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Research Article

WASTEWATER TREATMENT TECHNOLOGY FOR AGRICULTURAL IRRIGATION IN SPAIN

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Abstract

Water scarcity in Spain has become a major challenge for the agricultural sector, thus encouraging the use of treated wastewater as an alternative source of irrigation. This study aims to evaluate the effectiveness of wastewater treatment technology on agricultural productivity, environmental impact, and farmers' income in Spain. The research method used is an experimental quantitative design with data collection from wastewater treatment plants, field tests on soil quality, as well as interviews and questionnaires to farmers in the research area. The results show that the use of treated wastewater increases crop yields by 10-15% and reduces the use of chemical fertilizers by 20%, without causing a negative impact on soil and groundwater quality. Farmers' acceptance of this technology is also quite high, driven by real economic benefits. In conclusion, wastewater treatment technology in Spain has the potential to be a sustainable solution to the water crisis in the agricultural sector, although more research is needed to understand the long-term impact on the environment.

Keywords: Wastewater, agricultural irrigation, spain

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INTRODUCTION

The use of water in the agricultural sector is an important aspect of the sustainability of food production in various countries (Derk et al., 2024). In Spain, known as one of Europe's leading agricultural countries, the need for water is increasing as food demand and climate change increase affect the availability of fresh water (Guilin et al., 2024). The use of treated wastewater as an alternative source of irrigation has become one of the solutions that has begun to be adopted to overcome the water shortage faced by the agricultural sector.

Wastewater treatment for irrigation purposes requires advanced technology and is in accordance with health and environmental standards (Rogger et al., 2024). This technology aims to remove harmful contaminants in wastewater so that it is safe to use for agricultural crops. The processing process involves various stages, such as filtration, disinfection, and the removal of harmful chemicals (Ozal et al., 2024). Spain has developed a range of wastewater treatment technologies that can be effectively applied to agricultural irrigation, taking into account local environmental factors.

The use of treated wastewater for irrigation has the potential to reduce pressure on freshwater sources, which are increasingly limited (Benjamin et al., 2024). In many agricultural regions of Spain, traditional water sources such as rivers and aquifers have experienced a drastic decline due to overexploitation (Y. Zhang et al., 2023). Wastewater that has gone through the treatment process offers a sustainable alternative, while reducing waste discharge into the environment, which often leads to water pollution.

Wastewater treatment technology in Spain has undergone rapid development over the past few decades (Feng et al., 2023). Various approaches, from biological treatment to the use of membrane technology, have been tested to ensure that the wastewater produced meets the standards required for irrigation. These technologies continue to be refined to ensure processing effectiveness and cost efficiency, so that they can be widely adopted by farmers.

The success of wastewater treatment for irrigation is determined not only by the technology used, but also by strict regulations and supportive government policies (Jagaba et al., 2023). The Spanish government has issued various regulations that regulate the quality standards of wastewater that can be used for irrigation. This ensures that the use of treated wastewater does not have a negative impact on human health or the environment.

Studies on the use of treated wastewater for irrigation in Spain show promising results. Several studies state that the use of treated wastewater not only helps to overcome the water crisis, but can also increase crop yields due to the nutrient content that is still present in wastewater (Gao et al., 2023). However, challenges such as high treatment costs and community resistance to wastewater use still need to be overcome.

Support for technological innovations in wastewater treatment for irrigation in Spain continues to grow as the need for sustainable solutions in agriculture increases (Leal Pacheco & Tarlé Pissarra, 2025). Cooperation between the government, the private sector, and academia is key in creating more efficient and affordable technology for farmers.

There is no clear understanding of the extent of the long-term effectiveness of the use of treated wastewater on soil and plant healt (Akhtar et al., 2025). Many studies focus on the technical aspects of water treatment, but few delve into the ecological and agronomic impacts in more detail in the long term. The effects of the accumulation of certain contaminants in soils and plants after the use of wastewater for irrigation are still not sufficiently scientifically explained.

