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PROCEEDINGS BOOK

Irrigation and population dynamics in depopulated rural environments: Causes, implications, and sustainable solutions

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Abstract

The demographic evolution of Spain in recent years reveals an undesirable depopulated rural environment with internal imbalances and severe population decline. While various factors contribute to depopulation, such as aging, low birth rates, masculinization, and infrastructure deficiencies, a fundamental cause is the low profitability of agricultural operations, given that it is the main source of income for the population in these areas. This low profitability is linked to the Spanish agricultural structure, where 76% of the nearly 17 million hectares of cultivation are dedicated to rainfed agriculture, and only 24% to irrigation, in a country with a severe hydric deficit. Demographic analysis over the past decade indicates that provinces with a lower proportion of irrigated crops experience greater population loss, while those with higher proportions maintain or increase their population. Therefore, the work hypothesis states that the transformation into irrigation can be the key to establishing and increasing the population in depopulated rural areas, highlighting the importance of guaranteeing the sustainability of irrigation to improve its contribution to population fixation. Study objectives include establishing a scientific model for rural development in depopulated areas, analysing elements of population fixation and growth, and exploring interdependence in irrigation sustainability and resilience. The systematic methodology involves comprehensive data collection on depopulated areas, focusing on the "España Vaciada," and irrigation interventions using GIS tools. Subsequently, demographic data collection will address economic, social, and environmental factors influencing population evolution in rural areas. The next phase involves selecting demographic study areas, identifying those representatives of the issue, and highlighting model areas with successful population fixation through irrigation. The development of a survey, crucial in these areas, will be carried out simultaneously with the creation of an initial systems dynamics model, which will evolve into a definitive model after survey processing and statistical analysis of the results. The conclusions summarize findings to provide a solid foundation for decision-making and implementing measures to promote irrigation sustainability and population fixation in rural areas.

Keywords: sustainable irrigation, depopulated areas, rural demography, GIS, systems dynamics model

1. Introduction

The study conducted within the framework of the Observatory of Irrigation Sustainability (Spanish Agency) aims to scientifically establish the relationship between the benefits of implementing irrigation systems in depopulated areas and the stabilization and increase of the population (Silvestre & Clar, 2010). It also examines how population growth contributes to the sustainability of irrigation practices. The study is based on a hypothesis formulated from ethical principles, which guide the objectives and scientific methodology employed to test the hypothesis. The ethical foundations include the responsible and rational use of nature, the equal dignity and rights of all humans, and the balance between individual freedom and the common good, reflecting principles from international declarations and academic works (Steffen, W. et al., 2015).

This research aligns with international and European legislation and goals, such as the Sustainable Development Goals (SDGs), particularly Goal 6, which emphasizes efficient water use and community involvement in water management. It recognizes that despite the dominance of rain-fed agriculture, irrigation is essential for meeting future food demands, as highlighted in reports by the UN and various legislative frameworks. In Spain, significant policies like the National Irrigation Plan and emergency measures for water conservation underscore the importance of irrigation for agricultural productivity and rural population stabilization (Garcia-Asensio & Ayuga, 2017).

Spain's demographic evolution in recent years shows an undesirable concentration and territorial polarization, with two extremes: congested large cities and depopulated rural areas with significant internal imbalances and severe population decline (Figure 1).

