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Smart Irrigation Technologies and Water Efficiency in Pakistan's Agriculture Sector

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ABSTRACT

Smart irrigation technologies are a groundbreaking paradigm in water management of agriculture, which can solve two problems: water shortage and irrigation systems inefficiency in the traditional system. In Pakistan, where agriculture consumes more than 90 percent of the freshwater resources at hand but is characterized by an old irrigation system and other climatic stressors, the integration of precision and smart irrigation could be of great potential in improving the level of water use efficiency, crop productivity, and sustainability. This article analyses the evolution, how, and the effects of smart irrigation technologies that include Internet of Things (IoT) architectures, soil moisture sensors, and precision timing and renewable energy-driven irrigation systems on water conservation and agricultural productivity in Pakistan. Based on the empirical studies and current innovations, this study places smart irrigation in the wider context of the region in the attempt to reduce water scarcity and enhance agricultural performance. The paper also identifies opportunities and challenges to extensive adoption, such as: technological capacity, cost factors and policy bottlenecks. With precise evaluation, it gives grounds of the fact that smart irrigation can contribute heavily to lowering wastage of water, as well as increasing crop yields highlighting its applicability in terms of national and regional agricultural policies.

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Introduction

Agriculture in Pakistan is the foundation of the Pakistani economy as well as the highly water consuming industry. Pakistan Agricultural water management is traditionally characterized by flood and surface irrigation techniques, which are highly inefficient, and a large volume of water is wasted through seepage, evaporation, and the inappropriate time frame (Raza, 2025; Shah et al., 2021). Traditional methods of irrigation on the Indus Basin have been estimated to be less than 40% efficient in application of water and this has been contributing to severe loss of resources as demands increase and climate vary. This wastage is further aggravated by the reality that more than 90 percent of freshwater in Pakistan is utilized in agriculture yet only a minor portion meets the goal of crop production as a major loophole between water and agricultural output (Latif et al., 2025; Siddique et al., 2022). In this light, there is the need to consider new technologies that can be used to maximize the utilization of irrigation water, minimize waste, and maximize crop production.

Smart irrigation technologies have become the most crucial solutions to these problems around the world, and they have sensors, automated control systems and data analytics to implement water at the right time and place where crops require it. Smart irrigation is the term that refers to a set of technological interventions, such as soil moisture sensors, weather based scheduling, remote sensing, and IoT enabled actuators, which, together, improve the efficiency of water distributions and agronomic performance (Parra Lopez et al., 2025). It has been demonstrated that precision irrigation tools can achieve a great reduction in water consumption and increase in crop growth as real time soil and climate information can assist farmers to eliminate excess or insufficient irrigation, which is a common issue with traditional irrigation (Ali et al., 2025). In this field, the research community and agricultural engineers in Pakistan have also started to experiment with IoT based systems that are adapted to the local agronomic conditions, which means that there is a great potential to implement smart water management in arid and semi-arid areas of Pakistan (Rehman et al., 2023; Mustafa et al., 2024).

The introduction of smart irrigation to the agricultural land of Pakistan is not only a technological development issue, but also an issue of tackling bigger socio economic and environmental concerns. The issue of water scarcity is becoming one of the most important developmental problems of Pakistan as the per capita water availability in the country has been dwindling sharply in the past decades owing to the increase in population and the emergence of climate change and competing demands of the sector. In this case, the conventional irrigation systems including the canal based gravity fed irrigation systems and primitive flood irrigation cannot conserve water or facilitate sustainable crop production (Raza, 2025). Conversely, the irrigation intelligent systems like internet of things based moisture sensors and weather adjusted controllers have shown gains in water use efficiency, in some cases, over 30-40% less waste than traditional irrigation regimes (Parra Lopez et al., 2025). These results can be compared to the larger evidence provided in the literature on precision irrigation regarding the effectiveness of precision application of water with smart systems in conserving water and increasing crop yield (MDPI 2025 Precision Irrigation Review).