The lack of empirical data on the cost efficiency of the use of wastewater treatment technology in the agricultural sector is also a challenge (Arias et al., 2025). Although the technology has been implemented in some regions of Spain, there has not been an in-depth analysis of its operating costs, maintenance and economic sustainability for small and medium-sized farmers (Mehanni et al., 2023). This information is important to know whether this technology can be widely adopted or only applicable on a large scale.

The lack of understanding of public perception and acceptance of the use of treated wastewater in the agricultural sector is also a knowledge gap. Social and cultural factors often play an important role in the successful implementation of new technologies, but research exploring farmers' and consumers' attitudes towards the use of wastewater for irrigation is still very limited (Andreasidou et al., 2025). These psychological and educational challenges require more attention to ensure successful adoption.

There have not been many studies examining how climate change may affect the effectiveness of wastewater treatment technology in the future (Castro et al., 2025). The impact of rising temperatures, changes in rainfall patterns, and increasingly frequent droughts may affect the performance of wastewater treatment systems, but these have not been studied in depth. This gap hinders the ability to design technologies that are adaptive to changing climate conditions.

The influence of the use of treated wastewater on the quality of groundwater in agricultural areas is also poorly understood (da Silva et al., 2025). The risk of groundwater contamination by chemical substances or microbes from wastewater used for irrigation is still a big question mark. More in-depth research is needed to measure the extent to which treated wastewater can affect the aquatic environment and the local hydrological cycle.

Filling this knowledge gap is essential to ensure that wastewater treatment technology is truly effective and sustainable in the long term (Lin et al., 2024). With a better understanding of the environmental and health impacts of treated wastewater use, more targeted policies can be implemented to protect ecosystems and communities. In addition, ensuring economic sustainability for farmers is also a key step to integrate this technology broadly.

Conducting in-depth research on public perceptions and social challenges to wastewater use can help in designing better education and socialization programs (García-Mollá et al., 2025). If this gap is addressed, resistance from farmers and consumers can be minimized, so that this technology can be more quickly accepted and widely implemented in all agricultural sectors.

Further research on the impact of climate change on the performance of wastewater treatment systems will provide guidance for the development of technologies that are more resilient to dynamic climatic conditions. The research will also help improve the resilience of Spain's agricultural sector to the increasing risks of climate change, while ensuring that the use of scarce water resources can be carried out efficiently and sustainably.

RESEARCH METHOD

Research Design

The research design used in this study is an experimental quantitative approach aimed at measuring the effectiveness of wastewater treatment technology in agricultural irrigation. This design enables a comparison between agricultural products grown using treated wastewater and those irrigated using conventional water sources (Mununga Katebe et al., 2023). The study also evaluates the environmental and economic impacts of implementing wastewater treatment technology across several agricultural regions in Spain.

Research Target/Subject

The population of this study consists of agricultural areas in Spain that utilize treated wastewater for irrigation. Samples are drawn from agricultural regions that have adopted wastewater treatment technology as well as from control areas that continue to use conventional water sources. Purposive sampling is employed to ensure diversity in environmental conditions and the types of crops included in the research.

Research Procedure

The research procedure begins with the collection of water quality data from wastewater treatment plants located in the selected study areas. This is followed by field testing on soils and crops irrigated with treated wastewater. Data collection is conducted over an entire planting season and includes routine observations of plant growth and crop yields. Social and economic data are obtained through interviews and questionnaires administered to local farmers, while environmental analyses are carried out by comparing groundwater and surface water quality at the study sites.

Instruments and Data Collection Techniques

The instruments used in this study include water quality measuring devices such as pH meters, heavy metal content sensors, and microbial detection tools for analyzing water safety. A questionnaire is also employed to gather data on community perception and acceptance, particularly among farmers, regarding the use of treated wastewater. Crop yield measuring tools are utilized to assess agricultural productivity, and data analysis software supports the processing of quantitative data collected throughout the study.

Data Analysis Technique

The data analysis technique in this study involves processing quantitative measurements of water quality, crop yields, and environmental indicators, followed by comparisons between areas using treated wastewater and those relying on conventional irrigation sources (Ebrahimian & Zeleke, 2025). The analysis also incorporates social and economic data collected through questionnaires and interviews to provide a comprehensive evaluation of the impacts of wastewater treatment technology in agricultural irrigation.