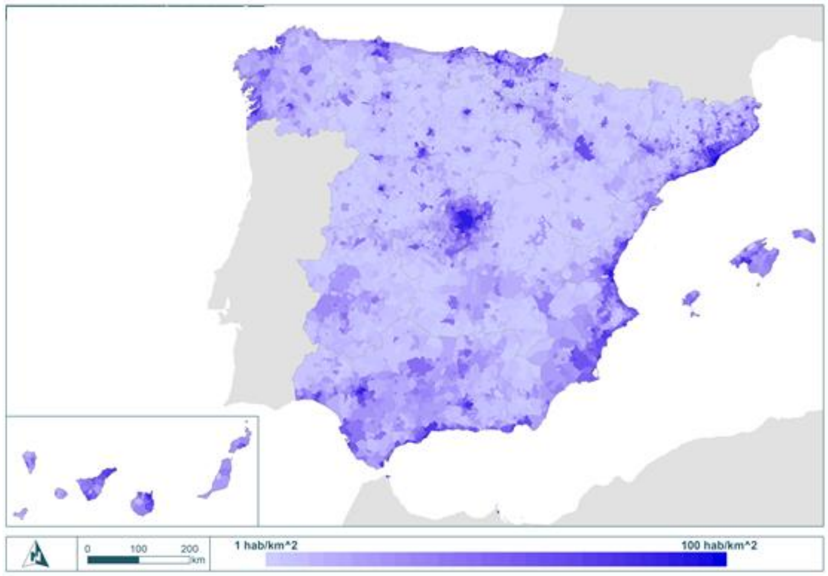

Figure 1. Population Density Distribution in 2021.

According to the National Institute of Statistics (INE) 2021 data (INE, 2021), 64% of the national territory has a population density of less than 25 inhabitants per km², housing only 6% of the total Spanish population. In contrast, 80% of the population is concentrated in urban areas, which cover just 20% of the territory. Moreover, municipalities with a density below 12.5 inhabitants per km², considered sparsely populated by the EU, occupy approximately 49% of the territory, where only 2.7% of the population lives. Areas with extreme depopulation risk, with a density of 8 inhabitants per km² or less, comprise 38% of the national territory and just 1.7% of the population.

The term "España Vaciada" (Emptied Spain) describes rural municipalities, primarily in regions like Castilla-La Mancha, Castilla y León, Aragón, Extremadura, Galicia, and Asturias, where a pronounced decline is evident. This situation worsens in disadvantaged areas, such as mountainous regions (40% of Spanish territory) and areas with challenging climatic conditions or low primary productivity potential (39% of the territory). Despite this, some rural municipalities with low or very low population densities are experiencing demographic revival through economic diversification, signalling a "rural renaissance". This depopulation is driven by high aging, low birth rates, masculinization, a technological gap with urban areas, reduced public services, and infrastructure deficits, particularly in agriculture, where 76% of nearly 17 million hectares of cultivated land is rainfed, and only 24% is irrigated. The demographic and irrigation data analysis between 2011 and 2021 indicates that provinces with significant population loss often have a lower proportion of irrigated land (Figure 2).

Derived from the outlined ethical principles and background, the initial hypotheses of this study are as follows:

- The transformation into irrigated land is a valuable tool for stabilizing and increasing the population in depopulated rural areas.
- Ensuring the sustainability of irrigation enhances its effectiveness in stabilizing the population.

The objectives derived from these hypotheses are:

- To establish a scientific model that incorporates irrigation activities for rural development in depopulated areas.
- To analyze the elements that contribute to population stabilization and growth.
- To explore the interdependence between the sustainability and resilience of irrigation systems.

