp.Ac.In

FARMERS' PARTICIPATION IN THE TRANSITION OF THE IRRIGATION MANAGEMENT SYSTEMS : Lessons Learned From The Wismp Program

Kuswanto Sumo Atmojo[1]

ABSTRACT

Awareness of the importance of farmers' participation has emerged since a long time in Indonesia and have succeeded in making farmers' participation as part of the irrigation sub-sector development policy. The development of farmers' participation officially became one of the important Indonesian government programs. One of them is the WISMP program which is funded with assistance from the World Bank. Many valuable lessons can be learned from the WISMP experience, including the application of models of cooperation between farmers and the government in implementing rehabilitation of irrigation schemes proven to be effective in increasing farmers' participation. There are three models of farmers and government cooperation, namely full self-management, appointment self-management and sub-contract. The sub-contract model is most widely implemented followed by the appointment self-management and the full self management models. The evaluation results of the level of farmer participation showed that the majority of WUAF (62.17%) reached high participation level, and the other half (35.65%) achieved a moderate participation level and a small percentage (2.17%) of low participation level. Institutionalization of farmers' participation faces five challenges and obstacles, firstly, the authority distribution of irrigation management according to the level of government, namely the central, provincial and district levels. Second,the separation of functions of fostering farmer institutions, technical development of irrigation and of agriculture handled by different government agencies. Third, the procurement of government services and goods regulations is less conducive for farmers's participation development. Fourth, the goverment's planning and budgets mechanism is so rigid that create hurdles for farmers' participation. Fifth, the existence and quality of government agencies' staff that are less supportive of the needs of developing farmers' participation. In the scale and scope of the WISMP project, these constraints cannot be fully overcome and even cause delays in the smooth running of activities. Greater difficulties will be faced in the environment of program and activity mechanisms that are routinely running.The urgency of developing farmers' participation is now facing new challenges arising from changes in the strategic environment. First, the increasing need of water for non-irrigation purposes which forces more efficient use of irrigation water. Second, impact of climate change and third, the rapid advancement of communication and information technology that makes easier for farmers to obtain information for farming production and marketing. Sooner or later, the need for modernization of irrigatioin as a logical response to these changes will make the issue of participation more questionable. The assumptions and principles of participation that have so far been held may have to be reviewed.

Keywords : farmer participation, irrigation modernization, socio-technical, climate change, informationn and comuniction technology.

1 Participatory Irrigation Management Expert, member of Indonesian National Water Resources Council, Vila Citra Bantarjati F4/31, Bogor City 16152, Indonesia. Email : sa.kuswanto@yahoo.com

COPING WITH CHANGE: EVOLUTION OF IRRIGATION ORGANIZATION IN TAIWAN

Yu-Chuan CHANG1[1],Ching-Tien CHEN[2], Sheng Hsin HSIEH[3],Shih-Wen CHOU[4], Kuang-Ming CHUANG[5] and Ying Jian LUO[6]

ABSTRACT

An irrigation system is a common-pool resource whose size or characteristics makes it costly, but not impossible, to exclude potential beneficiaries from obtaining benefits from its use. Especially, when the water supply is scarce and unpredictable, allocation of water is necessary to ensure that water is distributed equitably and used productively. With this concept to share the scarcity of water, development of rotational cropping and irrigation in Taiwan, particularly during the period of 1950s to 1980s had fulfilled its designated contemporary goal of producing adequate food to meet the need of that era with comparatively small amount of water. This achievement might attribute to the technical renovation on water management and heavy investment in the improvement of irrigation facilities. This practice had enabled water controllers to convince water users that the scarcity of water is being distributed equitably to a maximum extent.

Taiwan arguably has some of the best-performing irrigation systems in the world, which have made significant contributions to the country's economic development (Williams 1994; Chen 1997). Prior research suggests that the excellent irrigation performance can be attributed to the design of the country's irrigation institutions. Irrigation in much of Taiwan is governed by seventeen Irrigation Associations (IAs) – parastatal organizations are collectively owned by farmers, supervised by governments at multiple jurisdiction levels, managed by professional managers, led by local politicians chosen by farmers, and supported by a network of Irrigation Groups (IGs).Through IAs, farmers organize collective action for irrigation operation and maintenance (PIM) at the local level. This design combines professional management and government support on the one hand, and farmer participation and self-governance on the other.

Since the early 1980s, Taiwan's irrigation has been facing substantial challenges as agriculture lost its economic importance; the decline of agriculture has come with drastic changes to the country's social-political contours. As a result, irrigation in Taiwan has taken on new features including a dominance of part-time farming, an increasingly heavy reliance on groundwater, and a growing integration of irrigation into the national water management regime; all these have reduced farmers' incentives to engage in self-governing activities for irrigation management. Since 1993, the government has been paying membership fees to the IAs on farmers' behalf. As the irrigation sector is getting more and more reliant on government subsidy, the government feels obliged to impose tighter control to make sure that public money is appropriately spent. However, coordination in actual water delivery in Taiwan is maintained not by a grand plan or a pacemaker, but by an array of institutional arrangements that encourage local problem solving on one hand, and local mutual adjustments on the other.

Farmers in disparate situations can decide on how much effort they want to put in irrigation

1 Corresponding author, Professor,Hsing Wu University, e-mail: 096062@mail.hwc.edu.tw
2 Professor, National Chiayi University
3 Director, Department of Irrigation and Engineering, Council of Agriculture, Taiwan
4 Chairman, Chi-Sing Irrigation Association, Taiwan
5 Chairman, Chinese Taipei Committee, International Commission on Irrigation and Drainage (CTCID), Taiwan
6 Chairman, Taitung Irrigation Association, Taiwan

management, and their best ways to do it. The flexible institutional arrangements in Taiwan depend on the willingness of a small group of IG leaders who serve as the linkage to connec with farmers.

The worsening of climate change in recent years has brought the hydrological conditions into more extremes, and threatens the water sectors. Especially for irrigated agriculture, the irrigation land is always forced to keep fallow in order to transfer the water to other sectors. That is, traditional irrigation practices are no longer capable for the normal operation of water resources distribution, and hence new ideas are needed. The role of the IG has become increasingly important for the coordination with variability on field level. The IAs are surely aware of the situation, and have adopted measures to beef up the support and incentives for the IG leaders. In addition to find the sustainable development of Irrigation Associations, the Irrigation Associations should not confine themselves on the single service of irrigation. Instead, through diversification of the businesses by making better use of the facilities, land assets, and human resources, the financial situation of the Irrigation Associations should be significantly improved.

Keywords : Irrigation association, Self-governance, PIM, Taiwan

Papers Presented Under

SUB-THEME 3
Improving Agricultural Water Productivity with Focus on Rural Transformation

Topics

3.1 Utilizing Information Communication Technology (ICT) and innovations for Improving water productivity and maximizing agriculture production including smallholder farmers and indigenous people;

3.2 Optimizing value of water through integrated farming and market driven agriculture (i.e. labour per m^3, revenue per m^3, nutrition per m^3 etc), enhancing value chain of irrigation water to promote social economic community transformation (i.e. multifunction use of irrigation water, etc.).

3.3 Financial scheme and access development for improving agricultural water productivity in alleviating poverty in rural area.

USE OF DRONE FOR EFFICIENT WATER MANAGEMENT : A CASE STUDY

Pravin Kolhe[1] and T.N. Munde[2]

ABSTRACT

Water, which is a vital valuable, finite, renewable and shared resource demanded by several sectors, should be managed optimally. The stress due to unavailability or limited availability of water is growing at alarming rate. Irrigation sector is the biggest consumer of water as more than 80% of available water resources in India are being presently utilized for irrigation purpose, serving at just 25 to 40 % water use efficiency. Therefore, it is necessary to improve the irrigation and water use efficiency for getting maximum yield.

Drones are playing an increasing role in solving issues in agriculture and irrigation management. The use of Unmanned Aerial Vehicles (UAVs), also known as drones, and connected analytics has great potential to support and address some of the most pressing problems faced by agriculture in terms of access to actionable real-time quality data. Goldman Sachs predicts that the agriculture sector will be the second largest user of drones in the world in the next five years.

This paper presents a case study of use of Drone for mapping of command area of irrigation project in Pune region of Maharashtra State of India. The activity of drone survey was carried out on about 500,000 ha area. The objective of drone survey was to identify the crop wise area and using this information preparation of statement of water charges. The outcome of drone survey resulted in accurate estimation of area irrigated and accurate identification of crops. This helped department officials in saving in time and increased revenue. This technique brings transparency as drone images are preserved and can be verified.

Keywords: Drone in water management, Unmanned Aerial Vehicles, Information and Communication Technology, Crop Area Measurement, image processing, orthomossaic image.

1 Superintending Engineer, Water Resources Deptt., Govt. of Maharashtra, India, <pravinkolhe82@gmail.com>
2 Chief Engineer, Water Resources Department, Govt. of Maharashtra, India, <tnmunde@gmail.com>

EFFECT OF ALTERNATE IRRIGATION ON WATER AND SALT MOVEMENT UNDER MOISTUBE IRRIGATION

Zhan-yu Zhanga[11], Wei Qi[2], Ce Wang[3]

ABSTRACT

Many water-saving irrigation techniques are proposed in response to water scarcity in irrigation. Sub-surface irrigation is widely applied because it supplies water precisely and reduces surface evaporation effectively. A new type of irrigation technique—moistube irrigation was developed based on sub-surface irrigation and practiced well in China in Recent years. The major objectives of this study were to investigate the water and salt movement in soil by alternate irrigation with saline water of different mineralization degrees under moistube irrigation and to explore the potential of saline water application in moistube irrigation. Five irrigation treatments were performed using fresh water and saline water with four mineralized levels of 2, 3, 4, 6 g/L. The results showed that the mineralization degree of irrigation water had substantial effect on infiltration rate. The overall trend of infiltration could be well described by the Kostiakov empirical infiltration model despite the alternate irrigation. The propagation of wetting area in all treatments were similar, which gradually evolved from approximate circles to ellipses. The value of wetting area were in similar linear correlation with the cumulative infiltration amount in most treatments. The wetting area was significantly reduced when the mineralization degree of irrigation water was high in the first stage, which was probably due to the change of soil structure caused by high salt content. The soil moisture and salt were mainly distributed near the moistube. There was a sign that irrigating with water of low mineralization degree moved the salt near moistube to wetting edge in soil, which indicated the possibility of application of saline water in moistube irrigation and needed to be further investigated.

Keywords: Moistube irrigation, Alternate irrigation, Saline water,Wetting patterns, Water and salt distribution.

1 Professor, College of Agricultural Engineering, Hohai university. NO.1,Xikang Road, Gulou District, Nanjing 210098,China; E-mail: zhanyu@hhu.edu.cn, Zhanyu_Zhang@hotmail.com

2 Doctor,College of Water Conservancy and Hydropower Engineering, Hohai university.NO.1,Xikang Road, Gulou District, Nanjing 210098, China; E-mail:qiwei@hhu.edu.cn

3 Doctor,College of Water Conservancy and Hydropower Engineering, Hohai university.NO.1,Xikang Road, Gulou District, Nanjing 210098, China; E-mail: wang_ce@hotmail.com

OPERATIONALIZING WATER PRODUCTIVITY FOR BETTER INVESTMENT IN THE POST IRRIGATION DEVELOPMENT ERA

Xueliang Cai[1], Yasmin Siddiqi[1], Jelle Beekma[1], Wim Bastiaanssen[2]

ABSTRACT

Investment in Asia's irrigation is shifting away from expansion and rehabilitation and enters is entering a post development era of modernization. The concept of water productivity (WP) became popular as it focuses on linking irrigation water supply to crop production which is the intended output of modernization. This paper describes a framework for operationalizing water productivity in irrigation. Using remote sensing and modern information and communications technology (ICT) approach and by focusing on actual evaporation and transpiration, the framework incorporates beneficial/ nonbeneficial water uses to assess and diagnose both infrastructural and management challenges at spatial and temporal details. It can provide practical insights on actual water consumption, crop water stress, their variability, and water and non-water related contributing factors for practical investment and management. The aim is to apply research approaches to provide operational results. Pilot studies were carried out in six countries, e.g., India, Indonesia, Pakistan, People's Republic of China, Sri Lanka and Viet Nam. Results show that the framework helps not only to assess the baseline performance, but also identify factors affecting water productivity, assess the potential for improvement, and determine priority interventions. Crop patterns and irrigation infrastructure designed through a top-down approach can quickly be outdated with famers' own initiatives. A switch to high WP (expressed in USD/m^3 water used) crops are observed in Viet Nam, India, China, and Pakistan. As much as 21 times differences in WP were observed in Vietnam between traditional crops such as rice and coffee and new cash crops such as mango. The largest water savings and WP improvements exist by farmers adopting improved on farm water and land management practices. The proposed framework can be adopted by engineers and managers for performance evaluation and diagnosis for more targeted investment strategies.

1 Asian Development Bank, Manila, Philippines, 1550; xcai@adb.org
2 IHE-Delft Institute for Water Education, Delft, the Netherlands, 2611AX

WATER PRODUCTIVITY OF DIFFERENT MAIZE CULTIVARS WITH SUBSURFACE DRIP IRRIGATION

Fatemeh Heydari[1], Teymor Sohrabi[2], Hamed Ebrahimian[3*] and Hossein Dehghanisanij[4]

ABSTRACT

The objective of this research was to study water productivity of various maize cultivars under full and deficit irrigation. To achieve this purpose, subsurface drip irrigation (SDI) was used in two irrigation supply levels, including 100 and 80%, and in three cultivars of Single Crossover 704 (KSC704), Single Crossover 600 (KSC600), and Single Crossover 400 (KSC400) for producing forage and grain maize. The experiment was conducted at the research farm of the Department of Irrigation and Reclamation Engineering, College of the Agricultural and Natural Resources, University of Tehran, Karaj, Iran during June to November 2017. In subsurface drip irrigation system (SDI), the laterals were placed at 25 cm depth from the ground's surface and the experimental design was based on split plots. The results showed that supplying 80% of irrigation requirements in SDI had no significant difference on crop yield and water productivity for all corn hybrids. According to the results, hybrid of Single Crossover 704 (KSC704) had a better performance for production of forage and grain as compared to the other hybrids. Effects of crop cultivars on crop yield and water productivity are significant under two irrigation levels. Water productivity was significantly improved under supply of 80% of irrigation requirements. In treatments which were under full irrigation, for hybrids of KSC704, KSC600 and KSC400, the average quantities of biomass production was 19.52, 27.00 and 16.15 (ton/ha), average water productivity in biomass production was 3.14, 4.33 and 3.03 (Kg/m3), average quantities of grain production was 15.91, 8.43 and 14.80 (ton/ha) and average water productivity in grain production was 2.37, 1.26 and 2.33 (Kg/m3), respectively. On the other hand, these values in treatments which were under irrigation supply level of 80%, yields and water productivity of hybrids of KSC704, KSC600 and KSC400 were 18.75, 25.86 and 15.88 (ton/ha), 3.17, 4.37 and 3.05 (Kg/m3), 15.36, 8.2 and 14.1 (ton/ha) and 2.43, 1.3 and 2.35 (Kg/m3).

Keywords: subsurface drip irrigation, maize cultivars, deficit irrigation

1 Graduate student of Irrigation and Drainage, Department of Irrigation and Reclamation Eng., College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran.

2 Professor, Department of Irrigation and Reclamation Eng., College of Agriculture and Natural Resources, University of Tehran, P. O. Box 4111, Karaj 31587-77871, Iran.

3 Associate professor, Department of Irrigation and Reclamation Eng., College of Agriculture and Natural Resources, University of Tehran, P. O. Box 4111, Karaj 31587-77871, Iran (corresponding author). Email: ebrahimian@ut.ac.ir, Telefax: 00982632241119

4 Associate Professor, Agricultural Engineering Research Institute, Agricultural Research, Education and Extension Organization, Karaj 31359-13533, Alborz, Iran.

VALIDATION OF REMOTE-SENSING EVAPOTRANSPIRATION DATA OF SELECTED CROPS IN THE NILE DELTA

Atef Swelam [1], Ajit Govind[1], Mohamed Abdallah[2], Pasquale Steduto[2] and Ahmad Taha[3]

ABSTRACT

Evapotranspiration is a vital component of the water balance in arid regions and is a very important indicator of agricultural production. Many RS-based estimates are available for regional planning and policy development, but they are not rigorously validated. We conducted a study to validate the ET estimated using standard RS-based modelling platforms (WaPOR and SSEBop) using insitu monitored ET fluxes in different crops in the Nile Delta. We found that the trends and magnitudes agree but there are significant differences between the ET estimated using RS approaches and the one observed on the ground. The complex canopies architecture, such as orchards, have the biggest uncertainty vis-à-vis the nature of model parameterizations and the uncertainties in various RS-derived inputs used. In general, the orchards showed a large under estimation of ET as opposed to field crops. While SSEBop appears to perform better than WaPOR for the presented cases, there is a need for further validated using more insitu measurements and in-depth analysis of the causes of divergence.

Keywords: Evapotranspiration, Nile Delta, Arid Ecosystems, SSEBop, WaPOR, ET measurements, Validation of RS-based ET with Insitu Measurements .

1 International Center for Agricultural Research in the Dry Areas (ICARDA) Water, Land and Ecosystems Program (WLEP) Cairo, EGYPT.
2 FAO Regional Office for Near East and North Africa (FAO-RNE), Cairo, EGYPT
3 Agriculture Research Center (ARC) of Egypt, Giza, EGYPT.