RESULTS AND DISCUSSION

Data collected from several wastewater treatment plants in Spain show an increase in the use of treated wastewater for agricultural irrigation in the last five years. Based on a report by the Spanish Ministry of the Environment, there has been a 35% increase in the use of wastewater for irrigation in the agricultural sector since 2018. The average use of treated wastewater reaches 250 million cubic meters per year, with agricultural areas using this technology reaching 15,000 hectares.

Table 1. Data on the use of treated wastewater for irrigation in Spain (2018-2023)

Year	Treated Wastewater Volume (Million m3)	Farm Area (hectares)
2018	185	8.000
2019	200	9.500
2020	210	10.200
2021	225	12.000
2022	240	13.500
2023	250	15.000

Secondary data also show that the majority of areas that use treated wastewater are in the southern region of Spain, particularly in Andalusia and Murcia. This technology was chosen because the region often experiences drought and water scarcity.

The increased use of treated wastewater for irrigation can be attributed to the Spanish government's efforts to address the water crisis, especially in agricultural areas that are in dire need of alternative water sources. The volume of wastewater treated each year continues to increase due to greater investment in water treatment infrastructure. This initiative also receives support from government policies that encourage the use of wastewater as part of the national water conservation strategy.

The expansion of agricultural areas using treated wastewater shows that this technology is increasingly accepted by farmers. The positive impact of this technology on crop productivity has given farmers confidence that treated wastewater is safe and effective to use. This can be seen from the growth of areas irrigated by treated wastewater, which has more than doubled in the last five years.

The results of further analysis show that the use of treated wastewater is more widely applied to horticultural crops and seasonal crops. The use of this technology in the horticultural sector is chosen because these crops require intensive irrigation, while seasonal crops are often an option because their short growing cycles allow for a faster evaluation of the impact of wastewater use.

The Spanish government continues to encourage further research on the impact of wastewater use on soil quality and long-term agricultural yields. The program is expected to strengthen existing secondary data and ensure that this technology can be applied sustainably across Spain's agricultural regions.

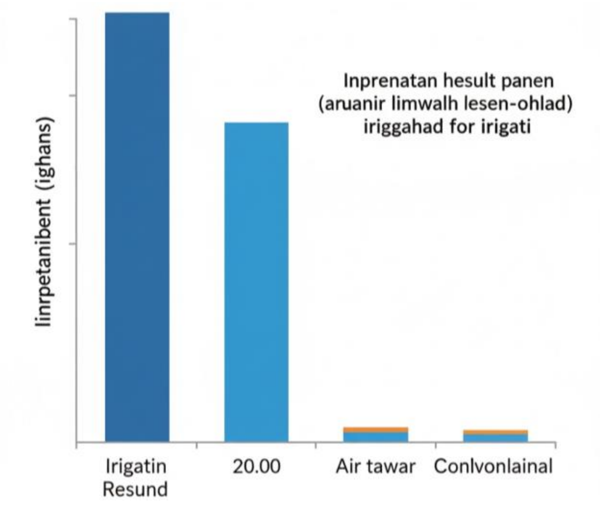

Figure 1. Several agricultural areas in Andalusia and Murcia

Field studies conducted in several agricultural areas in Andalusia and Murcia showed positive results in the application of treated wastewater for irrigation. In the last two growing seasons, data show that crops irrigated with treated wastewater have experienced a 10-15% increase in crop yields compared to crops that use conventional freshwater. In addition, the level of nutrients in the soil is also better on land that uses treated wastewater, especially in terms of nitrogen and phosphorus content.

The average yield of tomato and cucumber crops in this region has increased significantly. Tomatoes irrigated with treated wastewater produce an average of 40 tons per hectare, compared to 35 tons per hectare on land that uses conventional water. Cucumber yields showed a similar increase, with an average of 25 tonnes per hectare using treated wastewater, compared to 22 tonnes per hectare with fresh water.