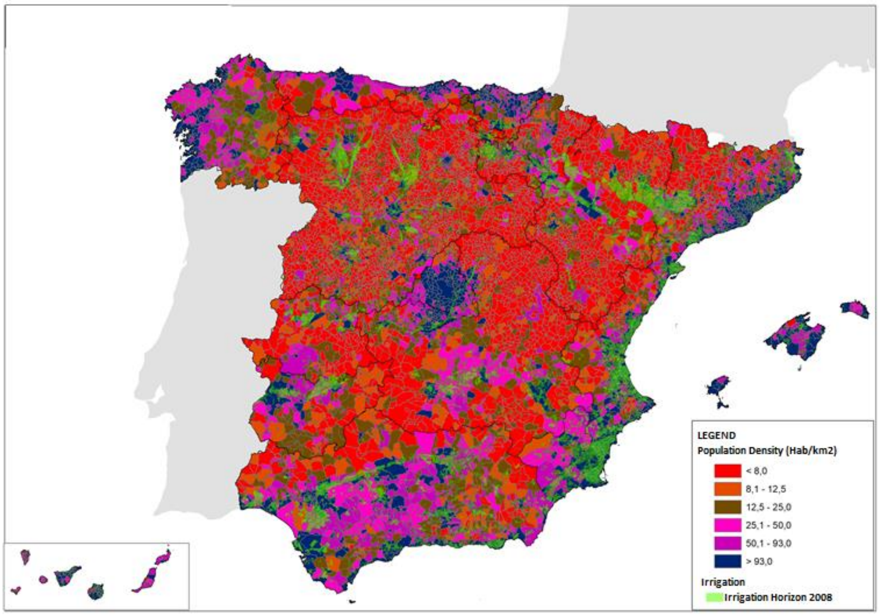

Figure 2. Map of Population Density in the Municipalities of Spain and Distribution of Irrigation Systems Horizon 2008

2. Materials and Methods

The methodology is divided into four key stages. Firstly, a comprehensive compilation of information on depopulated areas in Spain was carried out, as well as interventions in irrigation systems. This compilation was conducted using Geographic Information Systems (GIS).

Subsequently, information was gathered on demographic evolution based on various economic, social, and environmental factors, as well as scientific studies applying system dynamics to this evolution in rural areas and to the establishment and sustainability of irrigation systems. This literature review provides a solid theoretical framework for the study.

Based on this information, the selection of demographic study areas and model areas representing best practices was carried out. A survey was developed and distributed throughout Spain, with a special focus on the selected areas.

Simultaneously, a systems dynamic model of the relationship system between population and agriculture was developed, considering both direct and indirect employment generated by the activity (Pluchinotta et al, 2018). This model encompasses various productive modalities, including irrigation, allowing for the assessment of the effects on rural population of different change scenarios that may arise.

This method enables the derivation of conclusions and recommendations, providing a solid basis for the formulation of policies and strategies in the field of rural development and risk management.

2.1. Study areas

The strategic selection of study areas aims to shed light on the impact of irrigation on population and local socioeconomic development. Criteria such as demographic data analysis, consideration of agricultural diversity, and inclusion of successful cases guide the selection process. By focusing on agricultural regions as the unit of analysis, the study ensures a comprehensive understanding of irrigation's effects, accounting for factors like agricultural homogeneity, geographical context, and regional decision-making dynamics. The chosen regions, including Esla-Campos, Monegros, Bajo Aragón, Campos de Liria, Campo de Cartagena, Don Benito, and La Loma, represent diverse geographical and socio-economic contexts, providing valuable insights applicable to broader agricultural policy formulation.

The selected regions (Figure 3) offer a diverse yet representative sample to explore the intricate relationship between irrigation and population dynamics. Each region, characterized by unique demographic challenges and agricultural practices, presents an opportunity to identify patterns and learn from successful cases. By analyzing factors such as labor intensity, profit margins, and local decision-making processes, the study aims to provide actionable insights for policymakers and stakeholders seeking to promote sustainable development in rural areas. Through a comprehensive examination of these regions, the study seeks to contribute to a nuanced understanding of the role of irrigation in shaping local economies and communities.