A NUMERICAL MODEL FOR HYDRAULIC ENTIRE IRRIGATION CANAL SYSTEM

Natsuki Buma[1],Tetsuo Nakaya[2], Issaku Azechi[3], Masaomi Kimura[4] and So Fujiyama[5]

ABSTRACT

The authors developed a numerical model for hydraulic analyses of irrigation canal systems. The model comprises three submodels: (i) a one-dimensional unsteady open-channel flow model, including structures such as check gates, weirs, and inverted siphons; (ii) a water balance model in each paddy plot to obtain water depth; and (iii) control algorithms for check gates and turnouts. The model is applicable to open-channel systems branching into any number of lateral channels via turnouts. The developed model was applied to a paddy irrigation district in Japan. This district has a water shortage problem in the area downstream of its main irrigation canal. Discharge observations suggest that the reason for the water shortage is over-feeding into turnouts. Computational simulations were conducted to evaluate over-feeding andto test control algorithms for its prevention.Two objective domains were established for the simulations,one comprising a reservoir and a controlled turnout, the control input of which was the water depth of the reservoir, and the other comprising paddy fields fed by sublateral canals.The simulation with paddy fields showed that balanced water delivery to sublaterals and paddy plots is difficult in an open-channel system. However, the simulation with the controlled turnout showed the feasibility of using a control algorithm that uses the water level in the reservoir as input for the turnout. In future studies, the developed model will be applied to the entire canal system.

Keywords: automation, paddy irrigation, computational simulation, open channel flow.

1 Institutefor Rural Engineering, National Agricultural and Food Research Organization (NARO). 2-1-6 Kan'nondai, Tsukuba City, Ibaraki 305-8609, Japan.; E-mail: buman798@affrc.go.jp
2 Institute for Rural Engineering, National Agricultural and Food Research Organization (NARO). 2-1-6 Kan'nondai, Tsukuba City, Ibaraki305-8609, Japan.; E-mail:tnakaya@affrc.go.jp
3 Institute for Rural Engineering, National Agricultural and Food Research Organization (NARO). 2-1-6 Kan'nondai, Tsukuba City, Ibaraki 305-8609, Japan.; E-mail: issaku@affrc.go.jp
4 Graduate School of Agricultural and Life Sciences, The University of Tokyo. 1-1-1 Yayoi, Bunkyo-ku, Tokyo113-8657, Japan.; E-mail: akimur@mail.ecc.u-tokyo.ac.jp
5 Institute for Rural Engineering, National Agricultural and Food Research Organization (NARO). 2-1-6 Kan'nondai, Tsukuba City, Ibaraki 305-8609, Japan.; E-mail: fujiyamas455@affrc.go.jp

A DECISION SUPPORT SYSTEM FOR MATCHING IRRIGATION DEMAND AND SUPPLY IN A NEAR REAL TIME ENVIRONMENT

Mohsin Hafeez[1], Mahmood Ali Khan[2] and Mohammad Kaleem Ullah[3]

ABSTRACT

In Australia, recent drought conditions and climate change concerns have highlighted the need to manage water resources more sustainably especially in the Murray Darling Basin (MDB), which utilizes more than 70% of water for food production. Typically, improving water management in irrigated areas requires the analysis of real-time water demand to determine the options available to improve efficiencies in irrigation water's distribution and use whilst enhancing its utility. Real-time water demand information in irrigated areas is a key for planning about sustainable use of irrigation water as it informs decision making. These activities are needed not only to improve water productivity, but also to increase the sustainability of irrigated agriculture by reducing irrigation water losses and the environmental footprint of irrigation activities.

This paper presents an application of a holistic systematic approach of water accounting coupled with remote sensing and GIS technique at multiple scales (farms to 22 sub-irrigation systems and irrigation system) to evaluate actual water use efficiency and productivity in Coleambally Irrigation Area 'CIA' (world first gravity channel irrigation system with an area of 79,000 ha to achieve more than 90% delivery efficiency) located in the Murrumbidgee river basin, a major food bowl of the MDB. All hydrological data of inflow (i.e. surface water supplies, tube wells pumping, rainfall and capillary upflow) and outflow components (i.e. actual evapotranspiration, deep drainage, and surface outflow) were measured for all established sub-systems of the CIA. Mapping of actual water consumption from various agriculture crops was carried out using a remote sensing based algorithm (Surface Energy Balance System SEBS) and the output season actual evapotranspiration was validated with on-ground instrumentations (eddy Covariance flux tower and Large aperture scintillometers) in the study area. This paper also presents merits and demerits of using different innovative approaches (data mining, artificial neural network and remote sensing) for estimating irrigation demand and supply. Water accounting technique was applied to measure water accounting indicators across all spatial scales (farms, 22-sub-irrigation systems and irrigation systems) for two summer seasons in a Coleambally irrigation area. Overall demand forecast is more closely matched (85%) to actual water diverted during the summer seasons. Lastly, it presented an intelligent web-based decision support system using smart technology solutions (remote sensing, drones and information communication technology) to monitor and predict crop yield and water supply-demand balance for the irrigation area in a near real-time environment. The main features of the Coleambally decision support system are the introduction of various user categories with different access rights,

Keywords: Irrigation Demand forecasting, Decision Support System, Murray Darling Basin, Crop water requirement, Australia.

1 Principal Researcher and Country Representative, International Water Management Institute (IWMI)12 Km Multan Road, Lahore, Pakistan 53700; E-mail: m.hafeez@cgiar.org

2 Senior Water System Planner, WaterNSW, PO Box 1018, Dubbo, NSW 2830; E-mail: makhan_47@rediffmail.com

3 Assistant Professor, College of Civil Engineering, University of Lahore, Lahore, Pakistan; E-mail: kalimull23@yahoo.com

VOLUMETRIC CONTROL FOR CONTRASTING REMOTE-SENSING, IN SUPPORT OF HYDROLOGICAL PLANNING IN SPAIN

Tatiana Ortega[1], Jesús Garrido[2], Alfonso Calera[3] and Concepción Marcuello[4]

ABSTRACT

The Spanish General Directorate for Water hanging on the Ministry for the Ecological Transition (MITECO) is committed in the use of volumetric control for contrasting remote-sensing products as an imput for the hydrological planning process required by the Water Framework Directive (WFD). The results are temporal series maps of irrigated areas (surface) and their corresponding irrigation water requirements (net water volumes), which are based on earth observation (EO). The approach relies on dense time series of multispectral imagery acquired by the multi-sensor constellation arranged by Landsat-8 and Sentinel-2 satellites, jointly with meteorological data and hydrological and agronomic knowledge. The paper describes the operational application of these methodologies, including a preliminary approach for contrasting the modelled values of crop water requirements with actual mesurements of water consumption, registered in water-meters, what provides a valuable information for the management and planning of water resources. Hence, the outputs contribute to improve water governance at a basin scale.

Keywords: Hydrological planning, agricultural uses, water-meters, remote-sensing

1 Head of infrastructure and technology service, Ministry for the Ecological Transition. General Directotare of Water. Plaza de San Juan de la cruz s/n, 28003 Madrid; E-mail: tortega@miteco.es

2 Researcher, Remote sensing and GIS section, Regional Development Institute, Castilla–La Mancha University, Campus Universitario s/n, 02071 Albacete; E-mail: jesus.garrido@uclm.es

3 Remote sensing and GIS section Director, Regional Development Institute, Castilla–La Mancha University, Campus Universitario s/n, 02071 Albacete; E-mail: alfonso.calera@uclm.es

4 Deputy Assistant- Water Director of Planning and Sustainably Use of Water. Ministry for the Ecological Transition. General Directotare of Water; E-mail: cmarcuello@miteco.es

MEASURING SATURATED SOIL HYDRAULIC CONDUCTIVITY IN CULTIVATED AREA OF THE IRRIGATION PROJECTS IN THAILAND

Pattarapong Teerapunyapong[1], Areeya Rittima[1*], Yutthana Phankamolsil[2], and Yutthana Talaluxmana[3]

ABSTRACT

Saturated soil hydraulic conductivity (K_s) is a significant parameter especially for groundwater recharge modelling. In general, hydraulic conductivity can be measured by field measurements and laboratory test. Many field devices are used to measure in–situ infiltration rate and approximate K_s after infiltration rates are stabilized. However, measuring hydraulic conductivity in the field has also high uncertainty due to unprecedented climate conditions and surrounding environments. Therefore, laboratory test is one of the widely–used methods to measure K_s which can diminish the measurement uncertainties. Soil samples including clay, loam, and silty clay loam were collected from cultivated area of the Panomtuan, Song Phenong, and Banglen Sub–irrigation Projects, which is located in the Mae Klong River Basin, Thailand. Each soil type collected represents cultivating different crops in the different soil types; rice in clay soil, field crops in loam (sugarcane), and vegetables in silty clay loam (peppermint), and from the different soil depths of 0–0.5 m, 0.5–1.0 m, and 1.0–1.5 m Due to low soil permeability, falling head permeability test was then applied to measure K_s. However, other related soil water parameters such as infiltration rate, void ratio, field water content, saturated water content, and field capacity were also measured. These soil water parameters were signified and referred to effects of cultivation which might influence the calibration performance of groundwater flow model. Results of average K_s performed by falling head permeability test were 8.16x10^{-5} cm/hr (clay, 0–0.5 m), 2.18x10^{-3} cm/hr (clay, 0.5–1.0 m), 1.19x10^{-3} cm/hr (clay, 1.0–1.5 m), 8.34x10^{-3} cm/hr (loam, 0–0.5 m), 1.62x10^{-4} cm/hr (silty clay loam, 0–0.5 m), and 1.21x10^{-4} cm/hr (silty clay loam, 0.5–1.0 m). These results show that values of K_s depend on soil types and impact of land disturbance significantly. K_s of loam is higher than silty clay loam, and clay, respectively due to its larger pore size. The disturbance on soil structures strongly influences the decrease of K_s especially at the top layer of clay soil in paddy field. However, K_s of all soil samples are decreased along the vertical depth when non–disturbance on soil conditions is assumed.

Keywords: Saturatedhydraulicconductivity, Groundwatermodelling, Soil water parameters.

1 Department of Civil and Environmental Engineering, Faculty of Engineering, Mahidol University, Nakhon Pathom Province, Thailand; E–mail: Pattarapong.tee@student.mahidol.edu, areeya.rit@mahidol.ac.th (*Corresponding author)

2 Environmental Engineering and Disaster Management Program, Diversion of Engineering, Mahidol University, Kanchanaburi Province, Thailand; E–mail: yutthana.pha@mahidol.ac.th

3 Department of Irrigation Engineering, Faculty of Engineering, Kasetsart University, NakhonPathom Province, Thailand; E–mail: fengynt@ku.ac.th

A SIMPLE METHOD TO EVALUATE THE TOTAL PATROL LENGTH OF PADDY FIELD PLOTS FOR IRRIGATION WORK

Toshiaki Iida[1], Mutsuki Sakai[2], MasaomiKimura[3] and NaritakaKubo[4]

ABSTRACT

In paddy rice cultivation in Japan, expansion of management scale of selected pillar farmers is being encouraged by the national government. This policy inevitably induces widely scattered paddy field plots over a broader area which must be managed by fewer workers, causing considerable increase in water management labor per farmer. Thus, it is strongly recommended that paddy field plots be consolidated within a smaller area to reduce the total patrol length for water management. When a rearrangement plan of paddy field plots is considered among relevant farmers, an indicator to qualitatively show the scattering condition of paddy field plots is necessary. However, there is no simple indicator suitable for application to practical paddy field plot distribution so far. In this study, in order to estimate the labor required to patrol paddy field plots for water management, a simple method to evaluate the total patrol length was proposed. Considering the real condition of paddy field plot distribution, the sum of the minimum distances in the cluster analysis with the nearest neighbor method was applied.

It was revealed that the sum of the minimum distances between the plots was highly correlated to the actual total patrol length traced on a map, indicating the possibility to express the total patrol length by a simple linear regression equation of the sum of the minimum distances between the plots. After further analysis of the characteristics of the coefficient value of the linear regression equation using real paddy field plot distribution and randomly generated virtual paddy field plot distribution, a simple equation to evaluate the total patrol length was proposed.

Keywords: Paddy field, Irrigation work, Patrol length, Plot distribution, Cluster analysis, Minimum distance.

1 Associate Professor, Graduate School of Agricultural and Life Sciences, The University of Tokyo. 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-8657; E-mail: atiida@mail.ecc.u-tokyo.ac.jp

2 Engineer, Toban-Yosui Second Phase Irrigation Project Office, Kinki Regional Agricultural Administration Office, Ministry of Agriculture, Forestry and Fisheries. 30-19 Kandechokosokuno, Nishi-ku, Kobe, 651-2304; E-mail: mutsuki_sakai140@maff.go.jp

3 Assistant Professor, Graduate School of Agricultural and Life Sciences, The University of Tokyo. 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-8657; E-mail: akimur@mail.ecc.u-tokyo.ac.jp

4 Professor Emeritus, Graduate School of Agricultural and Life Sciences, The University of Tokyo. 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-8657; E-mail: anakubo@mail.ecc.u-tokyo.ac.jp

GROUNDWATER FLOW MODELLING FOR THE DEVELOPMENT OF MANAGED AQUIFER RECHARGE SCHEME IN IRRIGATION PROJECTS, THAILAND

Sasipong Rantasewee[1], Areeya Rittima[1], Yutthana Phankamolsil[2], and Yutthana Talaluxmana[3]

ABSTRACT

Groundwater is one of the most important natural resource to supplement uses of limited surface water for irrigation and industrial sectors especially in the Phanomtuan–Song Phenong–Banglen Sub–irrigation Projects, Thailand. Surface water in this region has been extensively used for many purposes in both the basin and *adjacent* areas. Therefore, conjuctive use of surface water and groundwater has been proposed in this area so as to utilize available water resources and to satisfy agricultural water demand. However, the overuse of groundwater can lead to the depleted groundwater availability, soil collapses, land subsidence, and saltwater contamination of the water supply, etc. Accordingly, this study aims at developing groundwater flow model using the USGS's modular hydrologic model (MODFLOW) to determine the permissible yield of groundwater and to propose the Managed Aquifer Recharge (MAR) scheme for sustainable use of groundwater in future. The geohydrological data during 2000–2016 were used as input to simulate aquifer system. Nine different confined aquifers separated by aquitard layers were identified and 2 flow observation stations established along the Tha Chin River provided input in the model. Evapotranspiration and recharge rates were estimated and identified corresponding to different landuse types. Hundreds of pumping wells having atotal pumping rate of 212 m^3/day per well were input in groundwater flow model. Model calibration was accomplished under both steady state and transient state conditions to adjust model parameters comprising hydraulic conductivity, specific yield, and specific storage. The observed head data from 20 observation wells and calculated head were compared to find deviation of model calibration. It is found that the normalized root mean square and correlation coefficient were 9.36%, and 0.96, respectively. The simulation result of groundwater budget during 2000–2016 shows that recharge rate has remained higher than the amount of groundwater withdrawal. The total permissible yield is 185,760 m^3/day which is higher than the current status of groundwater pumping quantified as 62% of total permissible yield. Moreover, 10 designated injection wells proposed at the Phanomtuan site could help increase the hydraulic head of water over the entire area.

Keywords : Groundwater Flow Modelling, MODFLOW, Phanomtuan–Song Phenong–Banglen Sub–irrigation Projects.

1 Department of Civil and Environmental Engineering, Faculty of Engineering, Mahidol University, Nakhon Pathom, Thailand; E–mail: sasipong.ran@student.mahidol.edu, areeya.rit@mahidol.ac.th (Corresponding author)
2 Environmental Engineering and Disaster Management Program, Diversion of Engineering, Mahidol University, Kanchanaburi, Thailand; E–mail: yutthana.pha@mahidol.ac.th
3 Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand; E–mail: fengynt@ku.ac.th

NARAYANPUR LEFT BANK CANAL AUTOMATION PROJECT

Sidharth Charkha[1] and V. D. Loliyana[2]

ABSTRACT

In present study, Narayanpur Left Bank Canal (NLBC) Automation System, comprises Supervisory control and data acquisition (SCADA) based automation from Dam to farmer delivery outlets supported by a robust communication system, Geographic Information System (GIS) based Irrigation Network Management Information System (INMIS).Due consideration of Indian economic, social conditions INMIS have been implemented for improving yield in command area by efficiently managing and distributing water judiciously. The system has been pioneering in its design, by the virtue of the farmers at the tail end have received water first time in the history of this canal irrigation project. The system features primarily centralized SCADA system closely integrated to GIS based INMIS for demand aggregation, water allocation and irrigation scheduling with vandalism proof Internet of Things (IoT) based integrated gates comprising of gate actuator, solar power system, level and flow control, wireless communication, security cage and robust design catering to Indian conditions.

Keywords: Farmer focused Canal Automation, Smart Irrigation, GIS, INMIS, SCADA

1 Vice President, Mechatronics Systems Private Limited, Email: sidharth.charkha@gmail.com
2 Hydrology Expert, Mechatronics Systems Private Limited, Email: virajloliyana88@gmail.com

EFFECT OF IRRIGATION, CHEMICAL FERTILIZATION, AND PROBIOTICS IN RICE FIELDS SOIL PROPERTIES

Raudha Anggraini Tarigan[1], Yu Ting Weng[2], Yu Min Wang[3] and Ying TzyJou[4]

ABSTRACT

Rice crop requires a large amount of base fertilizer through slow-release behaviour fertilizer. Implementation of the system of rice intensification with probiotics can be a potential innovation as a suitable strategy to improve soil properties and increase rice yields in an environmentally friendly manner. The aim of this study was to determine nitrogen fertilizer in the soil through impacts of two different rice cultivation methods particularly rice conventional and system of rice intensification. A field experiment was conducted in 2018 August until December. The experiment included three treatments viz. conventional method with 100% chemical fertilizer as a control, SRI method with 50% chemical fertilizer + 100% probiotics, and SRI method with 25% chemical fertilizer + 100% probiotics. Soil sample were taken from each treatments in six growth stages of rice i.e. 20, 30, 41, 62, 91, and 105 days after transplanting. Soil chemical NO_3^- was analysed by Ion Chromatography and organic content was analysed by Raman Spectroscopy. The results showed that soil texture tends to be uniform in SRI Field and NO_3^- was higher in SRI Field compared to conventional fields. Integration SRI with probiotics and chemical fertilizer can release NO_3^- that can be taken by the plants and reduce the use of chemical fertilizer by up to 75%. In conclusion, the study indicated that the SRI method with the addition of probiotics and chemical fertilizer had performed better than rice conventional. Moreover, probiotics have been contributed to support SRI method to distribute fertilizer evenly as compared with conventional method. Thus this method becomes sustainable management practice in rice field.