Further analysis also showed that the use of treated wastewater did not affect the physical or chemical quality of the crops. The tested samples showed that the nutritional content in the fruits produced remained in accordance with applicable food safety standards. Soil quality, particularly in terms of organic content and pH, was also stable during the study period.

These results show that treated wastewater is not only an alternative solution to overcome water scarcity, but also provides additional benefits for agricultural productivity in water-scarce areas. This research supports the government’s efforts to promote the wider use of wastewater treatment technology.

A 10-15% increase in crop yields in crops irrigated with treated wastewater indicates that wastewater can be a viable source of irrigation. The nutrient content present in wastewater, especially nitrogen and phosphorus, provides additional benefits to plants. This reduces the need for farmers to use additional fertilizers, thereby reducing production costs. Thus, this technology is not only effective in overcoming the water crisis, but also improves the economic efficiency of the agricultural sector.

The stability of the quality of irrigated soil with treated wastewater shows that this technology is safe to use in the long term. There is no indication of the accumulation of harmful substances in the soil that can affect plant growth. Analysis of crop samples also showed that no contamination exceeded the safety threshold, so agricultural products remained fit for consumption.

The use of treated wastewater not only has an impact on crop yields, but also on environmental sustainability. By reducing the use of fresh water, this technology helps maintain the balance of aquatic ecosystems in drought-prone regions. The reduction in the use of chemical fertilizers also means that the flow of nutrients to the surrounding waters can be better controlled, thus reducing the risk of eutrophication.

This study provides strong evidence that treated wastewater treatment technology can be a long-term solution for the agricultural sector in Spain. However, further research is needed to ensure that no negative impacts arise along with the use of this technology over a longer period.

The results show that the use of treated wastewater not only has a positive impact on agricultural products, but also on reducing production costs. The relationship between the nutrient content in wastewater and the increase in crop yield and the reduction in the use of chemical fertilizers is very clear (Khedher et al., 2025). The increase in nitrogen and phosphorus content in soils irrigated with treated wastewater plays an important role in increasing agricultural productivity.

The relationship between the quality of treated wastewater and crop yield shows that water that has gone through a treatment process with good standards can provide results equal to or even better than conventional fresh water (Hodaifa et al., 2025). This proves that wastewater treatment technology is able to produce water with quality that supports plant growth without posing a risk of contamination.

The relationship between the use of treated wastewater and economic efficiency also shows that this technology can reduce farmers’ operational costs, especially in terms of fertilizer use (Coppens et al., 2025). Significant increases in crop yields, accompanied by reduced agricultural input costs, can help increase farmers' incomes, especially in drought-stricken areas.

Data showing the stability of soil quality and crop yields reinforces the belief that this technology can be implemented sustainably (Okut et al., 2025). There is no indication that the use of treated wastewater has led to a decline in the quality of soil or agricultural products, thus providing confidence that the technology is safe for long-term use.

The case study conducted in the Murcia region provides a more in-depth picture of the implementation of wastewater treatment technology for irrigation. A farmer group in the region has been using treated wastewater for the past three years to irrigate tomato and melon fields. The data showed a 12% increase in crop yields in tomatoes and 10% in melons after the use of treated wastewater.