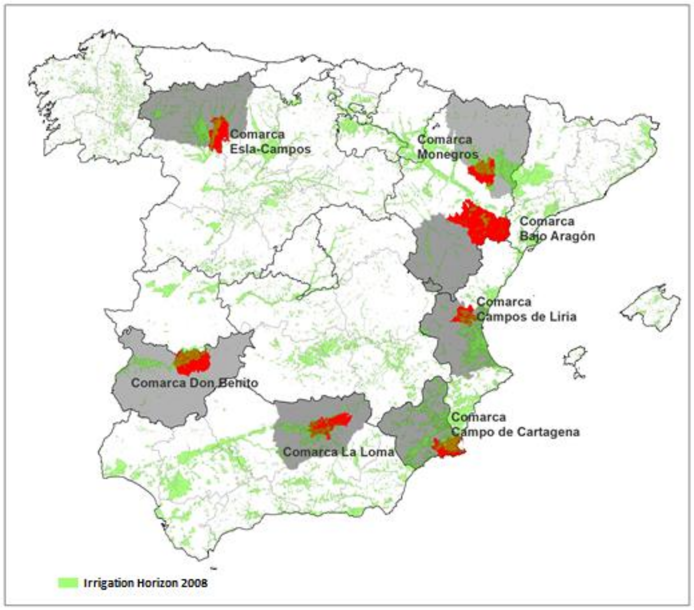

Figure 3. Study areas

2.2. Survey design

The methodology for designing the survey relied on the expert judgment-based decision-making method, utilizing group dynamics extensively (Colectivo IOÉ, 2015). A rigorous process was followed to identify experts, considering criteria such as their experience in the field, reputation in the community, availability and motivation to participate, as well as impartiality and personal qualities (Escobar-Pérez & Martínez, 2008). A natural focus group consisting of 10 individuals meeting these criteria was formed and used to gather relevant information on social cognitions related to the study (Skjong & Wentworth, 2001). Survey results were analyzed using descriptive statistics, employing tests like the Kolmogorov-Smirnov test to assess goodness of fit, the $\chi 2$ test to check the independence of categorical variables, and the Mann-Whitney W test to contrast central values (Ayuga-Téllez et al., 2013). Additionally, group comparison methods such as the Scheffe method or the Duncan method were applied to identify potential significant differences between them (Milliken & Johnson, 2009; Skjong & Wentworth, 2001). These statistical techniques ensured a rigorous evaluation of the results and provided a solid foundation for data interpretation.

2.3. Conceptual Formulation of the dynamic model

A dynamic model of the relationship system between population and agriculture has been designed, considering both direct and indirect employment generated by the activity. The model encompasses various productive modalities, including irrigation, allowing for the evaluation of the effects on the rural population of different scenarios of change. This design relies on identifying and analyzing all potential sources of statistical information that can feed into the system and establish statistical relationships between the different processes that comprise the model. The existence of different sources of information, each with its own characteristics and biases, allows for their incorporation into the model through sensitivity analyses, enabling the management of uncertainty levels associated with it.

The model estimates direct and indirect employment through an analysis organized into five different modules (Figure 4):

- Surface Module: Analyses the number, area, and characteristics of farms. It allows incorporating existing trends in land use changes, farm structure, and crop changes into the model.

- Direct Employment Module: Calculates employment generated on the farm, distinguishing between cultivation systems, dimensions, and logically differentiating between rainfed and irrigated land.
- Indirect Employment Module: Designed based on farm expenses related to crop cultivation, machinery rental and maintenance, and energy consumption.
- Product Transformation Module: Estimates employment generated by locally performed industrial transformation processes.
- Family Module: Analyses the population effects of the working population on other population groups (non-active population) based on family statistics. It considers minors, the elderly, family members engaged in family tasks (including caregiving).

The general approach of the model, described below, is summarized in the Figure 5, where each module is represented by a color code: Green: Surface module, Blue: Direct employment module, Red: Indirect employment module, Yellow: Employment in the food industry module, Gray: Family module.