Keywords: System of rice intensification, Probiotics, Raman Spectroscopy, Ion Chromatography

1 National Pingtung University of Science and Technology, Taiwan,International Master Program in Soil and Water Engineering; E-mail: anggataritarigan@gmail.com
2 National Pingtung University of Science and Technology, Taiwan,Department of Biological Science and Technology; E-mail: artistting@gmail.com
3 National Pingtung University of Science and Technology,Taiwan,Department of CivilEngineering; E-mail: wangym@mail.npust.edu.tw
4 National Pingtung University of Science and Technology,Taiwan,Department of Biological Science and Technology; E-mail: ytjou@mail.npust.edu.tw

ADAPTATION OF INNOVATIVE INTERVENTIONS FOR ENHANCEMENT OF WATER USE EFFICIENCY: AN EXPERIENCE OF FARMERS' EMPOWERMENT IN SSPC

R.B. Maraviya[1], C.R. Patel[2], M.M. Vaghasiya[3], M.M. Patel[4]

ABSTRACT

Water is an elixir of life and it plays an important role in economy of any country. The demand for water among various sectors is increasing due to population growth and economic development. The severity of this issue will have direct impact on water and food security of India in future. It has become scarce in many parts of the country. Around 70 % of the freshwater is used in agriculture for irrigation and therefore, Govt. of India has adopted an approach of 'more crop per drop', undertaking various programs of water resource development and management. The impacts of irrigation relate to the changes in quantity and quality of soil and water specifically in irrigation commands are crucial for sustenance of irrigated agriculture. The problems of deterioration of soil health and environment, there by reduction of productivity is common in command areas. Soil salinity is an enormous problem for agriculture under irrigation which not only decreases the agricultural productivity but also, reduces the economic returns and affects the physicochemical properties of the soil. The pesticides are considered a vital component of modern farming, playing a major role in maintaining high agricultural productivity. However, excessive use of it could result in adverse effect on environment and human health in particular. With a view to safeguard the environment and soil health by preventive and corrective measures, the soil quality, ground water depth and quality and pesticide residue are being monitored. Appropriate strategic actions viz. mitigation measures for land affected by excessive seepage, reclamation of 'Teliyo Khar' affected land, conjunctive use of water, restricted use of pesticides has been successfully carried-out in Sardar Sarovar Project Command.

In fact, the agricultural sector has been slow and has much room for improvement to save water through educational, economic, and policy incentives. However, in command areas probably more important is the involvement of the beneficiaries in the crop and irrigation management. Relay cropping is a complex suite of different resource-efficient technologies, which possesses the capability to improve soil quality, to increase net return, to increase land equivalent ratio, and to control the weeds and pest infestation. Cotton is a main crop covering over 40 % area of the command. A recommended practice of cotton-castor relay cropping that gives one and half times higher income than sole crop has been popularised. Cumin is a distinguished 2nd crop increased by multi-fold due to availability of irrigation. The improved practices of line showing instead of broadcasting, inter cropping with Isabgul/ Ajwain, raised bed sowing and practicing deficient irrigation that gives overall 43% higher yield is also being increasingly adopted. There are evidences of water saving of 30-35% by adoption of alternate furrow irrigation and irrigation at critical growth stages. The extension approach of demonstrations, trainings, exposure visits and awareness creation programs have been successful to the large extent in adaptation of judicious use of water, chemical fertilizers and pesticides.

Keywords: Judicious use, pesticide residue, soil salinity, agricultural extension

1 Executive Director (Agriculture), Sardar Sarovar Narmada Nigam Ltd., India, E-mail: ed.cd.ssnnl@gmail.com
2 SSNNL, GoG, chirag4966@gmail.com
3 Research Associate, vaghasiyamitesh27@gmail.com
4 SSNNL, GoG, mayank.patan1988@gmail.com

OPTIMAL OPERATION OF IRRIGATION CANAL NETWORK SYSTEM USING SWMM

Na-Kyoung Bang[1], Won-Ho Nam[22*], Hyun-Uk An[33], Tae-Hyun Ha[44], and Kwang-Ya Lee[54]

ABSTRACT

Irrigation water use efficiency is a primary performance evaluation that links the efficient use of water resources during severe drought conditions. Traditional irrigation allocation problems include water distribution systems with irregular delivery rates, low irrigation efficiency, and limitations in simulating irrigation canal network. It is necessary to compare the estimated irrigation demands though irrigation canal with the actual water supply conditions. In this study, we presented the hydraulic distribution analysis of irrigation canal operation to optimizing water allocation within a deficit inthe water supply. We have identified the hydraulic analysis model for irrigation canal flow by using the Storm Water Management Model (SWMM) module by adding the network modelling and the paddy water balance at Yongseolreservoir and Mansooreservoir in Anseong, South Korea. Hydraulic simulation models could be suitable tools for understanding the hydraulic characteristics of irrigation systems. This study proposes an evaluation of current Irrigation water distribution systems and shows the ways on how to improve existing approaches using drought scenarios based on weather, water supply and inflow pattern reflecting the practice of agricultural water supply.

Keywords: Irrigation canal network, Storm Water Management Model (SWMM), water distribution, optimal water supply.

1 Department of Bioresources and Rural Systems Engineering, Hankyong National University, Anseong, Republic of Korea; E-mail: nakyoung.bang@hknu.ac.kr

2 *Department of Bioresources and Rural Systems Engineering, Institute of Agricultural Environmental Science, Hankyong National University, Anseong, Republic of Korea; E-mail: wonho.nam@hknu.ac.kr

3 Department of Agricultural and Rural Engineering, Chungnam National University, Daejeon, Republic of Korea

4 Agricultural Drought Mitigation Center, Korea Rural Community Corporation, Daejeon, Republic of Korea

4 Agricultural Drought Mitigation Center, Korea Rural Community Corporation, Daejeon, Republic of Korea

FLYING SENSORS FOR SMALLHOLDER FARMING:AN INNOVATIVE TECHNOLOGY FOR WATER PRODUCTIVITY ASSESSMENT

Jonna D. van Opstal[1], Alexander Kaune[2], Corjan Nolet[2], Jan van Til[3], and Johannes E. Hunnink[4]

ABSTRACT

Agricultural water productivity is frequently used as an indicator to determine the performance of an agricultural area. It relates both efficient water consumption and profitable crop production in one indicator, thereby aiming at achieving increased food production whilst ensuring sustainable water management in agriculture. Remote sensing technologies have been used in the past to monitor water productivity through time and space. These technologies are mainly dependent on satellite remote sensing, which have a fixed spatial and temporal resolution. Multispectral remote sensing satellite platforms can be used for providing information on the crop conditions through vegetation indices. However, the highest spatial resolution found for satellite platforms is 10 or 30 meters with a limited re-visit time at the same location. An upcoming innovative solution for acquiring information is the use of flying sensors. These are adapted drones with an additional sensor to calculate vegetation cover and evaluate stress conditions. This innovative technology has been found to be suitable especially for smallholder farming and is rapidly being adopted in several countries. With this high-resolution imagery, it is possible to distinguish cropping patterns within small fields and determine crop cover. This information is coupled with a crop simulation model (AquaCrop) to calculate crop water productivity for each field and estimate the yield gap compared to optimal (non-stress) growing conditions. This information gives smallholder farmers the spatial location of yield losses due to crop stress (water, nutrients, diseases, etc.). Crop model simulations indicated that the introduction of mulching to reduce soil evaporation resulted in an increase of water productivity by 18%. The resulting spatial maps of water productivity indicated the fields with lower water productivity. The high-resolution imagery of the flying sensors was able to detect the fields displaying uneven planting densities. Planting density can be made more homogeneous throughout the field to achieve an overall higher water productivity. The integration of flying sensor technology and crop modelling is proven to be applicable for assisting smallholder farmers in their decision-making, which is demonstrated by the example of a case study of smallholder agriculture in Mozambique.

Keywords: Water productivity, Flying Sensors, Remote sensing, Crop modelling, AquaCrop, Smallholder agriculture

1 Water Productivity Specialist, FutureWater B.V., Wageningen, the Netherlands E-mail: j.vanopstal@futurewater.nl
2 FutureWater B.V., Wageningen, the Netherlands
3 HiView B.V., Arnhem, the Netherlands
4 FutureWater B.V., Cartagena, Spain

IRRIGATION MODERNIZATION BASED ON PRECISION AGRICULTURE AND CITY FARMING CONCEPT

Andri Prima Nugroho[1], Sigit Supadmo Arif[2] and Murtiningrum[3]

ABSTRACT

The agricultural production process is closely related to the utilization of natural resources. The current challenges are: the limited availability of water which requires an agricultural system that can improve the efficiency of water use; the phenomenon of global climate change, the rapid development of the population, and the increasing of land conversion to settlements. However, the rising population presents increasing food needs. Accordingly, the concept of City Farming (CF) or Urban Farming is an option for fulfilling food needs in conditions of narrow agricultural land in urban areas. To optimize the agricultural CF production system, Precision agriculture (PA) is one approach that can be adapted to increase agricultural productivity by optimizing resource use with the use of commensurate technology. The purpose of this paper is to present the application and strategy for implementing the concept of precision agriculture which is the adoption of new technology in modern agricultural systems concerning the irrigation modernization policy at the macro level. The concept of precision agriculture is applied to optimize agricultural production processes at City Farming through activities (a) Observation of aquaculture conditions in real-time, (b) Assessment of environmental conditions with estimates of surface water loss represented by reference real-time evapotranspiration values, (c) Control of micro irrigation with various control methods, and (d) observing the response of plants to the treatment of environmental conditions to improve the knowledge of farmers. Five sub-systems that need to be considered in the strategy of implementing precision farming at City Farming are: human ware, hardware, software, info ware, and organoware. Human factors (human ware) are the foundation and driving force for mentoring agricultural activities and knowledge management systems to maintain the sustainability of food farming systems in the future.

Keywords: Precision agriculture, city farming, irrigation modernization, information technology.

1 Dept. of Agricultural & Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Jln. Flora No. 1 Bulaksumur Yogyakarta 55281, Indonesia; E-mail: andrew@ugm.ac.id

2 Dept. of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Jln. Flora No. 1 Bulaksumur Yogyakarta 55281, Indonesia; E-mail: sigitsupadmoarif@ugm.ac.id

3 Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Jln. Flora No. 1 Bulaksumur Yogyakarta 55281, Indonesia; E-mail: tiningm@ugm.ac.id

USING SMALL SCALE DESALINATION BY CAPACITIVE EIONIZATION (CDI) TO IMPROVE CROP YIELD AND PROFITABILITY IN LOCATIONS WITH BRACKISH GROUNDWATER

Clare Bales[1], John Fletcher[2] and T. David Waite[3]

ABSTRACT

Around the world groundwater sources are becoming increasingly brackish and unusable. Desalinated water can provide yield improvements to many crops however large scale reverse osmosis is often not economic or practical in remote locations. Capacitive Deionization (CDI) is an emerging electrochemical desalination process that has been trialed for potable water. It can be directly powered by photovoltaic panels due to its low voltage requirements and is easily scalable through the addition of electrodes. An agricultural cash flow model was developed that couples a crop water salinity function to a membrane CDI (MCDI) sizing model to determine farm profitability for apples, tomatoes, carrots, maize and potato under increasing bore salinity. The model was applied in a semi-arid environment 5 ha plot for apples, tomatoes and carrots and 20 ha for maize and potato. Bore salinity thresholds above which the regime is not profitable were determined as 15 dS/m for apples, 7.2 dS/m for tomatoes, 9.4 dS/m for carrots, 4.2 dS/m for maize and 3.3 dS/m for potato. MCDI desalination was found to be more profitable than brackish groundwater for apples, tomatoes (for bore salinity >4.5 dS/m) and carrots (for bore salinity >2.3 dS/m). MCDI desalination was not found to increase profitably compared to brackish groundwater for maize or potato. For locations with increasing bore salinity, MCDI desalination is a profitable option for high to medium value crops. With this system farmers may also be able to grow higher value crops that were previously unviable.

Keywords: Desalination, Capacitive Deionization (CDI), Groundwater, Crop yield, Agricultural economics

1 PhD Candidate, Water Research Centre, School of Civil and Environmental Engineering, University of New South Wales, Sydney, New South Wales, 2052, Australia; E-mail: c.bales@unsw.edu.au

2 Professor, Energy Systems Research Group, School of Electrical Engineering and Telecommunications, University of New South Wales, Sydney, New South Wales, 2052, Australia; E-mail: john.fletcher@unsw.edu.au

3 Scientia Professor, School of Civil and Environmental Engineering and Executive Director and CEO, Centre for Transformational Environmental Technologies, University of New South Wales, Sydney, New South Wales, 2052, Australia; E-mail: d.waite@unsw.edu.au

IMPROVING AGRICULTURAL PRODUCTIVITY AND WATER USE EFFICIENCY THROUGH PER DROP MORE CROP SCHEME

Pankaj Tyagi[1] and Manish Singh[2]

ABSTRACT

Water is a natural resource, which is essentially required for agricultural production. To feed the ever increasing population of country, enhancement in production from limited resources is the need of hour. Agricultural productivity can be enhanced if land and water resources are utilized efficiently, and energy is channelized properly. India has 18% of world population, having 4% of world's fresh water, out of which 80% of the exploitable water resources in the country is consumed by different agricultural activities. Irrigation is major water consuming activity in agriculture with only 38% water use efficiency with prevalent method of irrigation therefore a lot needs to be done to improve it. Pradhan Mantri Krishi Sinchai Yojana (PMKSY)-Per Drop More Crop has provided a sound framework for the expansion of Micro Irrigation coverage area of 36.20 lakh ha in scheme from 15th July 2015.. The method of irrigation followed in the country is flood irrigation, which results in a lot of water loss. Greater efficiency in irrigation can be achieved through proper designing of irrigation system for reducing water conveyance loss. Adoption of water saving technologies such as sprinkler and drip irrigation system have proven extremely effective in not just water conservation but also leading to higher yields by delivering water in a controlled manner near the plant roots where it is most efficiently absorbed. It is also observed that contrary to common perception, drip and sprinkler irrigation is more energy efficient, since it required less energy than the surface irrigation. It is concluded that adoption of an integrated approach, which takes into account soil-water-crop-climate- resources management and farm mechanization, planning and implementation of location specific, cost effective, energy efficient, sustainable, interventions/strategies are the pathways to enhance Crop, water and energy productivity.

1 Director (RFS). *e-mail:pankaj.tyagi99@gov.in,* Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Krish Bhawan, New Delhi.

2 Consultant (RFS). & manishsinghswc@gmail.com, Contact No. 9880404700 and 8840133534

NEW STRATEGY TO DRASTICALLY INCREASE WATER PRODUCTIVITY THROUGH HIGH YIELDING PERENNIAL RICE RATOONING IN GHANA

Kazumi Yamaoka[1] and Joseph Ofori[2]

ABSTRACT

Recent increase in rice consumption in Africa are noteworthy. Especially the demand for rice from Sub-Saharan African countries is steadily increasing. Consequently, the consumption of rice in the countries is estimated to increase from 19.8 million tons in 2010 to 34 million tons in 2020 (Africa Rice Center, 2011), which will result in importing 14 million tons of milled rice in 2020 and consuming a large amount of foreign currency important for the economy of the countries. Boosting domestic production of rice is a prioritized economic issue of these countries. Most of the rice production in these countries depends on an enormous number of small-scale rice farmers. Because they have a poor investment capacity to increase their cultivated area or to invest for irrigation services for higher yield per acre, it is necessary to raise the annual yield by increasing the number of annual cropping and to improve the water productivity Tropical Perennial Rice (ToPRice) farming systems (SALIBU technology) allow seven-times-harvest of paddy rice in two years by cultivating ratoon crops with high yield and dramatically low consumption of irrigation water. The authors have conducted a series of cultivation test for selecting the suitable cultivar under the farming systems in Ghana for over a year. We cultivated four African varieties and four Asian ones and harvested the main crop and its subsequent three generations of ratoon crop. Of the eight varieties in total, the average yield of SALIBU ratoon crop over 3 generations is 6 t/ha in three varieties of African species and one variety of Asian species. And all varieties scored 4 t/ha or more in yield so that SALIBU technology has shown the high practical potential as rice farming technology under the Coastal Savannah climate in Ghana. Regarding the water productivity the ratoon farming systems scored 2.1 to 5.6 times more than conventional practice. This is comparable to that of wheat and maize.

Keywords: SALIBU technology, perennial rice, African variety, Asian variety, high water productivity

1 Senior researcher, Japan International Research Center for Agricultural Sciences (JIRCAS). 1-1 Ohwashi, Tsukuba, Ibaraki Prefecture, Japan; E-mail: kyamaoka@affrc.go.jp

2 Agromonist, Soil and Irrigation Research Center, Kpong, University of Ghana; E-mail: oforijos@yahoo.com

WATER USE EFFICIENCY AND PRODUCTIVITY IN PADDY FIELD UNDER SUBSURFACE DRAINAGE TECHNOLOGY WITH SHEET-PIPE SYSTEM

Chusnul Arif[1], Budi Indra Setiawan[2], Satyanto Krido Saptomo[3], Hiroshi Matsuda[4], Koremasa Tamura[5], Youichi Inoue[6], Zaqiah Mambaul Hikmah[7], Nurkholish Nugroho[8], and Nurwulan Agustiani[9]

ABSTRACT

Waterlogging with poor drainage is the main problem of wetland in Indonesia. Subsurface drainage technology such as sheet-pipe system may offer a useful option to prevent water-logging caused significantly reduced yield or even crop failure. The primary objective of the current study was to evaluate subsurface drainage technology with the sheet-pipe system on water use efficiency and productivity in a paddy field. Sheet-pipe is perforated plastic sheets that are installed and placed horizontally in the areas at 30-50 cm below soil surface by a heavy machine mole drainer, and then after being established, the sheets formed to be a pipe with capillary holes. In this study, sheet-pipe having a diameter of 5 cm and thickness of 1 mm has been installed at a depth of 40 cm with a drain spacing of 4 m and length of 100 m covering a paddy field located in Sukamandi District, Subang Regency, West Java, Indonesia. One rice-crop season experiment was conducted from May to August 2018 in two different paddy fields., In the first field is sheet-pipe (SP field) was installed and the second field was selected without the sheet-pipe system as control (NSP field).