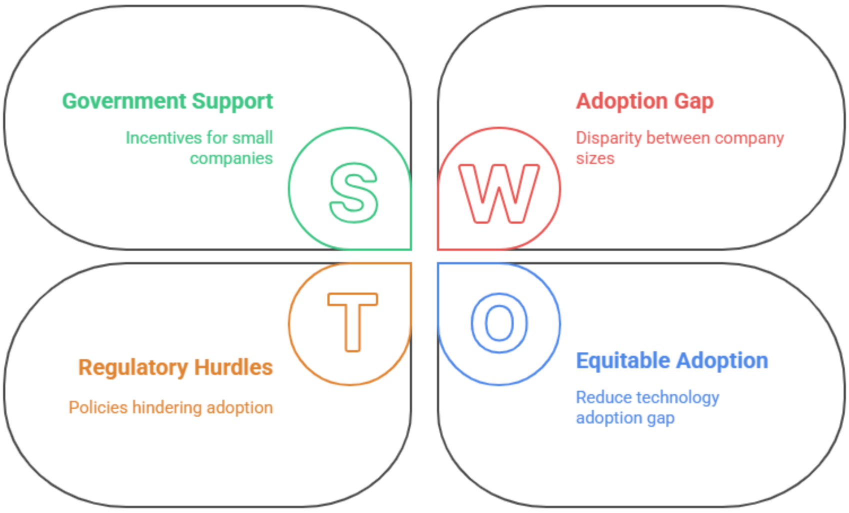

Figure 2. Blockchain Adoption in Food Sector

The use of treated wastewater in this area also reduces the need for farmer groups to use nitrogen fertilizers by up to 20%. Soil irrigated with treated wastewater has an increase in natural nitrogen content, so farmers can reduce the purchase of chemical fertilizers. This provides significant economic benefits for farmer groups, especially in the face of rising fertilizer prices.

The quality of groundwater around agricultural land is also not affected by the use of treated wastewater. The results of laboratory tests show that the content of harmful substances in groundwater remains below the threshold set by environmental regulations (Shah et al., 2025). This shows that the wastewater treatment technology used in the region has worked well in maintaining environmental balance.

The results of this case study provide evidence that treated wastewater can be used as a safe and sustainable source of irrigation in the long term. The implementation of this technology not only increases agricultural productivity but also reduces negative impacts on the environment, making it an ideal solution for drought-stricken regions.

Increased yields of tomatoes and melons in the Murcia region indicate that treated wastewater can yield better yields than conventional freshwater (Du et al., 2023). The positive effects of the natural nutrient content in treated wastewater, especially nitrogen, allow plants to grow more vigorously without the need for a lot of additional fertilizer. This provides direct benefits for farmers, both in terms of productivity and operational costs.

A reduction in the use of chemical fertilizers by up to 20% shows that treated wastewater can serve a dual function, both as a source of irrigation and a source of nutrients for plants. This reduces reliance on chemical fertilizers, which is often one of the biggest expenses for farmers. Thus, this technology not only helps in overcoming the water crisis, but also improves economic efficiency.

The quality of groundwater that is not affected by the use of treated wastewater is proof that the treatment technology used succeeds in maintaining environmental balance. The absence of an increase in harmful substances in groundwater gives confidence that this technology can be used without the risk of long-term pollution. This is very important, especially in agricultural areas that rely heavily on the quality of groundwater for irrigation and consumption purposes.

This study supports the view that treated wastewater can be a safe and effective alternative to agricultural irrigation in areas experiencing water scarcity. The results obtained in Murcia can serve as an example for other regions in Spain to adopt this technology and obtain similar benefits.

The relationship between increased crop yields and the use of treated wastewater in Murcia suggests that wastewater can serve as a more efficient source of irrigation. The increased nutrient content in treated wastewater has a direct impact on plant productivity, resulting in higher yields. The reduction in the use of chemical fertilizers shows the existence of double efficiency resulting from the application of this wastewater treatment technology.

The relationship between the use of treated wastewater and the quality of groundwater shows that good treatment technology can reduce the risk of environmental contamination. Data from the case study in Murcia shows that groundwater remains of good quality, which means that the use of treated wastewater does not pose a long-term pollution risk.

The relationship between the use of wastewater treatment technology and the economic efficiency of farmers is very clear in this case study. The reduction in the use of chemical fertilizers and the increase in crop yields show that this technology not only provides a solution to the water crisis, but also has a significant economic impact on farmers.

Data from this case study shows that wastewater treatment technology can be widely adopted in Spain, especially in regions experiencing water shortages. The relationship between the results of this study and the Spanish government’s policies also supports the adoption of this technology on a national scale, as part of a strategy to maintain the sustainability of agriculture in the future.

This study shows that the use of treated wastewater for agricultural irrigation in Spain has a positive impact on increasing crop yields and economic efficiency for farmers. Yields increase by 10-15% in crops such as tomatoes and cucumbers, while the use of chemical fertilizers can be reduced by up to 20%. The quality of soil and groundwater is maintained, without the accumulation of harmful substances that can harm the environment. Wastewater treatment technology has proven to be effective in overcoming the water crisis and providing sustainable solutions for drought-stricken agricultural areas.