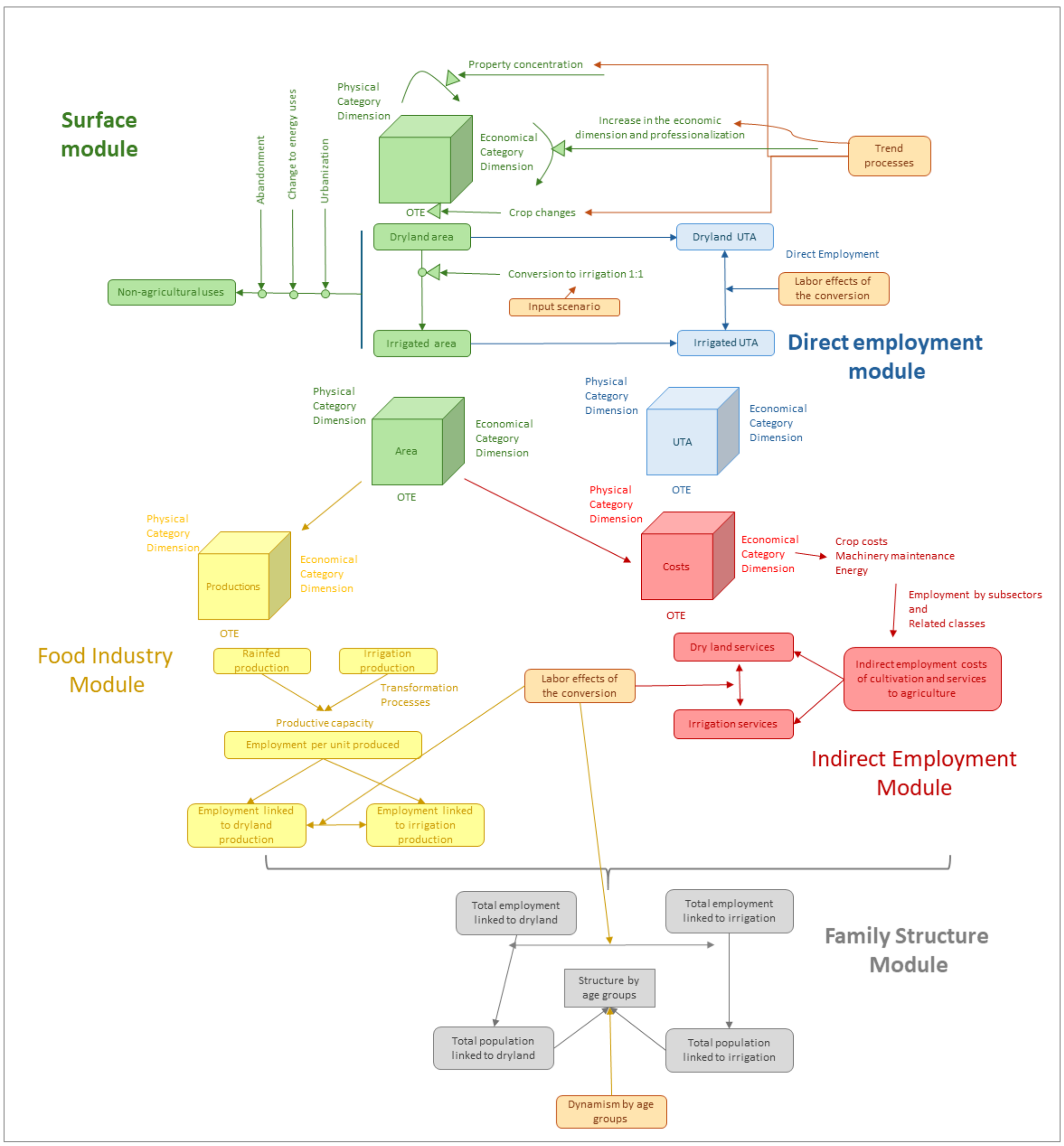

Figure 4. According to the type of agricultural exploitation of the respondents' municipality

In addition to its conceptual design, the model is being incorporated into specific system dynamics software. For this purpose, the STELLA®, program has been chosen, which allows for the inclusion of all the relationships described in the preceding pages. Moreover, it enables sensitivity analysis, which makes it possible to identify which elements of the model produce the greatest changes and where it is most important to complement tools for statistical analysis of official data with other sources of information, such as specific surveys or fieldwork, which could illustrate future lines of work. It also allows for the analysis of the effect of the statistical variability expected to be found in the identified relationships.