The fields were planted by three rice varieties with four replications. Water depth sensors were installed in those fields as along with automatic weather stations (AWS). Water balance components such as irrigation, percolation, and drainage were estimated by Excel Solver based on the change of water depth (water level) and weather parameters. In this season, the total water supply (irrigation and rainfall) was comparable among the fields, i.e., 2403 mm and 2427 mm for the SP and NSP fields, respectively. Since there is no water depth control system, water depth (water level) in the SP field was lower than that the NSP field in all growth stages. Consequently, the SP field drained 45% more water compared to the NSP field. Interestingly, grain yield was more produced in the SP field. The average rice productivities were respectively 5.77 and 5.09 ton/ha for the SP and NSP fields.

1 Department of Civil and Environmental Engineering, IPB University (Bogor Agricultural University), Kampus IPB Darmaga Bogor, Indonesia. Email: chusnul_arif@apps.ipb.ac.id
2 Department of Civil and Environmental Engineering, IPB University (Bogor Agricultural University), Kampus IPB Darmaga Bogor, Indonesia. Email: budindra@apps.ipb.ac.id
3 Department of Civil and Environmental Engineering, IPB University (Bogor Agricultural University), Kampus IPB Darmaga Bogor, Indonesia. Email: saptomo@apps.ipb.ac.id
4 Graduate School of Sciences and Technology for Innovation, Yamaguchi University, Ube, Japan. Email: hmatsuda@yamaguchi-u.ac.jp
5 Kyowa Kensetsu Kogyo Co., Ltd, Hagi, Yamaguchi, Japan. Email: tamurako@kyouwagrp.jp
6 Kyowa Kensetsu Kogyo Co., Ltd, Hagi, Yamaguchi, Japan. Email: inoue@kyouwagrp.jp
7 Indonesia Center for Rice Research, Sukamandi Field Station, Subang, West Java, Indonesia. Email: zakiaemha@gmail.com
8 Indonesia Center for Rice Research, Sukamandi Field Station, Subang, West Java, Indonesia. Email: nugroho.nurkholis@gmail.com
9 Indonesia Center for Rice Research, Sukamandi Field Station, Subang, West Java, Indonesia. Email: wulan_bbpadi@yahoo.co.id

The SP field also improved water use efficiency index and productivity. Their values were 0.26 and 1.65 g grain/kg water, respectively. The values were 15% and 20% higher than that the NSP field. Based on the current results, it may be concluded that the subsurface drainage with the sheet-pipe system could provide better soil and water conditions for rice production in wetlands .

Keywords: water productivity, subsurface drainage, sheet-pipe system, water management, paddy fields

REGULATORY APPROACH FOR SUSTAINABLE WATER RESOURCE MANAGEMENT IN THE STATE OF MAHARASHTRA (INDIA)

K. P. Bakshi and Vinay Kulkarni[1]

ABSTARCT

Maharashtra is the second largest state, located in western and central part of India. The geographical area of the State is 3.08 million ha. And the population is 112.4 million. The water sector in Maharashtra faces multiple challenges like wide temporal and spatial variations in availability of water, depleting ground water resources, low operational efficiency, growing imbalance between demand and supply, lack of assured user access to available water due to inadequate operation & maintenance of the irrigation infrastructure, conflicts between various categories of water users, degrading water quality etc. These challenges coupled with the continuously increasing demographic burden and geographical conditions create a complex socio-economic and political scenario around water governance. Traditionally, the government departments headed by politicians were managing the water resources. However, in post liberalization era, the concept of community ownership of water resources came forward and some water sector reforms took place. Water Sector Regulatory Authorities were established to ensure credibility of regulation by entrusting water related decisions on water sector experts which can work independently without political influence.

Maharashtra Water Resources Regulatory Authority (MWRRA) was been set up as an independent regulatory authority in August 2005, as per the enactment of Maharashtra Water Resources Regulatory Authority Act, 2005. This act has given a comprehensive mandate to the authority with well-defined regulatory and monitoring powers. The formation of MWRRA led to a domino effect in the water sector reforms in India. Several other states set up independent regulatory institutions. Being operational for more than a decade, MWRRA has experienced varied set of challenges in operationalizing its regulatory tools and has branched into a niche experiential knowledge in the water regulatory domain.

This paper is focused on surface water regulation and intendeds to emphasize the role of water regulator in ensuring, sustainable water resource management and showcase the various regulatory interventions done by the MWRRA such as,basin/sub-basin level equitable distribution of water, project level deficit sharing among various category of users, establishing state specific reasonable water use standards,devicing the criteria for bulk water tariff system, along with other regulatory tools such as annual water budgeting and water auditing mechanism,increasing block tariff, incentives and disincentives devised to ensure efficient use of water, resolution of disputes etc.

The paper also discusses the case study of Upper Godavari sub-basin, in which MWRRA has adjudicated the dispute between among upstream and downstream water users in the sub-basin, by devising a system for equitable and judicious allocation of water, along with the practical experiences of equitable water distribution. The paper concludes the importance of independent regulatory authority in sustainable water resource management and emphasise the need of autonomy for the regulator. The paper will provide an opportunity for sharing knowledge in water regulatory governance.

Keywords: Bulk water tariff system, Regulatory interventions, Stakeholder engagements,Water Entitlement, Water Deficit Sharing,Water Resources Regulatory Authority,

1 Member (WR Engineering), Maharashtra Water Resources Regulatory Authority, 9th Floor, Centre –1, World Trade Centre, Cuffe parade, Mumbai-400005. Email: member.eng@mwrra.i

APPLICATION OF DEEP LEARNING TECHNIQUE FOR THE DEVELOPMENT OF A WATER MANAGEMENT TOOL FOR SMALL IRRIGATION RESERVOIRS

Daisuke Hayashi[1], Tsumugu Kusudo[2], Daisuke Matsuura, Yutaka Matsuno[3] , and Nobumasa Hatcho

ABSTRACT

There are approximately 200,000 small to medium sized irrigation reservoirs in Japan that have been constructed since ancient times, especially in areas where precipitation is insufficient for crop growth. Economic growth and urbanization in the modern era have resulted in a decrease in agricultural land area, and with the aging of farmers and due to decreasing management efforts and increases in the frequency of torrential rains due to climate change, performing efficient water management of reservoir irrigation systems has become an emerging issue in many regions of the country.

This study was aimed to develop and assess a low-cost ICT (Information and Communication Technology) system for reservoir water management. The reservoir's water level and climate data were set to be transmitted to the server and displayed on the its web page in real time. When an overflow from the sluice was observed, an e-mail notification is automatically sent to users. In addition, the system is linked to a weather forecasting service to acquire information on predicted future rainfall intensities around the reservoir; it is also connected to a hydrological model that was developed by applying a Deep Learning technique (LSTM: Long Short-Term Memory) for predicting the reservoir's water level changes with given forecasted rainfall.

This system allows for water management to reduce the risk of downstream flooding, while ensuring sufficient water storage for irrigation, since it is able to determine the appropriate amount of water to be released from the reservoir prior to rainfall events. The developed system was installed and assessed in Takayama Reservoir in Nara Prefecture, Japan from 2018. The model was trained and tested using the data obtained and performed well with reasonable accuracy.

Keywords: Irrigation reservoir, Water management, ICT, Hydrological model, Deep Learning.

1 Faculty of Agriculture, Kindai University, 3327-204
2 Nakanachi, Nara, 631-8505 Japan
3 Agricultural Technology and Innovation Research Institute, Kindai University, 3327-204 Nakamachi, Nara 631-8505 Japane,E-mail- Contact:Email: matsuno@nara.kindai.ac.jp, TEL: +81-0742-43-9264.

DEVELOPMENT OF FARM-CANAL COOPERATIVE WATER MANAGEMENT SYSTEM WITH ICT

Tetsuo Nakaya[1], Atsusi Namihira[2] and Hiroyuki Taruya[3]

ABSTRACT

It is becoming increasingly important to reduce labor costs, improve the efficiency of irrigation and drainage infrastructure to conserve energy, and use water resources more effectively. Diversification of farming practices is also needed to balance demand for water with available supplies. The development of appropriate water distribution by demand-oriented water management would help to achieve these goals. This group has developed a water management system based on information and communication technology (ICT) that allows irrigators and infrastructure managers to manage water jointly. Testing of the system in a rice paddy area irrigated by pipeline revealed that both farmers and infrastructure managers could control the water supply. Monitoring and control of the water supply to a large area was easy by computer, tablet, or smart phone. in greatl improving water management. Demand-led water management could be controlled through the use of ICT strategies such as cloud computing and low-power, wide-area wireless technology. Water and electricity conservation were made possible by proportional–integral–derivative control and by estimating end-pressure control of pumps by hydraulic model analysis. Efficient demand management reduced pumping costs by 40%.

Keywords: ICT, paddy field, pipeline, SCADA, water management

1 Unit Leader, Institute for Rural Engineering, National Agriculture and Food Research Organization,Kannondai 2-1-6 Tsukuba, Ibaraki 305-8609 Japan; E-mail: tnakaya@affrc.go.jp

2 Chief Researcher, Institute for Rural Engineering, National Agriculture and Food Research Organization,Kannondai 2-1-6 Tsukuba, Ibaraki 305-8609 Japan; E-mail: namihira@affrc.go.jp

3 Professor,Kitasato University; Higashi23, 35-1,Towada,Aomori 034-8628,E-mail: taruya@vmas.kitasato-u.ac.jp

IMPROVING AGRICULTURAL WATER PRODUCTIVITY THROUGH RURAL COMMUNITY PARTICIPATION AND IMPROVEMENT OF FARMERS' FARMLAND MANAGEMENT (CASE STUDY: URMIA LAKE BASIN)

Hossain Dehghanisanij[1], Majid Mirlatifi[2], Vahidreza Verdinejad[3], Fereshteh Batoukhteh[4], Mohsen Soleymani Roozbahani[5], and Yosefali Ahmadi Mamagani[6]

ABSTRACT

Lake Urmia is located in the northwestern part of Iran. The area of the lake, however, has gradually shrunk concurrently with the decrease in water inflow since Year 2000. The principal cause of decline of the lake surface area has been reportedly attributed to chronic drought and the increase in quantity of water intake for agriculture. Accordingly, the only way to stabilize the current conditions of the lake and prevent its complete dryness is to save and supply water from the internal sources of the basin or to increase agricultural water productivity... In order to reduce agricultural water consumption, application of various agronomic and management techniques such as conservation agriculture systems, improvement of conventional surface irrigation systems, irrigation based on actual plant requirement, irrigation management, optimization of irrigation plots and etc. were investigated through the rural communication participation and improvement of farmers skills. The focus was on the knowledge transfer, green technology transfer, stakeholder participation, empowerment and increased human resource skills rather than transfer of technology and hardware. The empowerment and involvement of local communities in the rural sector and small landholders was the main indicator in this project. The project was carried out in the years of 2014-2016 for autumn and spring cultivation in 90 villages. The effectiveness of implemented techniques was studied based on water application efficiency (Ea), yield (Yc), water use productivity (WP) indicators on wheat, barley, rapeseed, garlic, and sugar beet. As a results, training and increasing farmers' skills in planning and decision-making for farm management could have a positive impact on increasing water productivity. The results indicate that water application in different treatments at farm level decreased between 5% and 45%as compared to the control. Water productivity increased in all the treatments; for example wheat water productivity increased by 14% to 63%. Increasing productivity in barley fields was between 21% and 32%. The water productivity of sugar beet increased by 39%.

Keywords: Urmia Lake, Sustainable Farming, Farmer Participatory, Water Productivity.

1 Associate Professor, Agricultural Engineering Research Institute, Agricultural Research Education, and Extension Organization, Karaj, Iran. Monitoring team, The Conservation of Iranian Wetland Project,Email:h. dehghansanij@areeo.ac.ir
2 Associate Professor Department of Water Engineering,TarbiatModdares University, Monitoring team, The Conservation of Iranian Wetland Project, Tehran, Iran.
3 Associate Professor, Department of Water Engineering, Urmia University, Monitoring team, The Conservation of Iranian Wetland Project, Urmia, Iran.
4 MSc of irrigation and drainage, Water export of Rahab Pars Company, Monitoring team, The Conservation of Iranian Wetland Project Alborz, Iran.
5 National ProjectManager, The Conservation of Iranian Wetland Project, Tehran, Iran.
6 Project Coordinator, The Conservation of Iranian Wetland Project,Tehran, Iran.

PERFORMANCE OF RING IRRIGATION SYSTEM FOR MELON BREEDING IN A GREENHOUSE

Satyanto Krido Saptomo[1], Willy Bayuardi Suwarno[2], Heru Anggara[2], Yanuar Chandra Wirasembada[1], and Budi Indra Setiawan[1]

ABSTRACT

The popularity of melon in Indonesia should be supported with superior varieties and high-quality seedsat affordable price. This requires researches in melon breeding with proper conditions for healthy growth including nutrients, environment, and water supply. Ring irrigation is one of the new methods for increasing the efficiency of irrigation, which had been previously studied for its application in a greenhouse, outdoor, as well as modeled for its performance in distributing moisture in the soil. In this study ring irrigation system was developed and applied for a melon breeding experiment in a greenhouse. The objective of the research was to evaluate the performance of ring irrigation system in its application for the cultivation of multi-variety melon in the greenhouse, including water consumption, product weight, and water productivity. Ring irrigation network developed consisting of ring-shaped emitters, manifolds, laterals water transmission pipes and Marriott-tube reservoir, to supply totally 75 plants at the beginning of the experiment, divided into three types of emitters by their discharges. The experiment was conducted in one planting season and resulted average water consumption per plant for emitter type I, II and III of 50.56 l, 73.19 l and 38.58 l. Water consumption for emitter II showed inconsistency considering the discharge design of the emitters. The number of plants survived for each emitter are 18, 15, and 16, with the total number of fruits of 16, 12 and 12 and total fruit weight of 20.52 kg, 14.84 kg and 15.81 kg. Water productivity for each emitter was 18.21 kg/m^3, 10.55 kg/m^3 and 20.17 kg/m^3. These results demonstrated the performance of ring irrigation system as it was expanded to a higher number of irrigated plants than the previous research. However, there is still a challenge to improve the uniformity of the water distribution in the irrigation network as shown in the varied total water supplied per plant.

Keywords: Water-saving irrigation, water productivity, greenhouse irrigation, horticulture

1 Departement of Civil and Environmental Engineering, IPB University (Bogor Agricultural University), Fateta IPB Dramaga Campus, Bogor, Jawa Barat, Indonesia 16680; corresponding e-mail: saptomo@apps.ipb.ac.id
2 Department of Agronomy and Horticulture, IPB University (Bogor Agricultural University), Faperta IPB Dramaga Campus, Bogor, Jawa Barat, Indonesia 16680.

IRRIGATION WATER PRICING UNDER CONJOINED WATER, SALINITY AND NITROGEN STRESSES

Farimah Omidi[1], and Mehdi Homaee[2]

ABSTRACT

In most arid and semi-arid regions of the world, cultivated soils have become saline due to lack of precipitation and irrigation with saline water. On the other hand, water scarcity and water and soil resources salinity have led farmers to apply chemical fertilizers in order to decrease the effect of water and salinity stresses and improve crop yield. On the other side, water scarcity and its importance as an intermediate good, have increased the competition for demanding water and have posed it as an economic good. So, determining the irrigation water price when deficit irrigation along with chemical fertilizers is being applied to improve water productivity is of vital importance especially when water and soil resources are scarce and saline. For this purpose, green pepper (*Capsicum Annum*) was cultivated applying four irrigation, three salinity and three nitrogen treatments which were 120, 100, 70 and 50% of crop water requirement, 0.5, 2 and 4 , 100, 70 and 50% of crop nitrogen requirement respectively. The crop yield was then collected and measured as dry matter at the end of the cultivation period. Crop-water-salinity-nitrogen production functions were derived and then irrigation water price was calculated in order to optimize irrigation depth, and to calculate irrigation efficiency and water productivity. The results indicated that increasing salinity in each irrigation treatment, decreased water price. Also, increasing salinity along with increasing nitrogen application decreased water price. But, water stress affected water price more than salinity stress and nitrogen treatments respectively. Regarding to the results, applying 50% of crop water requirement with the salinity of 0.5 to 2 and 100% of crop nitrogen requirement, maximized irrigation efficiency (IE). But, applying 70% of crop water requirement with the salinity of 0.5 to 2 and 100% of crop nitrogen requirement, maximized water use efficiency. Also, Physical, physical-economical and economical productivity decreased in all irrigation treatments with salinity increases. All the conducted results also indicated that the salinity threshold value is 2 for green pepper (*Capsicum Annum*). In addition, to apply 100% of crop nitrogen requirement when deficit irrigation was implemented decreased crop yield and water productivity consequently. The results concluded that water pricing method is of vital importance in water stressed regions. Also, supervising on farm scale based on irrigation optimization results can improve water productivity and enhance water consumption in an ascending trend.