Farmers’ acceptance of the use of treated wastewater is also quite high, especially in areas that experience difficulties in accessing fresh water. The success of this technology is not only limited to increasing productivity, but also to reducing agricultural operating costs. Case studies in Murcia show that farmers benefit in terms of crop yields and reduced fertilizer costs, making this technology a viable solution to be applied on a wider scale. The empirical data obtained supports the adoption of this technology as part of the national water management strategy.

Wastewater treatment technology in Spain has gone through a fairly comprehensive technical and economic evaluation process. Testing in different regions gives an idea that this technology can not only be implemented in one region, but has the potential to be applied throughout the agricultural regions of Spain. The results of this study reinforce the view that the use of treated wastewater is a sustainable solution in the face of an increasingly serious water crisis.

The effectiveness of this technology is also reflected in the stability of the quality of the soil and water irrigated with treated wastewater. Plants that grow on the land do not show any negative impacts, both in terms of growth and crop quality. Soil quality is maintained, even increasing in terms of nutrient content such as nitrogen and phosphorus carried by treated wastewater.

The results of this study are in line with previous studies that also found that treated wastewater can increase crop yields and reduce the use of chemical fertilizers. Studies conducted in Israel and Australia showed similar results, where the use of wastewater for agricultural irrigation not only increases productivity, but also helps maintain the balance of the ecosystem. However, several other studies in regions with different climates, such as Southeast Asia, show that crop yields with treated wastewater are not necessarily higher, depending on the quality of the water and the treatment process applied.

The difference between the results of this study and other studies lies in the type of processing technology used. In Spain, the wastewater treatment technology applied is of a high standard and uses a multi-step process that ensures the water produced is safe for irrigation. Meanwhile, in some countries, the technology used is still simple, so the quality of treated wastewater is not always consistent. This affects crop yields and public acceptance of the technology.

Some studies have also expressed concerns about the long-term accumulation of harmful chemicals in the soil due to the use of treated wastewater. However, the results of this study show that, at least in the time period studied, there is no indication of the accumulation of harmful substances. This difference is likely due to the stricter quality of wastewater treatment in Spain compared to other countries.

The results of this study are also different from several studies that report social resistance to the use of treated wastewater in the agricultural sector. In Spain, the acceptance of this technology is quite high, likely due to educational campaigns and government policy support promoting the use of wastewater as a solution to the water crisis. Social and cultural factors also play an important role in these differences in outcomes.

The results of this study show that treated wastewater treatment technology in Spain is already at a mature stage and is ready to be implemented more widely. The increase in crop yields and production cost efficiency is a sign that this technology has great potential to help the agricultural sector adapt to the challenges of the water crisis. It also shows that technology can provide significant solutions without sacrificing environmental health.

Another sign that emerges from these results is the importance of government regulations and policies in supporting technology adoption. The use of treated wastewater in Spain has been strictly regulated, ensuring that the water used meets safety and quality standards. This is proof that strong policy support is crucial in ensuring the successful implementation of new technologies, especially in sensitive sectors such as agriculture.

These results are also a sign that wastewater treatment technology not only has an impact on the environment, but also on social and economic aspects. The acceptance of the community, especially farmers, towards this technology indicates that technology can be widely accepted if it is supported by adequate educational programs (Wu et al., 2023). It is also a signal that innovations in agriculture need to be adapted to local conditions and involve the active participation of the user community.

This research indicates that a comprehensive approach to wastewater treatment, from technology to education and regulation, can be the key to success in dealing with water problems in the future. Without a holistic approach, technology alone may not be enough to make a significant impact.

The implication of the results of this study is that treated wastewater treatment technology can be a sustainable solution for agricultural areas that experience water scarcity. With increased agricultural productivity and reduced input costs, these technologies can help the agricultural sector adapt to the challenges of climate change and the growing water crisis. The results of this study support the expansion of the adoption of this technology to other regions of Spain and even in other countries with similar water problems.