3. Results and Discussion

For the survey design two meetings were held, one to discuss a questionnaire proposal presented by the group moderator, with a consensual outcome agreed upon by all members. The second meeting was held to discuss some minor modifications to the questionnaire, issues that arose after its application to a pilot group of 50 participants, mainly irrigation cooperative managers. The result is a questionnaire consisting of 45 questions, with 12 aimed at characterizing the population, 28 focusing on their attitudes toward rural life conditions, and 5 regarding the improvement in life brought about by irrigated crops.

The survey is structured into two main parts: one directed at population in irrigated areas and another at population in rainfed areas, with some common questions at the beginning. The first section gathers basic demographic data, such as age, gender, education level, and employment status. It also explores satisfaction with rural life and the necessary conditions to remain in these areas.

Subsequently, depending on whether the participant lives in an irrigated or rainfed area, they are directed to specific questions. For irrigated areas, perceptions about the importance of these crops for the local economy, population retention, and improvement of services and employment are explored. For rainfed areas, questions are asked about the potential implementation of irrigated crops and their effects.

In both sections, the impact of various factors on rural-to-urban migration is assessed. The sequential and thematic structure of the survey allows for the collection of detailed and relevant information to understand the needs and preferences of rural communities.

The survey was implemented using the Google tool and the link was emailed to the mayors of 2,000 town councils in sparsely populated areas, requesting its dissemination to more residents of the town.

The survey respondents' characteristics are representative of the population, with gender and age well represented. With over 1000 responses obtained, the statistical reliability of the results is ensured. The data obtained mostly correspond to municipalities with low population. The sample is fairly balanced in most aspects, except for the composition of education levels, where the number of responses from individuals with no education or primary education is lower than the rest.

Regarding the dynamic model of the relationship system between population and agriculture, the application of the model was made on the selected areas and validated with the official real data. First results have shown that the accuracy improve significantly when applied to larger areas. Initially, provinces were used for the analysis, but this caused distortions in the results, leading to the selection of regions with similar climatic characteristics, based primarily on average precipitation. Despite these adjustments, representativity problems persist, especially in less common production systems. Additionally, technical-economic orientations (OTE) do not adequately differentiate between rainfed and irrigated systems, which affects the combination of agricultural and livestock activities.

To address these challenges, it was decided to analyze farms with pure characteristics of the production system. The dominant crop types were studied on farms with more than 80% in that type, and the minority types on farms with more than 50%. When there is sufficient representativity, the method reflects cost savings due to economies of scale well. However, smaller farms distort the model due to low representativity and high dispersion of labor data.

The model improved by grouping the smaller classes into those dominated by larger farms, thus correcting the deviations. However, this correction is not applicable to all types of production systems, especially in crops like citrus or intensive horticultural crops, where the distortion in small farms is lower.

The differences between rainfed and irrigated farms vary between 6% and 10% in crops with equivalence between the two and are greater in those without equivalents. At the regional level, the results reflect official employment data well, although there is dispersion at the municipal level since the model is based on typical farms and might not fully adjust to reality. The farm cost data are also adequately reflected, although the transformation data show greater discrepancies.

4. Conclusions

From the survey results, it is concluded that the improvement in services, including internet access, is considered essential for retaining rural population and preventing migration, even more so than increasing job opportunities. Satisfaction with life in rural areas is high, and the perception of the importance of irrigation and improving rural living conditions is also high and shared by individuals living in municipalities with and without irrigation. The majority opinion is that the implementation of irrigated crops improves economic and social conditions and job opportunities; it promotes the increase and/or improvement of services (healthcare, education, commercial), and would help in retaining the population.

The system dynamics model demonstrates good representational capacity and significant improvement by adjusting the analysis zones and grouping farms, although it still faces challenges in representativity and accuracy at the local level and in certain production systems. It is necessary to deepen the discrimination of industry types and their relationship with industrial land, on the one hand, and the productive differences between rainfed and irrigated systems, on the other. When data is entered into the model, changes in farm structure (towards concentration) and land use have a greater impact than the differences between rainfed and irrigated systems. However, there are fewer losses in irrigated areas, which are more stable from a labor perspective. The project will continue by improving this SD model and making simulations for the future in different scenarios.

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