Keywords: Nitrogen, crop production functions, irrigation water depth optimization, irrigation efficiency, economic productivity, simultaneous abiotic stresses

1 Ph.D. Scholar of Irrigation Science and Engineering, Tehran, Iran. Email: farimahomidi@ymail.com, *Corresponding Author

2 Professor, Irrigation and Drainage Department, Agriculture and Natural Resources Campus, Tarbiat Modares University, Tehran, Iran. Email: mhomaee@modares.ac.ir

ENHANCING WATER PRODUCTIVITY IN WHEAT THROUGH IN-SITU RICE RESIDUE RETENTION BY HAPPY SEEDER IN NORTH-WESTERN INDIA

Rajbir Singh[1] and A.K.Singh[2]

ABSTRACT

The rice-wheat system (RWS) is the most prevailing production system in North-Western (NW) states of Punjab, Haryana and western Uttar Pradesh, recognized as heartlands of Green Revolution which contribute bulk of rice and wheat in the national food basket. Cultivation of high yielding varieties of rice and wheat produces about 34 MT of paddy straw in this region of which Punjab alone contributes about 65%. It is estimated that in NW states of India about 23 MT of rice residues are burnt in the field as an easy and quick method of its disposal. Burning crop residue causes pollution problems in the atmosphere and huge nutritional loss and soil physical health deterioration. About 80-90% of N and S and 15-20% of P and K contained in rice residue are lost during burning. Total amount of N, P, K and S in 23 MT of rice residue is about 0.7 MT. Therefore, burning of 23 MT of rice residues will lead to a loss of about 9.2 MT of C equivalent to a CO_2 load of about 34 MT per year and a loss of about 1.4×10^5 t of N (equivalent to 3 million US Dollar, USD) annually. The science based evidence suggests that *in-situ* retention of crop residues can play an important role in buffering soil moisture and temperature (adaptation to climate risks), replenishing soil nutrients and organic matter, in addition to reducing environmental footprints (mitigation of greenhouse gas emissions, GHGs). Happy Seeder has been recognized as a key technological innovation for direct seeding of wheat in standing stubbles. Demonstrations on Happy Seeder were laid out in a systematic approach at research farm of Agriculture Science Centres popularly known as Krishi Vigyan Kendras (KVKs) and selected strategic locations in 16 districts of Punjab. A total of 675 and 962 demonstrations were laid out precisely during 2015-16 and 2016-17 respectively at these locations. The results of these demonstrations revealed a saving of 59.8 mm and 64.6 mm of irrigation water during 2015-16 and 2016-17, respectively in happy seeder sown wheat compared to conventional wheat cultivation resulting into saving of average 19.7 % of total irrigation water. The water productivity of direct-seeded wheat with Happy Seeder was found to be 20.7 kg/m^3 compared to 16.1 kg/m^3 with conventional wheat cultivation practices resulting into 28.6 % improvement in water productivity. Similarly, direct seeding of wheat with Happy Seeder resulted into net profit of INR 6500/ha. During 2018, Government of India has initiated Central Sector Scheme on *In-situ* Residue Management for promotion of mechanization with an outlay of 170 million USD for two years which had impact on scale covering about 0.8 million hectares area in Punjab and Haryana during 2018. If two million hectare area is covered under Happy Seeder in next two years under RW system in Haryana and Punjab states, this would result into saving of 1.1 billion cubic meter (BCM) water and net saving of 13 billion INR.

Keywords: Happy Seeder, Water Productivity, Direct-seeded Wheat, *In-situ* Retention, Paddy Straw

1 Director, ICAR-Agricultural Technology Application Research Institute (ICAR-ATARI), PAU Campus, Ludhiana-141004, Punjab, India; E-mail: rajbirsingh.zpd@gmail.com

2 Deputy Director General (Agri. Extension), ICAR, KAB-1, New Delhi-110012, India, E-mail: aksicar@gmail.com

DROUGHT ANALYSIS TO SUPPORT URBAN AGRICULTURE IN WANGGU CATCHMENT AREA, INDONESIA

Fajar Baskoro Wicaksono[1], Arbor Reseda[2], Eka Nugraha Abdi[3] and F.X. Suryadi[4]

ABSTRACT

Wanggu River is part of the Wanggu catchment area, Poleang WS - Roraya. Wanggu River passes through South Konawe District and Kendari City. Kendari is the capital city of Southeast Sulawesi Province. FAO (2017) issued data on per capita vegetable consumption per year from 1961 to 2013 for Indonesia which showed an upward trend with an average increase of 2.2% per year. The Indonesian Central Bureau of Statistics (2016) showed that vegetable consumption in Southeast Sulawesi Province is above the national average vegetable consumption. Urban agriculture may be one solution to overcome the increasing consumption of agricultural products and also the trend towards urbanization of population in developing regions..

Drought analysis might help to determine which plants are suitable for urban agriculture. Drought analysis in this paper uses the deciles and theory of run methods. Deciles method can show how severe drought in previous years. Theory of run method can provide information about the beginning and end of the drought period, drought return period, and the effect of the drought on the planted type of crop.

Crop water needs are used based on FAO (1986) for cabbage, soybean and tomatoes. The crop water needs used in this simulation are assumed to be the highest crop water needs with the longest crop duration. For paddy and secondary crops, a drought analysis with the “theory of run” method is also carried out. Crop water needs are used in accordance with the results of the study by Oldeman (1980).

Deciles method shows that drought had occurred in Wanggu Catchment Area in 1996, 1997, 1998, 1999, 2001, 2009, 2011 and 2012. Drought analysis with the theory of run method which is done on those five types of plants, cabbage has the shortest duration within longest average duration of drought which is 5 months and the smallest average drought intensity which is 78.19 mm/month. Suitable planting period for cabbage cultivation is in the period of December-January-February-March and April-May-June-July. This result shows that cabbage cultivation is suitable for the application of urban agriculture because of the small possibility of crop failure due to drought.

Keywords : Drought, Decile Method, Theory of Run Method, Urban Agriculture

1 Directorate General of Water Resources, Ministry of Public Works and Housing Republic of Indonesia; E-mail: fbwicaksono@gmail.com
2 Directorate General of Water Resources, Ministry of Public Works and Housing Republic of Indonesia; E-mail: arbor.reseda@gmail.com
3 Directorate General of Water Resources, Ministry of Public Works and Housing Republic of Indonesia; E-mail: enugraha@hotmail.com
4 Department of Water Science and Engineering, IHE-DELFT Institute for Water Education, Delft, the Netherlands; E-mail: f.suryadi@un-ihe.org

AT FARM LEVEL UNDER PUBLIC AND CIVIL CANAL IRRIGATION SYSTEMS IN PESHAWAR VALLEY

Rabnawaz[1], Muhammad Jamal Khan[2], Tahir Sarwar[2], Muhammad Jamal Khan[3]

ABSTRACT

Agriculture consumes more water than any other human activity. In Pakistan, the contribution of irrigated agriculture is more than 90%, thus the sustainable water supply to meet the food and fibre demand of the ever increasing population is a big challenge. Increase in crop water productivity (CWP) is one of the most important options for sustainable use of water resources in semi-arid environment. A field study was conducted during *Rabi* 2010-11 and *Kharif* 2011 crop seasons to compare the CWP of main crops (sugarcane, wheat, maize and tomato) under public and civil canal irrigation systems in Peshawar Valley. For this purpose, 18 farms were selected under public canal system and 13 under civil canal systems. Results revealed that average CWP of wheat, maize, sugarcane and tomato was 0.96, 1.11, 3.31, 3.61 kg m^{-3} under public and 0.90, 0.77, 2.36, 2.98 kg m^{-3}, respectively. In public canal system, the average CWP of the selected crops was 7, 40, 44 and 21% higher than civil canal system, respectively. Low CWP in civil canal system was mainly attributed to over irrigation (because of high water allowance).

Quantitative analysis of the yield per unit volume of water applied was carried out using dummy-regression model. The difference in means for maize, sugarcane and tomato crop was found highly significant while in case of wheat it was non-significant. This study concludes that the public system remained more productive with high CWP at farm level for all the major crops. However, there is a great potential for increasing CWP under civil system by rationalizing the water allowance.

Keywords: Crop Water Productivity, Public Canal System, Civil Canal System, *Rabi*, *Kharif*

1 On Farm Water Management Department, Govt. of Khyber Pakhtunkhwa, Peshawar
2 Department of Water Management, The University of Agriculture, Peshawar
3 Department of Soil and Environmental Sciences, The University of Agriculture, Peshawar, *Corresponding author: Rabnawaz, Address:On Farm Water Management Department, Govt. of Khyber Pakhtunkhwa, Peshawar, Telephone: +92-91-9216257; Fax: +92-91-9216984, E-mail: drabnawaz97@gmail.com

COMMUNITY WATER RESOURCES MANAGEMENT IN THAILAND

Chataramongkol Singhawiboon[1], Wongsathit Boonthunyakorn[2], and Jumpol Nimpanich[3]

ABSTRACT

Water is one of the most important natural resources for human being and wildlife all over the world. The physical planet has changed and we have recently seen a number of unwanted developments: global warming, climate change, greenhouse effect,el nino event, la nina event, drought and others, these changes have made the available volume of water unstable. Furthermore, the increse of the world population will increase from 7.2 to 9.2 billion people in the next 31 years that can have impacts on water and food security.So the important world and Thai organizations are concerned on how to manage water resources. The hypothesis of this research was that the communities could manage the water resources by themselves. And the objectives of this research were 1) To study and value the community in water resources management, 2) To study the roles and responsibilities of community in water resources managementand and 3) To find “Community Water Resources Management ways” in order to develop thecommunity best practices.

This research design was a qualitative study, the following research tools were based on Walter Wallace Wheel’s Diagram, documentary research and indepth interview from the Key-informants divided into three groups. The first group was the twenty-five farmers who were continuously engaged in water resources, the second group was two members of private sector organization involved in commercial water resources management and the last group was fourteen government officials with expertise in water resources management.

The four research areas were used as follows. The first area was Loa CheeKui village located in the North of Thailand. The second was Don Rug village located in the South of Thailand. The third was Huy Ta Klae village located in theCentral of Thailand. And the last was KraSeaw Dam located in theCentral of Thailand.

The research has shown that civil society, the private sector and the public sector needed to work together to find solutions to water resources and food security. And the communities themselves should hold the core of water resources management and food security to avoid the watercrisis in the near future.

Keywords: Community, WaterResources, Mangement

1 Ph.D. of Public Administration and Irrigation Engineer of Royal Irrigation Department of Thailand. Email: chatara039@gmail.com

2 Ph.D. Candidate of Public Administration of Rangsit University and Irrigation Engineer of Royal Irrigation Department of Thailand.

3 Associate Professor Doctor of Rangsit University.

APPLYING APSIM FOR EVALUATING INTERCROPPING UNDER RAINFED CONDITIONS: A PRELIMINARY ASSESSMENT

Vimbayi Grace Petrova Chimonyo[1], Albert Thembinkosi Modi and Tafadzwanashe Mabhaudhi

ABSTRACT

Climate change and variability in rainfall pattern have amplified the effects of water scarcity in agriculture in semi-arid regions. Intercropping can improve crop productivity through increased water use efficiency (WUE). However, limited information exists to support its adoption and promotion. The Agricultural Production Systems Simulator (APSIM) model was used to develop best management practices for improved yield and WUE for a sorghum–cowpea intercrop system at Ukulinga Research Farm, Pietermaritzburg, South Africa. We considered planting dates, fertilizer application rates and irrigation. For both sorghum and cowpea, ideal planting date for high and stable yields [559.7 kg ha^{-1} (± SD 258.42).and 220.7 kg ha^{-1} (± SD 79.58), respectively] was 15 November. Adding fertilizer did not improve yield but increased WUE of the intercrop by 5.08%. Deficit irrigation was more effective at increasing yield (12.84%) but reduced WUE (-16.79%). APSIM can be used to develop best management practices for improving productivity of sorghum-cowpea intercrop systems under limited water conditions.

Keywords : Climate variability, Intercropping, Irrigation, Water Use Efficiency

1 Centre for Transformative Agricultural and Food Systems, School of Agricultural, Earth and Environmental SciencesUniversity of KwaZulu-NatalPietermaritzburgSouth Africa

IMPACT OF JAIN IRRIGATION'S AGRI BUSINESS MODEL ON ENVIRONMENT

Dilip N. Kulkarni1

ABSTRACT

Jain Irrigation' Agribusiness model is socially responsible and environmentally conscious. The mission statement of the company, which was coined in late 70s states that "Leave this world better than you found it" conveys the philosophy behind the business policy of Jain Irrigation and all the actions and business activities of the company are leading to a sustainable business. All the products that company manufactures and all its business activities lead to conservation and preservation of natural resources and environment. Water creation and conservation through rain water harvesting, efficient on farm storage of water and water conveyance through pipes saves water by preventing leaching out and evaporation which happens in open canal system. Micro irrigation saves water to the extent of 50-60% depending upon soil type helps in conserving water which could be used for irrigating more land thus helping in solving food security related issues and making available more water for drinking and for industrial activity. Presently 82% of all the available water is used for agriculture and 40% of India's agricultural land is irrigated mostly by flood irrigation with a water use efficiency of only 35%. Micro Irrigation can save 50% of this water which will not only fulfill the need of population for drinking and domestic use and industrial requirement but also can be used for bring additional land under irrigation thereby increasing crop productivity. Jain Irrigation promotes Good Agricultural Practices through its Jain GAP program bringing safety, hygiene, sanitation and traceability in agriculture. This program leads to judicious use of agricultural chemicals and the system of scientific methodology of handling. Jain irrigations energy division has developed strong renewable energy development program in bio-energy through plant and agri waste and also through its solar energy program. Solar pumps manufactured by Jain Irrigation are becoming a boon to energy starved farmers. Jain Irrigations business focus has been on Sustainable Agriculture, Water Use Efficiency and Production and Use Renewable Energy. All these business activities conserve natural resources and protect the environment to make it better than we found.

1 President-Sustainable Agriculture, Jain Irrigation Systems Limited, Jain Hills, Shirsoli Road, Jalgaon 425001, MS, India Email ID – dr.kulkarni.dilip@jains.com

WATER AND ENERGY FOOTPRINT IN A DRIP IRRIGATED AND SPRINKLER FROST PROTECTED BLUEBERRY CROP IN CONCORDIA, ARGENTINA

Alejandro Pannunzio[1], Eduardo Holzapfel[2],Pamela Texeira[3], Javier Brenner[4], Francisco Dufour[5], and Gerardo Demarco[6]

ABSTRACT

Yield, Water and Energy footprint was measured in a Snowchaser variety of blueberry (Vaccinium corymbosum L.) commercial crop of 30 ha of 10 years old in Concordia , Entre Ríos province, Argentina. The crop is planted in rows separated 3.5 m and the plants at 75 cm. The crop is irrigated by a drip system with two laterals of drip tubes per each line of crop. Drippers are at 30 cm of distance with a flow or 1.1 liter per hour. The system is operated by a submergible pump with an electrical motor of 60 kilowatts, working on well of 60 meters depth. The crop is protected of the effects of frosts by a sprinkler systems, giving 3 mm per hour of precipitation. To protect the crop the system must works beginning before the temperature is below zero degrees Celsius and continuously till all the ice formed during the nights over the plants is liquified. That means a pumping requirement of 900 cubic meters per hour of instant flow, provided by 4 wells with turbines pumps, working simultaneously and moved by diesel engines. The objective is to quantify the fresh fruit harvested, the water footprint and the energy footprint per year from 2010 to 2018. Energy footprint is divided in blue energy footprint and grey energy footprint. The blue energy footprint was measured in watts per kg of fresh fruit produced and the grey energy footprint in centiliters of gasoil per kg of fresh fruit, that´s because irrigation system works with electrical energy and the anti-frost system with diesel engines. Average yield of the crop was from 2010 to 2018, of 11,14; 11,72; 12,60; 11,01; 13,15; 16,41; 13,53; 10,70 and 9,4 ton per ha respectively. Water footprint of the 30 has was 981, 350, 257, 243, 196, 266, 209, 265 and 318 liters of water per kg of fresh fruit from 2010 to 2018 respectively. Blue energy footprint was 37, 23, 11, 12, 12, 18, 22, 29 and 27 watts per kg of fresh fruit from 2010 to 2018 respectively, while Grey Energy footprint was 27, 8, 10, 9, 2, 7, 3, 3 and 3 centiliters of gasoil per kg of fresh fruit.

Keywords: Water management, water footprint, energy footprint, blueberry.

1 M. Sc, Head Professor, University of Buenos Aires, Av. San Martin 4500, Buenos Aires, Argentina. Mobile: +549-11-5422-3000. pannunzio@agro.uba.ar
2 PhD, Prof. Centro de Recursos Hídricos para la Agricultura y la Minería, Chillán, Chile. eholzapf@udec.cl
3 Eng., University of Buenos Aires, Av. San Martin 4500, Buenos Aires, Argentina. texeira@agro.uba.ar
4 Eng., University of Buenos Aires, Av. San Martin 4500, Buenos Aires, Argentina. brenner@agro.uba.ar
5 Eng., University of Buenos Aires, Av. San Martin 4500, Buenos Aires, Argentina. dufour@agro.uba.ar,
6 Eng., University of Buenos Aires, Av. San Martin 4500, Buenos Aires, Argentina. demarco@agro.uba.ar

NUTRIGATION TO ENHANCE THE CROP YIELD BY SOLAR POWER

Kinge Manisha[1], Pachpande Sagar[2] and Yewalekar Dilip[3]

ABSTRACT

Yield of crop is the function of irrigation and nutrients. Nutrigation is a simple term coined two words nutrient and irrigation. Currently in spite of placing up modern irrigation (Drip/ Sprinkler) system, growers (farmers) are till believing on more water means more yield rather than focusing on nutrient application and nutrigation efficiency. Means growers till following traditional way of fertilizer application to partially good & bad way of fertigation. There are number of equipment available for injection of fertilizers such as venturies, fertilizer tanks, dosing pumps, injectors mainly working at pressure differential principle engendered manually with certain constraints:

- Inconsistent mixing of nutrients in water resulted in leaching off valuable nutrients.
- Optimum pH & EC level of nutrients, resulting asymmetrical nutrient uptake rate.
- Toxicity increases in plant; this fact is normally ignored by many of us, if it goes beyond the limit, leads to formation of toxicity in plant, soil and ground water as well. One of the examples is soils in Punjab, Haryana, Maharashtra, and Gujarat has turned to sodic and hardly to grow any crops because of excess application of fertilizers.
- 30-60% wastage of fertilizers.
- Overall input cost increases significantly.
- Less Nutrigation efficiency resulted in substantial reduction in yield.

Solar Powered Nutrigation System (SPNS) plays important role to plug up the gap between irrigation and nutrients. In SPNS, nutrients are vaccinated along with irrigation water in pulses at desired pH & EC in order to match up the nutrient up rate of crop without creating the toxic effect to soil, water and plant. Photosynthesis process takes place in day time; obliviously nutrients must be applied during photo period only along with irrigation water. Since solar radiation is harvested in day time, the entire nutrigation to crops has to be concluded in day time, to enhance the photosynthesis process which may result in faster growth and increase in yield. Required nutrients application is to be clubbed with irrigation demand of crops based on the fluctuation of solar radiation from morning to evening and season to season. The present article throws light on the use of Solar Powered Nutrigation System to increase nutrigation efficiency and enhancing crop productivityalong with case study.