Another implication is that with the right policy support, this technology can be applied more widely. The Spanish government has shown that strong regulations and the right education programs can encourage farmers' acceptance of new technologies (Tian et al., 2023). This shows that an integrated approach between technology, regulation, and community participation is key to addressing future environmental challenges.

The environmental implications of the results of this study are also significant. With the use of treated wastewater, the risk of freshwater exploitation can be reduced, which in turn helps to maintain the balance of the aquatic ecosystem. In addition, the reduction in the use of chemical fertilizers means that water and soil pollution due to excess nutrients can be minimized, providing additional benefits to the environment.

This research also has important implications in terms of future water resource management. With climate change causing an increase in drought in many regions, treated wastewater treatment technology can be one of the main solutions in the national water management strategy. This places this technology as one of the important pillars in agricultural sustainability and water management policies.

The positive results of this study are likely due to the quality of the wastewater treatment technology applied in Spain. The technology used in the country is designed to very strict standards, ensuring that the water produced is safe for use in the agricultural sector. The multi-step treatment process, including filtration, disinfection, and removal of hazardous chemicals, allows treated wastewater to be used without the risk of contamination to plants and soil.

Strong government regulation also plays an important role in the success of this technology (Álvarez-González et al., 2025). The Spanish government has implemented policies that support the use of treated wastewater, including incentives for farmers who adopt this technology (C. Zhang et al., 2023). This creates conducive conditions for the spread of wastewater treatment technology in the agricultural sector, ensuring that it is well received by users.

Farmers' acceptance of this technology is also influenced by the real economic benefits. Increased crop yields and reduced input costs provide clear financial incentives for farmers to switch to treated wastewater (Garrido et al., 2025). These benefits make the technology more attractive, especially in regions that experience frequent droughts and have limited access to fresh water.

Another factor that affects this result is the level of public awareness and education carried out by the government. Educational programs involving farmers and the general public ensure that these technologies are well understood and accepted (Carter et al., 2025). This shows that the success of technology depends not only on technical factors, but also on social and cultural acceptance.

This research shows that treated wastewater treatment technology has great potential to be further developed. The next step is to expand the adoption of this technology to other regions in Spain that are experiencing similar water problems (Ramm & Wojciechowska, 2025). In addition, further research is needed to observe the long-term impact of treated wastewater use on local soils and ecosystems. This is important to ensure that this technology remains sustainable in the long term.

The Spanish government needs to continue to support the development of this technology by providing the right incentives and regulations (Pampinella et al., 2025). Policies that support the adoption of technology by farmers, including subsidy and education programs, must continue to be strengthened to ensure the successful implementation of these technologies on a wider scale. Thus, this technology can be an integral part of the national strategy in managing increasingly scarce water resources.

The development of wastewater treatment technology must also be adapted to the challenges of climate change in the future. Additional research is needed to understand how these technologies can adapt to changing climatic conditions, such as rising temperatures and changing rainfall patterns (Oosterbaan et al., 2025). This will ensure that this technology remains effective in dynamic environmental conditions.

The next step must also involve international cooperation. The wastewater treatment technology that has worked in Spain can be adapted and applied in other countries that face similar water problems. This opens up opportunities for global collaboration in addressing water issues and ensuring the sustainability of the agricultural sector around the world.

CONCLUSION

The most important finding of the study is that the use of treated wastewater for agricultural irrigation in Spain not only increases crop yields by 10-15%, but also reduces the use of chemical fertilizers by 20%, while maintaining soil and groundwater quality. These results show that the wastewater treatment technology applied in Spain has succeeded in providing a solution to water scarcity without causing a negative impact on the environment or the quality of agricultural products.

This research provides added value in the development of the concept of agricultural sustainability through wastewater treatment technology, which is able to overcome the water crisis with a holistic approach between technical, economic, and social aspects. The limitation of this study is that there is no long-term analysis of the impact of treated wastewater use on soil and ecosystems, which indicates the direction of further research to understand the environmental implications more deeply and technological adaptation to climate change in the future.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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