Keywords : Nutrigation, Nutrients, Solar powered, Drip, Sprinkler, EC, pH, Venturies

1 Project Engineer Overseas, Jain Irrigation Systems Ltd. P. O. Box 72, National Highway No.6, Bambhori, Jalgaon, Maharashtra India 425001, E-mail: kinge.manisha@jains.com.

2 Project Engineer Overseas, Jain Irrigation Systems Ltd, P. O. Box 72, National Highway No.6, Bambhori, Jalgaon Maharashtra India 425001, Email: Pachpande.sagar@jains.com.

3 Vice President Overseas Business, Jain Irrigation Systems Ltd, P. O. Box 72, National Highway No.6, Bambhori, Jalgaon Maharashtra, India 425001, Email: yewalekar.dilip@jains.com.

AGRICULTURAL REVISION IN DROUGHT PRONE ARID REGION OF KUTCH: PEOPLE LED, MARKET ORIENTED GROWTH UNDER ADVERSE CLIMATIC CONDITIONS

Praharsh Patel[1]

ABSTRACT

Water availability and soil suitability are the primary requirements for stable agricultural production. Due to erratic rainfall and lack of irrigation for agriculture, arid regions suffer from volatile conditions for agriculture. Kutch, the western most district of India in the state of Gujarat is well-known for its arid climate. More than half of its land is either partially inundated by sea water or classified as desert making it unsuitable for agriculture. The remaining land mass experiences low (15 Year Annual Normal = 450 mm) and erratic (45 per cent Coefficient of Variation) rainfall making agriculture in the region, not a very promising occupation. But, in recent years due to access to irrigation through groundwater, the advent of micro irrigation practices and increasing market-oriented crops supported by good rainfall spell for over one decade starting from 2003 have led to significant improvement in agriculture for the District of Kutch. There has been a significant shift towards less water-intensive high-value horticulture crops making it one of the horticulture hot spots in the Gujarat state.

This paper makes a data-based assessment of the agriculture in Kutch to study the transition into different non-traditional high-value crops. It also synthesizes major findings of the field exploration carried out to understand the key success factors in horticulture and the adoption of technology for micro-irrigation creating a higher value chain of the water used. The findings show promising outcomes for less water-intensive farming as well as high-value crops along with highlighting a few hurdles which have to be addressed for smoothly taking up drought resilient and market-oriented agriculture in adverse climatic condition.

Keywords: Adaptation strategies, Agriculture in Adverse climate conditions, Innovative crop water practices, Agriculture in an arid region, Kutch.

1 Research Consultant, IWMI-Tata Water Policy Program, Anand; Email: p.patel@cgiar.org

SPECIALIZED NITROGEN FOR IRRIGATED CANOLA (*BRASSICA NAPUS*) IN SASKATCHEWAN

Gary Kruger, PAg[1], Joel Peru, PAg[1], Garry Hnatowich[2], Scott Anderson[3], Rigas Karamanos[4], Kaitlyn Gifford[5], and Murray Kasper[6]

ABSTRACT

Canola (*Brassica napus*) is the most widely grown irrigated crop in Western Canada. It is strongly responsive to applications of nitrogen and is fertilized with the highest application rates of the major crops grown in the region. Potential for reduced losses of nitrogen is the greatest for this crop in Canadian irrigated production systems because of the area of canola grown under irrigation and the relatively high rates of nitrogen applied to the crop. Four sources of nitrogen were broadcast to an irrigated production field on the soil surface prior to seeding in spring of 2018. Of the products tested, “Super U” fertilization gave the highest canola seed yield in this demonstration increasing irrigated canola seed yield by 560 kg/ha(15%). This project indicated the potential for increased irrigated crop yields with use of improved nitrogen efficiency fertilizer products under irrigation.

1 Irrigation Agrologist, Saskatchewan Ministry of Agriculture, Outlook, SK, Canada
2 ICDC Research Agronomist, Outlook, SK, Canada
3 Agronomist, Rack Petroleum Ltd., Broderick, SK, Canada
4 Senior Agronomist, Koch Agronomic Services, Calgary, AB, Canada
5 Director, ICDC Board, Outlook, SK, Canada
6 Producer, Broderick, SK, Canada

Corresponding email contact: gary.kruger@gov.sk.ca

NAGARJUNA SAGAR PROJECT – MODERNIZATION FOR IMPROVING WATER MANAGEMENT THROUGH WARABANDI (ON/OFF) SYSTEM

S. Suneel[1] and V.Narasimha [2]

ABSTRACT

The Multipurpose Nagarjunasagar Project on River Krishna, near the then Nandikonda village, Peddavoora Mandal, Nalgonda District is the pride of Andhra Pradesh. The Project comprises of a 409 feet (130 m) high Dam, a 810 MW main Power House at Dam, and two canals named Jawahar canal and Lal Bahadur canal taking off from the reservoir on right and left side respectively to irrigate about 22 lakh acres (900000 ha) benefiting the districts of Guntur and Prakasam under Jawahar Canal and Nalgonda, Suryapet, Khammam, Krishna and West Godavari under Lal Bahadur Canal.In the last Rabi 2017-18 season, Nagarjuna Sagar left canal planned to provide 40 TMC of water to 1.618 lakhs hactares in Zone 1 and Zone -2 in the Nalgonda, Suryapet and Khammam districts. In this season the farmers grown crops in 2.1 lakhs hectares, about an area of 1.21 lakhs hectares in Nalgonda &Suryapet districts of Zone-1, and 0.89 lakh hectares in Khammam district under zone -2. NS Left canal ayacut record-level crop yields are observed due to optimum use of water, the following are the reasons for such records:Left canal modernization works under the Water Sector Improvement Scheme (WSIP) was initiated in 2010 and renovation of Major canals, Distributary Canals and Dam Safety works were taken up. Modernization of canals with adoption of ON & OFF system, Water reached to tail-end areas of canals, and ayacut increased significantly compared to the past. Earlier the yield is about 99 bags of paddy per hectare, now it is increased to.123 bags per hectare. Earlier Water used for irrigating 2428 hectares in continuous supply, is now irrigating about 4856 hectares with adoption of ON & OFF method of supply. Also the farmers are able to get the irrigation water to their tail-end areas without any effort.

Keywords: Water Use Efficiency, Water productivity, Krishna River, Modernization, On/Off System, Integrated Water Management.

1 Retd.Chief Engineer, Nagarjuna Sagar Project & AMRSLBC Project, Irrigation & CAD Department, Hyderabad. Government of Telangana. E-mail:suneelsiri@gmail.com.

2. Chief Engineer, Nagarjuna Sagar Project & AMRSLBC Project, Irrigation & CAD Department, Hyderabad. Government of Telangana. E-mail:censpamrp@gmail

OPTIONS FOR IMPROVING AGRICULTURAL WATER PRODUCTIVITY UNDER INCREASING WATER SCARCITY IN SOUTH AFRICA

Tafadzwanashe Mabhaudhi[1], Sylvester Mpandeli[2], Luxon Nhamo[3], Aidan Senzanje[4]
Vimbayi Grace Petrova Chimonyo [1], and Albert Thembinkosi Modi[1]

ABSTRACT

South Africa is ranked among the thirty driest countries in the world, a challenge that is negatively affecting agricultural production. Other challenges such as population growth, rural-urban migration, changing food preferences and drought exacerbate pressure on agricultural water productivity. The review critically assessed the different considerations for increasing agricultural water productivity under water scarce conditions in South Africa. While under these conditions, irrigation may seem an obvious solution to increasing agricultural water productivity as a response to frequent droughts and mid-season dry spells. However, considerations on the availability of water and energy for irrigation expansion and the accessibility of irrigation services to different farming groups in the country. It is generally argued that irrigation is an expensive option and not necessarily readily accessible to most farmers.

There are prospects for tapping into South Africa's groundwater resources but the extent to which they can contribute to expanding area under irrigation is contested given the challenges of quantifying and pumping the water. Most smallholder farmers currently lack access to water, energy, infrastructure and technical skills to irrigate thus making irrigation a challenging option in this sector. An alternative would be to explore rainwater harvesting and soil water conservation technologies, which involve inducing, collecting, storing and conserving runoff water for agriculture. The drawbacks to this are that, apart from scale issues, rainfall is becoming more erratic and droughts more frequent and hence the feasibility of this approach under frequent drought could be challenged.

Keywords : Climate risks, Drought, Management, Rainwater harvesting, Smallholder

1 Centre for Transformative Agricultural and Food Systems, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, P. Bag X01, Scottsville 3209, Pietermaritzburg, South Africa
2 Water Research Commission of South Africa, Private Bag X03, Gezina 0084, Pretoria
3 International Water Management Institute (IWMI-SA), 141 Cresswell St, Weavind Park, Silverton 0184, Pretoria, South Africa
4 School of Engineering, University of KwaZulu–Natal, P. Bag X01, Scottsville 3209, Pietermaritzburg, South Africa

MISSION KAKATIYA – FOR RESTORATION OF TANKS AND WATER BODIES IN TELANGANA

Deshpande Sridhar Rao[1], Veerabomma Ajay Kumar[2], and Menaka Devender [3]

ABSTRACT

Telangana state has emerged as 29th state of India with a total geographical area of 112,077 Sq.Kms. and is blessed with ample rainfall in monsoon from June to Sep. ranging from 900 mm to 1100 mm per annum (ADB 2015).Over 85% of the farmers in the state belong to the small and marginal category with an average land holding size of 1.11 ha (2.75 Acres). 63% of the farmers in Telangana depend on rain fed agriculture and more than 70% of cropped area is rain fed resulting in lower yields per unit area. Evidences reveal that Tank building activities started in Telangana in Pre Satavahana (271 BC to 30 BC) era. It attained excellence in Kakatiyas era. The legacy of Kakatiyas was carried forward by the Qutubshahis, Asafjahis who ruled Deccan Region. Millions of Hectares of land was brought into cultivation. Villages have become self-sustainable. Drought was a very rare occurrence in Telangana. Tanks have been life line for rural Telangana and a source of livelihood for various rural communities apart from farming community since ages. Further, tank in a village has been a cultural center. Many village festivals are celebrated at the tanks. Tanks which are the backbone for rural economy in Telangana were neglected and no comprehensive program to restore the existing Chain of tanks was taken up in the last few decades which worsened Irrigation sources in Telangana. After formation of Telangana State in 2014, new Government contemplated MK program, a comprehensive action plan for restoration of all Minor Irrigation Tanks & water bodies in the state in phased manner to bridge the gap between Irrigation Potential Created and Irrigation Potential Utilized (Govt. of Telangana 2015 & 2016). So far 20192 Tank works have been restored since launching of this program in March 2015 with an expenditure of 39795.30 Million Rupees. A gap ayacut of 5,58,554 Ha has been stabilized duly restoring the storage capacity to an extent of 227.66 M Cum (Manual 2015). Multifaceted Impacts of MK were observed in various independent studies conducted by NABARD, IWMI, Michigan and Chicago Universities, Ground Water Dept. & Fisheries Dept.. MK Program was acclaimed by eminent personalities and common people as well.

Keywords: Mission Kakatiya, Restoration of tanks, Objectives of Mission Kakatiya, Impacts of Mission Kakatiya, Significance of tanks, De-silting of tanks, Community Participation, Irrigation policy

[1,2,3] Irrigation and Command Area Development Department Government of Telangana, Hyderbad, India. E-mail: ceminorts@gmail.com

GOVERNANCE OF INVESTMENT IN PUMPED DRAINAGE IN WATERLOGGED POLDERS

Stijn Reinhard[1], Toine Vergroesen[2] and Femke Schasfoort

ABSTRACT

Polder 2 in Satkhira district in SW Bangladesh suffers from waterlogging during and after monsoon. The waterlogged areas are not suitable for farming during most of the year. The main objective is to show local farmers that an investment in pumps will raise their income and increase their nutrition intake. Therefore three lines of research are necessary (i) Water management: test the technical feasibility of installing pumps for drainage; (ii) Governance research: how to organise the farmers for management of the pumping for successful operation and maintenance of the pumps ;(iii) Economic analysis, do the benefits of the extra crops outweigh the costs of pumped drainage. At one location pumps are installed and operated for at least one year to learn also from the practical issues that pop up in this year to be dealt with by the farmers and the researchers. A methodology is developed based upon the three lines of research to give structure to the project, the learning process and the diffusion of this concept after the pilot. The methodology and results from this pilot are applied in a guidebook to stimulate and facilitate adoption of the concept by adjacent farmers and elsewhere.

1 Wageningen Economic Research, The Netherlands, stijn.reinhard@wur.nl
2 Deltares, The Netherlands, toine.vergroesen@deltares.nl

ASSESSMENT OF IRRIGATION WATER PRICE FOR RICE AND WHEAT CROPS IN INDIA

A. Upadhyaya[1] and L.B. Roy[2]

ABSTRACT

In India, gross irrigation potential has increased about five folds since 1951 as a result of phenomenal expansion in irrigation development. But, in terms of direct recovery from these irrigation schemes it has been abysmally low. This staggering difference between expenditure incurred and revenue recovered is largely responsible for dismal performance of the irrigation sector. This can be attributed to defective pricing structure for irrigation water, which is highly subsidized not reflecting true supply cost. Under pricing of water induced unscrupulous use leading to environmental problems like waterlogging in the irrigation commands. Water rates have not been revised in many states. Even now, lower and outdated water rates have been continuing and as a result there has been a drop in the revenue from water charges. Another important issue is less water allocation for agriculture in future due to diversion of water to meet demands of urban areas, growing industries and ever increasing population. So a study was undertaken with an objective to estimate cost of irrigation water to grow per kg of rice and wheat in Paliganj distributary command under Sone canal system in India.

Data/information regarding canal water and tube well water charges were collected from Irrigation/Water Resources Department and data/ information from farmers were collected through developed questionnaire and by applying Residual Value method in which difference of gross returns of each crop and costs of production (excluding water) is divided by the amount of water applied (m^3), price of irrigation water in terms of (kg of cereal per m^3 of irrigation water) was worked out. The studies brought out a better assessment of Irrigation water price and it was observed that present irrigation water charges are much lower than actual irrigation water price. If assessment of irrigation water price is done correctly and it is included in cost of cultivation properly, Govt. may think of revising MSP of agricultural products and thus farmers' benefits may increase. In addition to this when farmers will know the real cost of water, they may start using water more efficiently.

1 Principal Scientist, Division of Land and Water Management, ICAR Research Complex for Eastern Region, Patna – 800014, India

2 Professor, Department of Civil Engineering, National Institute of Technology, Patna – 800005, India.

EVALUATION OF FARMING ACTIVITIES SUPPORTED BY CLIMATE SUB-LOANS IN TAJIKISTAN AND UZBEKISTAN

Shukhrat Mukhamedjanov[1], Sherzod Mominov[2], Rustam Sagdullaev[3], and Nazokat Khasanova[4]

ABSTRACT

Increased pressure on environment in combination with extreme weather events, such as droughts and floods, may lead to unsustainability of agriculture. Most probably, decreased crop yield may cause disproportion between production and population need for food.

In Uzbekistan and Tajikistan agrarian sector is the main consumer of water, which is used for irrigation. Climate change and its consequences (increased temperature, low precipitation and decreased area of glaciers) may lead to increased deficit of water availability and increased need for irrigation water in the future.

To improve sustainability of agriculture under climate change, investments will be required, firstly, for reorganization and improvement of irrigation and agriculture infrastructure. In addition, climate risks in agriculture and water sector will require separate investments. In this context, it should be clear, what specific problems need to be financed. It is also essential to understand that these investments should be targeted, with the use of existing high tech tools to solve specific tasks.

The paper presents the assessment of efficiency related climate investments in agriculture in Uzbekistan and Tajikistan. Basic criteria and indicators of assessment were developed. Climate anomalies and risks in agriculture production and adaptation measures were defined.

1 Scientific Information Center of the Interstate Commission for Water Coordination of Central Asia
2 Scientific Information Center of the Interstate Commission for Water Coordination of Central Asia
3 Scientific Information Center of the Interstate Commission for Water Coordination of Central Asia
4 Student

MORE CROP PER DROP THROUGH KEN BETWA RIVER LINK SYSTEM

Rajesh Kumar Jain[1]

ABSTRACT

The interdepandance of the water with food and energy is well reiterated worldwide and the present challenge is on how to produce more crop per drop per kwatt energy per unit area of land. From this point of view the micro irrigation in general and drip irrigation in particular has received considerable attention to increase water use efficiency, agricultural productivity, economic growth, and environmental sustainability. The analysis of economics of crop cultivation under drip irrigation has revealed that the drip method of irrigation has a significant impact on resources saving, cost of cultivation, yield of crops and farm profitability in long run.

With this objective, National Water Development Agency (NWDA) Ministry of Jal Shakti, Department of WR,RD&GR Government of India identified 30 Inter Basin Water Transfer(IBWT) links for detailed studies; 14 under Himalayan Component and 16 under Peninsular Component. Four priority links for the preparation of Detailed Project Reports(DPRs) under Peninsular Rivers Component have been identified viz; Ken-Betwa Link Project(KBLP) (Phase–I & II), Damanganga-Pinjal Link Project,(DP) Par-Tapi-Narmada Link Project(PTN) and Godavari-Cauvary Link Project.

Out of these, DPRs of KBLP, DPLP and PTNLP links have been completed. The project has been declared as the first national project under ILR Programme of the Government of India.

The Ken-Betwa Link Project (KBLP) a multipurpose project will provide an annual irrigation of 904 thousand ha. The water utilisation from the project is about 4843.26 MCM including for irrigation and domestic water supply. The project will generate103 MW of hydropower at 27 MW solar power through the panels proposed to install on the proposed canal tops. The main project components planned under the KBLP project are Daudhan Dam, Lower Orr Dam, Bina Complex Multipurpose Project, Kotha Barrage, repairing/strengthening of Bariyarpur Pickup Weir, Paricha Weir and Barwa Sagar Dam. To maximize the irrigation and water use efficiency, micro irrigation system has been proposed to be introduced in the entire command areas of the project coming under the concerned State Governments of Madhya Pradesh and Uttar Pradesh. This will save 395 MCM of water and provide additional irrigation to the tune of 90000 ha. Culturable command area equivalent to 520536 MT of food production. Through this paper an attempt is made to highlight the importance of adopting drip irrigation, cost benefit, enhancement of irrigated area, employment generation and overall economic development of the specific regions.

Keywords: water-energy-food-nexus, water use efficiency, environmental sustainability, crop cultivation and yield of crops

1 Chief Engineer, NWDA, 18-20 Community Centre Near Anupam PVR Saket New Delhi, New Delhi, 110017,India

MODULAR WEIR: NEW METHOD OF WEIR CONSTRUCTION TO IMPROVE IRRIGATION PRODUCTIVITY

James Zulfan[1], Slamet Lestari[1], Ririn Ririn Rimawan, Marta Nugraha Hidayat[1], and Nuryanto Sasmito Slamet

ABSTRACT

For many decades, most of the weirs were built as a massive concrete structure across the river. However, there are some cases that a fixed structure weir is not suitable to be used in some rivers for example a river with a high bed degradation rate. This could be a problem for the stability of the structure because the conventional weir cannot accommodate the river bed level change. Furthermore, the cost and time period of the conventional weir construction is quite high. Therefore, a new method of weir construction which called Modular Weir has been developed. The modular weir is made by a modified shape of precast concrete blocks which are hooked and locked with one another to make it as a unit of structure. This structure has been tested on a scale model in the Hydraulic Laboratory of PUSAIR and applied on several rivers in Indonesia. The field test results in Cikarag River shows positive performance in which the modular structure prototype worked well as a weir. The construction method is easier and faster which leads to time and cost saving. Therefore, this new method of weir construction can be an alternative option for weir construction.

Keywords: Modular Technology, Weir, Irrigation, Precast Concrete, Concrete Block

1 Experimental Station for Hydraulic Structure and Geotechnic, Research Centre for Water Resources, Ministry of Public Works and Housing. Jl.Ir.H.Juanda no.193, Bandung 40135, Indonesia. E-mail: jameszulfan@gmail.com

SUSTAINABLE AGRICULTURAL GROWTH FOR THE RURAL DEVELOPMENT IN ASIA: A REVIEW

Kyung Sook Choi[1] and Vijay K Labhsetwar[2]

ABSTRACT

The current world population of 7.6 billion is expected to reach 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100, according to a new United Nations report (2017). Most of the addition will be in developing countries, and the exponential growth in population would require doubling the current food production. Regionally, the population in Asia will nearly double to over 4 billion (47%) people in 2025. In order to meet up with the challenges of feeding the future population, agricultural production must increase substantially. Many factors influence the agricultural growth vis-á-vis food grain production. Water, among others, plays a crucial role in increasing food production.

This paper uncovers several strategies developed to cope with Sustainable agricultural growth for the Rural Development in Asia. In Korea, despite the decline in investments in food production in recent time, the continuous interventions from the government are critical because agricultural water use is essential for the improvement of rural living standard. Thailand shifted its rural development from a growth-oriented approach to the new model of holistic people-centered development and sustainable development. Japan emphasized the importance of the Multi-functionality to be taken into account to evaluate water use for agriculture in Asia. Indonesia accepted the challenges based on the current roles of irrigation development in food security and poverty eradication. The challenges were the increase in population, agricultural land conversion, degradation of the watershed, and climate change. Turkey flagged its Group Agricultural Practices (GAP), a South-eastern Anatolia Project, to showcase its multi-sector and integrated regional development approach in the context of sustainable development. It aimed to improve living standards and income of people to eliminate regional development disparities and to contribute to such national goals as social stability and economic growth by enhancing productivity and employment opportunities in the rural sector. Taiwan's strategy included the promotion of private upland pipeline irrigation and guidance to construct and operate public facilities since upland irrigation system may alleviate problems being faced in the rural areas and enhance the income of farmers.

Traditionally, agricultural water in Asia is deeply rooted in its culture and livelihood. Paddy farming has been practiced for thousands of years all over the world, especially in Asia. Importantly, it is necessary to find a way to use agricultural water for production and environmental services at the same time for sustainable rural development. It is, therefore, clear that the nine-country papers and case studies gave some insights on the role of agricultural water towards sustainable agricultural growth and rural development. In addition, it is needed to share each experience with partnership and member countries to use the limited water resources wisely for sustainable rural development with poverty eradication to meet SDGs (Sustainable Development Goals).

Keywords: Agricultural water management, rural development, food security, SDGs

1 Kyungpook National University (KNU), 80 Daehakro, Buk-gu, Daegu, Korea 702-701. Email: ks.choi@knu.ac.kr, niazrai@yahoo.com

2 ICID, New Delhi 110021, India. E-mail: vijaylabh@gmail.com

"TAIL TO HEAD" A TECHNIQUE IN IMPROVING WATER USER EFFICIENCY AND PRODUCTIVITY OF SRIRAM SAGAR PROJECT TELANGANA STATE (INDIA)

Bhuram Shankar[1], Punnana Nagabhushana Rao[2], Bejjanki Sravan Kumar[3]

ABSTRACT

The growing concern and periodic warnings in era of water scarcity, with increasing demand for food and competing use within water sector, the pressure is on irrigation professionals to manage water efficiently. The main objective of this study is to address current issue encountered in Irrigation project command areas in Telangana State. The problems in the irrigation canal network after practical approach are identified as limited amounts of water available at water source and high water consumption in head reaches which result in water shortages at tail end of the Project. Moreover farmers at the head reach cultivate high water intensive crops like paddy.Sriramsagar project, which is a major irrigation project in Telangana state is designed for ID Crops but farmers have become habitual incultivating paddy which raised major concerns for equitable distribution of irrigation water. To overcome this situation Government of Telangana in the year 2016-17 Rabi decided to adopt "TAIL to HEAD" method for distribution of water. The localized ayacut in the tail-end is given water first and the ayacut in the beginning given at the last. The implementing methodology, the ground hurdles and the solutions for implementation, analysis of the water productivity before and after the introduction of the scheme are presented in the paper

Keywords: Tail to Head, Water use Efficiency technique,water regulation, water release in irrigation canal, Sriramasagar Project,Change in agriculture pattern, High water consumption in head reach.

1 Administrator-cum-Chief Engineer, Sriramasagar Project, Irrigation & CAD Department, Government of Telangana, e-mail: acesrsp1hyd@gmail.com
2 Executive Engineer, Division No. 1, GVC-4, Sriramasagar Project, Irrigation & CAD Department, Government of Telangana, e-mail: bhushan22222@gmail.com
3 Assisstant Executive Engineer, O/o Administrator-cum-Chief Engineer, Sriramasagar Project, Irrigation CAD Department, Government of Telangana, e-mail:shrawan19@gmail.com

THE PRIVATE PUBLIC PARTNERSHIP A STRATEGIC CHOICE FOR EFFICIENT AND SUSTAINABLE IRRIGATION MANAGEMENT IN MOROCCO

A. El Bouari[1], M. Ouhssain[2], S. Oudrhiri[3], R. tanji[4]

ABSTRACT

Irrigated agriculture is at the heart of Morocco's economic and social development. It plays a crucial role in meeting Morocco's food needs. It also generates more than 75% of the country's agricultural exports and providing jobs for half the rural labour force. However, irrigation monopolizes the country's scarce water resources, accounting for 85% of water usage. With water resources becoming increasingly scarce, Morocco urgently needs to find a better way to manage water for irrigation.

Indeed, the sector of irrigation in Morocco is confronted with several constraints, in particular because of the limits of the institutional framework which continues to govern the sector. These limits, which mainly concern the Regional Offices for Agricultural Development (ORMVAs), can be summarized as follows: their statutory framework as public institutions of an administrative nature; their current budgetary framework which does not clearly establish the principle of separation of public service missions and commercial missions; their dependence on the State's budgetary resources; and the relational framework that establishes a state-to-user relationship in which the farmer positions himself in the state's favor rather than as a customer of the water service.

These limits have not allowed the irrigation sector to generate sufficient internal financial resources to guarantee the sustainability of the equipment and to ensure an efficient water service. The expenses, even recurrent of this service, continue to be partly covered by budgetary transfers.

In this context and since the end of the 1990s, the Department of Agriculture after a thorough examination of the feasibility of the various possible options: (i) the autonomy of the water service within the ORMVA, (ii) the transfer of management to farmers and (iii) the delegated management in a private setting, concluded that the option of delegated management in a public-private partnership framework is appropriate. The interest of this option has been demonstrated through the realization of the Public Private Partnership project for the safeguarding of the citrus area of El Guerdane in Souss (10,000 ha). In fact, a delegated management agreement was signed in 2005 between the Ministry of Agriculture and a private operator (Amensouss company) to co-finance, implement and manage the irrigation infrastructure. Indeed, the construction was completed in July 2009 and management by the delegate started in October 2009 after inauguration by HM King Mohammed VI, may God glorify him, on October 2nd, 2010. Building on the success of this unprecedented international experience, the Ministry of Agriculture adopted the public-private partnership in irrigation as an important institutional reform for the upgrading and modernization of irrigation.

1 Agricultural Engineer, Director of Irrigation and management of agricultural land, Ministry of Agriculture, Fisheries, Rural Development, Water and Forests. bouariahmed@gmail.com
2 Agricultural Engineer, Head of PPP Division at Directorate of Irrigation and management of agricultural land, ouhssain1971@gmail.com
3 Agricultural Engineer, Head of Service of Monitoring and regulation of PPP in Irrigation
4 Agricultural Engineer, Head of Service of promotion and implementation of PPP in Irrigation

Today, the program of public-private partnership in irrigation is concerning many perimeters, we name as some important ones: The seawater desalination irrigation project in the Chtouka Ait Baha area in Souss-Massa to irrigate 15,000 hectares; Azemmour - Bir Jdid coastal zone irrigation project (3,200 hectares) and extension of irrigation project in the Dakhla zone using desalinated water and wind energy on 5,000 hectares.

Keywords: Morroco, Irrigation, Irrigated agriculture, Public-Private Partnership

BACKGROUND PAPER CONTRIBUTORS

SUB-THEME 1:
Enabling Policy Environment for Water, Food and Energy Security

Jelle Beekma

Jelle Beekma is a senior water resources specialist at ADB since 2018. Between 2001 and 2018 he worked as consultant on various project designs, river basin management projects, basin planning, investment planning, design of irrigation, drainage and bank protection structures, including nature-based solutions and project implementation and supervision. Prior to that he worked as research and teaching assistant on groundwater hydrology and drainage and salinity control at the New Mexico Tech in the Rio Grande Basin and worked on researcher, advice and teaching at the International Institute for Land Reclamation and Improvement in Wageningen and the International Waterlogging and Salinity Research Institute in Lahore. Mr. Beekma holds an MSc. in processes in physical geography from Utrecht University, studied at Wageningen Agricultural University and did his Ph.D. candidacy in hydrology at New Mexico Tech, Socorro.

Jeremy Bird

Jeremy Bird advises a number of international organisations on water resources management issues. From 2012 to 2017 he was Director General of the International Water Management Institute based in Sri Lanka and before that, from 2008-2011, he was Chief Executive Officer of the Mekong River Commission. Earlier he worked with the Secretariat of the World Commission on Dams and the Asian Development Bank. Mr Bird holds Masters' degrees in Water Law and Policy from Dundee University and Irrigation Engineering from Southampton University and a Bachelor's degree in civil engineering from Bristol University.

Adey Nigatu Mersha

Ms. Adey Nigatu Mersha is an Associate Researcher at the Water and Land Resources Centre of Addis Ababa University, Ethiopia. Moreover she is currently a final year PhD researcher at IHE Delft Institute for Water Education in the Department of Water Science and Engineering, The Netherlands. She obtained her MSc in Soil and Water Engineering from Haramaya University of Ethiopia in 2006. In the period 2006-2013, she has served as a Lecturer in the department of Water Resources Engineering at Hawassa University of Ethiopia, Water Sanitation and Hygiene (WASH) program officer in an International Development Program of CRS, and as researcher in the South Agricultural Research Institute of Ethiopia. Since 2015, she has been also working as a joint coordinator of ICID Young Professionals e-Forum (IYPeF).

Stijn Reinhard

Stijn Reinhard is senior scientist and water economist with Wageningen Economic Research. Currently Stijn is as an expert involved in several projects that either link water to economic models or incorporate economics in hydrological analyses in the Netherlands and in Bangladesh. He leads the team that assesses potential projects that applied for funding from the Dutch Delta Programme for fresh water availability. His thesis about modelling water quality received the Wageningen University thesis award. He received the American Agricultural Economics Association, best dissertation award for his dissertation on the econometric estimation of economic and environmental efficiency of Dutch dairy farms. Stijn was member of the Dutch working group on economics of the EU Water Framework Directive and of the Commission of the Dutch knowledge impulse programme “Living with Water”. He edited the Resources for the Future book “Water Policy in the Netherlands”. Stijn has led many impact assessment projects.

Sanmugam Ahembaranathan Prathapar

Dr. S.A. Prathapar is a Senior Water Resources Specialist at the Asian Development Bank seconded by the Australian Water Partnership, since Jan 2018. He held leadership and managerial positions at the International Water Management Institute (1996-2000 and 2011-2014), Sultan Qaboos University, Oman (2002-2011), CSIRO Australia (1987-1996), Department of Primary Industries, NSW, Australia (2001-2002, and 2014-2017). He did his post-doctoral research at the University of Arkansas, USA (1986-1987), obtained M.S. (1982) and Ph.D. (1986) from Texas A&M University, USA, and BSc (Hons.) from the University of Sri Lanka (1978). He specializes in groundwater management, treatment and disposal of wastewater, irrigation, drainage, and salinity management.

Golam Rasul

Dr Golam Rasul, Chief Economist, at International Centre for Integrated Mountain Development (ICIMOD). He is a national of Bangladesh. Prior to his appointment as a Chief Economist, he served as a Theme Leader livelihoods, Head of the Economic Analysis Division and Policy Development Specialist at ICIMOD for about nine years. Dr Rasul holds a PhD in regional and rural development planning from the Asian Institute of Technology (AIT), Thailand. He worked for more than a decade in the Bangladesh Civil Service in different ministries and was involved in the formulation and implementation of national policies, plan and programs. He has been actively involved in research in areas of agriculture, rural development, natural resource management, food security, poverty alleviation, regional cooperation, food, water, energy nexus and sustainable development in South and Southeast Asia region. He contributed to over 150 papers in books, refereed journals, policy briefs, position papers, and technical reports, including 50 peer-reviewed articles in reputed journals. His research findings incorporated in many national and global policy papers. He also provided policy inputs to number of ICIMOD’s member countries on development issues. He is a Coordinating Lead Author of IPCC special report on Ocean and Cryosphere.

Jeffrey Richey

Jeffrey Richey is a Professor in the School of Oceanography and Adjunct Professor in the School of Environmental and Forest Sciences, Department of Civil and Environmental Engineering, and the Quaternary Research Center, University of Washington. He received his B.A. from Stanford University, MSPH from the University of North Carolina, and PhD from the University of California, Davis. His research involves the biogeochemistry and hydrology of large-scale river basins, and how to implement geo-information systems for analysis of complex basins. He has over 150 publications, multiple conference presentations and invited seminars. He has been involved in number of World Bank projects, and was a member of the World Bank's Hydrology Expert Facility. He is a Fellow of the American Geophysical Union, a member of the Brazilian Academy of Sciences, recipient of the Ademar Cervellini Medal of Academic Merit of the University of Sao Paulo and the Zayed International Prize for the Environment with the Millennium Ecosystem Assessment. He was awarded the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) Sao Paulo Excellence Chair.

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Jouke Van Campen

Jouke Campen became an engineer in Applied Physics at the Technical University of Delft, specialized in heat and mass transfer. He started working at Wageningen UR in 1997. His main field of research is energy and climate control in protected horticulture. Over the years he has become an expert in computational fluid dynamics calculations for greenhouses. He finished his PhD on dehumidification of greenhouses October 2009. Currently he is the coordinator of the energy program of the ministry of Agriculture in The Netherlands involving annually 7 million EURO of projects on reducing energy use in the Dutch protected horticultural sector. Aside of this task he is international project manager for the last 10 years working on numerous projects all around the world. The establishment of research centers where experiments under local conditions can be done is an important part of the work. This work includes setting up the research agenda, designing the centre, involvement during the construction, and participating in the research. Through these type of projects the knowledge of Jouke Campen on the application of protected horticulture all around the world has been established including the cultural and social aspects.

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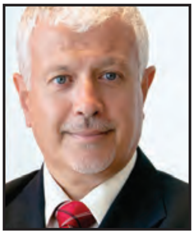
Raqab Ragab

Dr. Ragab (born in 1949) obtained BSc. in Soil and Water Sciences (1970), MSc. in Irrigation (1974), and Ph.D, in Rural Engineering, University of Leuven, Belgium (1982). He was the Chairman of the British National Committee on Irrigation and Drainage (ICID-UK) and working as Head, Water, Soil and Landscapes Group at the Centre for Ecology & Hydrology, CEH, (Natural Environment Research Council, NERC) Wallingford, UK. He has more than 40 years of experience in irrigation, drainage, catchment's hydrology, remote sensing application in hydrology, integrated water management, climate change impact on water resources, soil-water-plant- atmosphere relations, rainfall harvesting, use of poor quality water (saline/brackish, treated waste water) for crop production, organic farming and urban hydrology.

Dr. Ragab is also associated with many professional organizations which include: British Society of Soil Science Society (BSSS), American Society of Agronomy (ASA), Soil Science Society of America (SSSA), and European Soil Science Society. Dr. Ragab actively participated in several events of ICID including IECs and Congresses. He also Authored and Co-Authored numerous scientific papers and Editor and Co-Editor of several special issues of International Journals as well as Conference Proceedings.

Chris Perry

Chris Perry has a degree in engineering from Imperial College and a PhD in Economics from the University of Stirling. He worked for the World Bank for more that twenty years, and was Deputy Director General if IWMI for five years. After retiring early was Editor in Chief of Agricultural Water Management.



Rabi Mohtar

Rabi H. Mohtar, Dean, Faculty of Agricultural and Food Sciences (FAFS), the American University of Beirut, is also a TEES Research Professor in the Department of Biological and Agricultural Engineering and the Zachry Department of Civil Engineering at Texas A&M University. At A&M, Mohtar founded the Water-Energy-Food Nexus Initiative and serves as an Advisor to the Energy Institute. He is adjunct professor at Texas A&M – Qatar, and was founding executive director of the Qatar Environment and Energy Research Institute (QEERI), Qatar Foundation. At Purdue University, Mohtar was the inaugural director of Purdue's Global Engineering Programs, and developed the concept of Global Design Teams: real-world, full-cycle design experiences that help raise global awareness; he continues his affiliation with Purdue as an adjunct professor. Mohtar has 130 peer-reviewed articles, 8 books, and 30 book chapters. He has participated in or organized more than 300 technical sessions, conferences, and workshops worldwide; and has supervised more than 75 Ph.D. and M.Sc students, taught innumerable undergraduates, hosted over 30 postdoctoral and visiting scholars, and worked in research and training in more than 15 countries. With more than $15 million in funded research grants, Mohtar research focuses on analytic frameworks for linking science and policy, pedostructure characterization of the soil-water medium, non-traditional water in agriculture, and applications for sustainable integrated water management. He continues to address global resource challenges on topics including: development of the Water-Energy-Food Nexus framework linking science and policy, characterization of the soil-water medium using thermodynamic modeling; efficacy of non-traditional water, and applications for sustainable integrated water management such as implementation of the Sustainable Development Goals (SDGs). Mohtar is a Governor of the World Water Council, a Senior Non-resident Fellow at OCP Policy Center, a Fellow of the American Society of Agricultural and Biological Engineers, and a Distinguished Alumnus of the American University of Beirut.

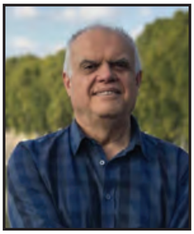
Laurie Tollefson

Laurie Tollefson VP Hon ICID has been an employee of the Canadian Government for 30+ years. His specialty is sustainable irrigated crop production. He has served roles as a scientist, manager and senior manager in Agriculture and Agrifood Canada. He has been involved as the Project Director for work in Canada, Egypt, Ethiopia, Afghanistan, China, India etc. He is past VP of ICID, Chairman of Permanent Finance Committee, recipient of Queen Elizabeth Diamond Jubilee medal, and Distinguished Canadian Agrologist.

Fuqiang Tian

Dr. TIAN Fuqiang is a Tenured Associate Professor in Department of Hydraulic Engineering, Tsinghua University, and Beijing, China. In the ICID family, he served as the chair of Bio-energy Working Group from 2015 to 2018, and he is currently the secretary of Climate Change Working Group. Also, he serves as the Chairman of Panta Rhei Decadal Initiative of IAHS (2019-2021) and the editor of two prestigious journals <Hydrology and Earth System Sciences> and <Journal of Hydrology>. His research interest includes agricultural water management, streamflow and flood forecasting, and transboundary water resources management. He has been awarded the Water Saving Technology Award by ICID in 2019 based on his achievement in water and salt regulation scheme under mulched drip irrigation in arid regions. He has published more 150 peer-reviewed journal papers.

SUB-THEME 2:
Role of Civil Society and Non-State Actors in Farm Extension and Facilities



Olcay Ünver

Dr. Ünver is Vice Chair of UN-Water, and Senior Water Olcay Advisor at the headquarters of Food and Agriculture Organization (FAO) of the United Nations in Rome, Italy. He served as the Deputy Director of Land and Water Division at FAO from September 2013 to March 2019. At FAO, he was responsible for managing water, land and soil-related activities and programs, mainstreaming water across the various sectors and disciplines, and cooperating with partners and stakeholders within and outside the UN system. Before joining FAO, Olcay was the coordinator of the UN World Water Assessment Programme and the director of the UNESCO Programme Office on Global Water Assessment. Prior positions include a professorship with Kent State University, Ohio, where he founded the Euphrates-Tigris Initiative for Cooperation between Iraq, Syria and Turkey. While he was president of the Southeastern Anatolia Project Regional Development Administration in Turkey, Olcay transformed a large infrastructure project into a sustainable socioeconomic development program. In 1999, he was listed among 19 “European Visionaries” by Time Magazine and was featured in New York Times for his efforts for sustainable, human-centred development.

Olcay holds a PhD in civil engineering from The University of Texas at Austin and master’s and bachelor’s degrees, also in civil engineering, from the Middle East Technical University, Ankara, Turkey.

Melvyn Kay

Melvyn Kay is an independent consultant who works with national and international agencies, like DFID, FAO, World Bank, and UNESCO writing and editing on all matters of water resources management, particularly specialising in water for food production. He was Editor in Chief of UN Water's 2018 review of progress with SDG 6 (the 'Water Goal') and is author of 'Practical Hydraulics and Water Resources Engineering' 3rd edition for CRC press. Prior to this he was Senior Lecturer in Irrigation Engineering at Cranfield University (Silsoe College) in UK following an earlier career with consulting engineers in the Middle East and Africa.

Konda Chavva

Konda is the Assistant FAO Representative in India. He has expertise is in usage of experiential learning processes to build institutional capacity of organizations working with under-served populations. His core expertise is in demystifying and contextualizing research and technical knowledge for field applications. Specifically, he has coordinated multi-disciplinary professional teams of bilateral and multilateral agencies, National, State and Local Governments, on natural resources management, conjunctive water use, improving agricultural productivity, improved livestock management, climate change adaptation, and integrated development of vulnerable areas and communities. Konda has also designed landscape management approaches that engage communities to manage their common resources sustainably. He played a pivotal role in conceptualizing and implementing innovative approaches, such as the Farmer Water Schools (FWS) and the Farmer Climate Schools (FCS). He contributed to the FAO's 'Farmer Field School Guidance Document: Planning for quality programmes'. Also, he has contributed to several technical manuals, tool kits and has a modest number of internationally peer-reviewed research papers to my credit.

Konda is a graduate of the Centre for International Education (CIE), University of Massachusetts, USA. His dissertation focuses on—'Cultivating Communities of Practice to Develop Local Preparedness for Climate Change'.

Amali Abraham Amali

Amali Abraham Amali is a hydrology and water resources expert with focus on hydrological modelling and real-time analysis for water resources management. He is currently a joint coordinator of the ICID Young Professional's e-Forum and leads the African Young Water Professionals Forum. Mr Amali is also a graduate student in Integrated Water Resources Management with the TH-Koeln, University of Applied Sciences. Prior to moving to Cologne, he was engaged as a research assistant with a natural resources consulting outfit focused on irrigation water management. Mr Amali holds a Bachelor's degree in Agricultural and Environmental Resources Engineering from the University Of Maiduguri, Nigeria

SUB-THEME 3:
Improving Water Productivity with Focus on Rural Transformation

IJsbrand H. de Jong

Mr. de Jong is the World Bank's Lead Water Resources Specialist for South Asia, based in New Delhi, India. His responsibilities include providing advice on the strategy and long-range policy and program for WRM, irrigation, drainage and flood control, leading the preparation and supervision of investment operations in South Asia related to water resources development and management, leading analytical studies on issues related to water resource management, and developing partnerships with government and non-government institutions to address national and transboundary water resource management issues in South Asia.Prior to joining the World Bank, Mr. de Jong held numerous positions, among others with the United Nations, NGOs and private sector in South, South-East and Central Asia and Africa in the field of irrigation, water resources management and rural development.

Mr. de Jong holds a Master of Science degree in water resources from the University of Wageningen.

Narges Zohrabi

Dr. Narges Zahrabi is an assistant professor in Department of Water Science Engineering at Ahvaz branch, Islamic Azad University (IAU) Since July 2007. She is the Head of International Research Program for Irrigation and Drainage - Iran Regional node (IRPID-IRN) since July 2018 and acting as a member of ICID/IRPID AC (Advisory Committee).Dr. Zahrabi has been a member of the Executive Board of the Iran National Committee on Irrigation and Drainage (IRNCID) and Head of Khuzestan Regional Committee on Irrigation and Drainage (KRCID) since 2016. She served as an adviser to Khuzestan Water and Power Authority affiliated to the Ministry of Energy with respect to modern water science and technology 2014-2018. Dr. Zahrabi holds a Ph.D. in hydrology and water resources from Tehran University of Science and Research (IAU) with more than 15 years of academic and industrial experience.

Klaus Roettcher

Prof. Dr.-Ing. Klaus Röttcher is a full professor for water management and hydraulic structures at Ostfalia University of applied sciences, faculty of civil and environmental engineering in Suderburg, northern Germany. He is also the head of the institute for sustainable irrigation and water management in rural areas and vice chairman of the German water history association. Research in the fields of sustainable irrigation, flood risk management, river restoration and traditional water management. Prof. Röttcher study civil engineering and holds a Ph.D. from Kassel University.

Neelam Patel

Dr. Neelam Patel is Principal Scientist and Incharge, Centre for Protected Cultivation Technology, Indian Agricultural Research Institute, New Delhi since June, 2015 after graduating in Agricultural Engineering from Allahabad University and Master's degree from Indian Institute of Technology, Kharagpur and Doctoral degree from Indian Agricultural Research Institute, New Delhi. She has demonstrated her engineering capabilities in various ventures including sensor based automatic irrigation, precision irrigation and waste water treatment technology. Working as member FAD -17 in Bureau of Indian Standards for formulating the different standards of irrigation system. Her research contributions have earned several recognition including Wat Save Best Young Professional (ICID) and outstanding women scientist, Indian Council of Agricultural Research, New Delhi.

Eman Ragab

Dr. Eman Ragab is Currently the Head of Information Management Department and a researcher at the Research Institute for Groundwater, National Water Research Center. Dr. Eman has more than 15 years of working experience hydrogeology, groundwater, numerical modelling, aquifer storage and recovery, aquifer exploration and sustainability of water uses and demands across sectors. She holds a Ph.D. and a Masters in Civil Engineering (water resources planning and management) from Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University and Bachelor's degree in Irrigation and Water Work Structures, Civil Engineering from Ain Shams University.

Paavan Kumar Reddy Gollapalli

Er. Gollapalli Paavan Kumar Reddy is the Project Manager at Watershed Organisation Trust (WOTR), Telangana, India since February 2019. He is the active member in the ICID Young Professionals and WG-SDTA from 2017 onwards. Reddy is having experience in the Evaluation of Irrigation Schemes through advanced technologies like Remote Sensing & GIS based approaches for water management. He is the Agricultural Engineering graduate and received PG Diploma from Indian Space Research Organisation (ISRO), India. Currently he is working in the rural areas of Telangana State in promoting, empowering and teaching the farmers on water management practices through System of Rice Intensification (SRI), Micro Irrigation and conserving water through soil moisture conservation practices with support of line Departments.

Sigit Supadmo Arif

Sigit Supadmo Arif is a Professor in Irrigation and management of Gadjah Mada University, Yogyakarta Indonesia, He was Graduated from Agricultural Engineering (irrigation Engendering) Central Luzon University, the Philippines 1990, Water resources engineering (irrigation and Drainage engineering), AIT Bangkok, 1984, and Agricultural Engineering, 1978. He is also serve as member of National Committee on Modernization of irrigation from 2011 until recently and Member of INACID committee form 2004 until recently.

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Iwan Hadihardaja

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Kaluvai Yella Reddy

Dr. Reddy is the Dean, Faculty of Agricultural Engineering and Technology ANGR Agricultural University. He did his Masters (1984) and Ph.D (2002) from Indian Institute of Technology (IIT) Kharagpur. Dr. Reddy has rich experience of above 30 years in teaching, research, extension, project management and administration. Under his supervision, he successfully guided the Norwegian funded "ClimaAdapt" Project implemented in Nagarjuna Sagar project area during 2012-17. Dr. Reddy has established collaboration with the international centre of excellence in water resources management (ICEWaRM), Adelaide, Australia and organized 15 Australia Award fellowships during 2016. He has organized various national and international events successfully.

He has been actively involved in ICID activities since 2008. Dr. Reddy has successfully organized two side events, during the 22nd ICID Congress held in Gwangju, South Korea in 2014 and the 2nd World Irrigation Forum held in Chiang Mai, Thailand 2016, involving WALAMTARI, FAO, Norwegian Institute of Bio-Economy and other international partners. He was also the recipient of ICID WatSave Technology Award in 2008.

INTERNATIONAL REVIEW COMMITTEE

Dr. Naoko Koshiyama (Japan)	koshiyama-n@ceri.go.jp
Prof. A.K. Gosain (India)	gosain@civil.iitd.ac.in
Ms. Robina Wahaj (FAO)	Robina.wahaj@fao.org
Mr. Kamran Zeinalzadeh (Iran)	k.zeinalzadeh@urmia.ac.ir
Dr. Clarke “Ballard (Australia)	ballardc@eftel.net.au
Dr. Waleed Hassan Abou El Hassan (Egypt)	waleed-hassan@live.com
Ms. Mary Jean (South Africa)	MaryJeanG@daff.gov.za
Mr. Eko Subekti (Indonesia)	esubekti@gmail.com
Mr. Nadjaji Anwar (Indonesia)	nadjadji@gmail.com
Prof. Dia El-Din Ahmed El Quosy (Egypt)	Lmewp2000@gmail.com
Dr. Ashwani Randev (India)	ashwanirandev19@gmail.com
Engr. Jerome R. Osias (Philippines)	jeromeosias@yahoo.com
Dr Ahmed El Bouari (Morocco)	bouariahmed@gmail.com
Dr. Chandra S Pathak (USA)	Chandra.S.Pathak@usace.army.mil
Dr. Sangjun IM (Japan)	junie@snu.ac.kr
Dr. Momon Sodik Imanudin (Indonesia)	momon_unsri@yahoo.co.id
Mr. Indratmo (Indonesia)	indratmo1957@gmail.com
Mr. Suripin (Indonesia)	suripin@undip.ac.id
Dr. Momir Vranes (Australia)	Momir.vranes@fao.org
Dr. Kyung Sook Choi (Korea)	ks.choi@knu.ac.kr
Dr. Brian Wahlin (USA)	bwahlin@westconsultants.com
VPH Mohamed Wahba (Egypt)	mswahba@hotmail.com
Mr. Sigit Supadmo (Indonesia)	sigitsupadmoarif@yahoo.com
Mr. Iwan Krida (Indonesia)	iwanhadihardaja@gmail.com
Er. Narges Zohrabi (Iran)	nargeszohrabi@gmail.com
Mr. Laurie Tollefson (Canada)	laurie.tollefson@canada.ca
Mr. Peter S. Lee (UK)	peterlee.icid@btinternet.com
Dr. Katsuyuki Shimizu (Japan)	shimizu@tottori-u.ac.jp
Mr. Eko Subekti (Indonesia)	esubekti@gmail.com
Mr. Nadjaji Anwar (Indonesia)	nadjadji@gmail.com
Dr. Budi Santoso Wignyosukarto (Indonesia)	bwignyosukarto@gmail.com
Dr. Tsugihiro Watanabe (Japan)	nabe@kais.kyoto-u.ac.jp

Engr. Mohammad Fashaee (Iran)	am.fashaee@gmail.com
Dr. Tsugihiro Watanabe (Japan)	nabe@kais.kyoto-u.ac.jp
Dr. C. Tamara Avellán (UNU-FLORES), Germany	avellan@unu.edu
Mr. Indratmo (Indonesia)	indratmo1957@gmail.com
Mr. Suripin (Indonesia)	suripin@undip.ac.id
Dr. Franklin E. Dimick (USA)	fdimick@sisna.com
Dr. Alireza Salamat (Iran)	alirezasalamat10@gmail.com
Dr. Kaluvai Yella Reddy (India)	yellark@gmail.com
Dr. L.B. Roy (India)	lbroy@nitp.ac.in
Mr. Sigit Supadmo (Indonesia)	sigit.supadmo@gmail.com
Mr. Iwan Krida (Indonesia)	iwanhadihardaja@gmail.com
Dr. Olcay Unver (FAO)	Olcay.unver@fao.org Olcay_unver@yahoo.com
Mr. Ian Makin (UK)	I.Makin@cgiar.org
Dr. Hossein Dehghanisanij (Iran)	dehghanisanij@yahoo.com h.dehghanisanij@areeo.ac.ir
Dr. Nozar Ghahreman (Iran)	nghahreman@ut.ac.ir
Mr. Eko Subekti (Indonesia)	esubekti@gmail.com
Mr. Nadjaji Anwar (Indonesia)	nadjadji@gmail.com
Prof. Dr. Sayed Abdelhafez (Egypt)	s.a.abdelhafez@gmail.com
Mehdi Jorabloo (Iran)	jorabloo.mehdi@gmail.com
Dr. Ding Kunlun (China)	klding2005@aliyun.com klding@iwhr.com
Prof. Graziano Ghinassi (Italy)	graziano.ghinassi@unifi.it
Mr. Indratmo (Indonesia)	indratmo1957@gmail.com
Mr. Suripin (Indonesia)	suripin@undip.ac.id
Prof. Sylvester Mpandeli (South Africa)	sylvesterm@wrc.org.za
Dr. Mohammad Javad Monem (Iran)	javadmonem@gmail.com
Dr. Poolad Karimi (Iran)	p.karimi@un-ihe.org
Dr. Nader Heydari (Iran)	nrheydari@yahoo.com
Mr. Sigit Supadmo (Indonesia)	sigit.supadmo@gmail.com
Mr. Iwan Krida (Indonesia)	iwanhadihardaja@gmail.com
Dr. Vijay K. Labhsetwar	vijaylabh@gmail.com

AUTHOR INDEX

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ICID Central Office:
48 Nyaya Marg, Chanakyapuri, New Delhi 110 021, India
Tel : +91 11 2611 6837, +91 11 2611 5679, +91 11 2467 9532,
Fax : +91 11 2611 5962
E-mail : icid@icid.org, Website : http://www.icid.org

/icidat /icidorg
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