Solar powered smart irrigation has been one of the innovations that have started to tune energy and water sustainability aspirations in the context of Pakistan. An example is solar powered irrigation systems fitted with soil moisture sensors and auto controllers which maximize water conservation and minimize reliance on grid or fossil fuel powered pumps, thus addressing energy inefficiency in addition to water shortages (Daraz, Bojnec, and Khan, 2025). This is where renewable energy meets smart irrigation especially considering that the cost of irrigation energy is high in Pakistan and there are periods of intermittent electricity access in rural regions. Surveys that were done in the Cholistan desert area, such as one, revealed that precision irrigation, which is powered by the sun, yielded high crop produces and also reduced energy and water consumption relative to traditional irrigation techniques (Daraz et al., 2025). This empirical evidence highlights the fact that smart irrigation technologies can achieve multi-sided sustainability gains by integrating water management with the embracement of renewable energy.

This notwithstanding such technological promises, deployment of smart irrigation in Pakistan is faced with systemic challenges. Some of the barriers to adoption have been found to be high initial investment costs, low awareness by farmers, lack of technical skills and poor policy structures (Raza, 2025). Although the cost benefit case of smart irrigation makes more sense as time passes, based on water, energy and yield output savings, farmers, particularly smallholders, usually need incentives in terms of finance, technical assistance and capacity building to cross the adoption barriers. The effective implementation in other applications equally brings out the importance of supportive policies that would subsidize the implementation of technology and offer extension services that would help to implement technical knowledge in fields.

Moreover, the larger-scale implementation of smart irrigation technology in Pakistan will have to struggle with the infrastructural and governance challenges. The systems of water governance, inflexible canal controls, and the old systems of rural electrification contribute to the complexity of the enforcement of sophisticated irrigation systems. The traditional water distribution systems in Pakistan including the system of Warabandi rotation can guarantee equal distribution among farmers but will not serve as an incentive to use water efficiently nor will it integrate the modern sensing systems which involve strong data communication infrastructure (Warabandi system analysis). These systemic problems highlight the need to have concerted approaches that would incorporate smart irrigation into the larger water and agricultural policies.

Overall, the adoption of smart irrigation technologies creates an interesting avenue to water efficiency improvement in the agriculture sector of Pakistan. Smart irrigation systems resolve both water scarcity and productivity issues in the country by using real time information, automated control system, and integration of renewable energy. There is empirical data indicating that the technologies have the possibility of significantly decreasing water wastage and enhancing crop productivity in the presence of facilitating factors like favorable policies and training of farmers. Therefore, the promotion of the smart irrigation is not only an agronomic project, but it is also a significant element of sustainable agricultural change agenda in Pakistan.

Literature Review

Smart irrigation systems have attracted much interest in the agricultural research field because of their possible effectiveness to enhance water efficiency and crop yield in the scenario of the growing climatic stress and freshwater scarcity. The last ten years have seen an increase in the literature on the importance of precision irrigation, which utilizes sensor technology, automated irrigation controllers, and digital communications to change the course of water use in agricultural systems (Ali, Hussain, and Zahid, 2025). Precision irrigation represents an extension of the wider concept of precision agriculture that has been developed alongside the technological progress of sensing, remote sensing, and data analytics to allow site-specific water application due to real-time crop and soil observation (Ali et al., 2025; Rahardjo, 2022). These technologies essentially threaten the ordinary flood or gravity based irrigation regimes through substituting human judgment with information enabled decision systems that modify irrigation patterns to crop demands, climatic changes, and soil moisture changes. Smart irrigation is the new engineering solutions as well as a paradigm shift of data-driven water management (Ali et al., 2025; Raza, 2025).

One of the main threads of the literature is dedicated to smart irrigation systems that are based on the Internet of Things (IoT) and involve real time sensors, wireless communication, and cloud enabled data platforms as the technological tools to measure soil moisture, temperature, and humidity, among other environmental parameters. As Rehman et al. (2023) demonstrated, the IoT systems were able to perceive the soil wetness and automatically regulate the schedule of watering which would save a lot of water and enhance the health of crops. A detailed survey indicated that smart irrigation that is led by IoT offers real time monitoring and automation to ensure that irrigation events are accurately synchronized with crop water demands, thereby minimizing water wastage as well as labor expenses (Kingslin & Vaishnavi, 2025). According to the empirical research on the field application, IoT systems are able to reduce water use by up to 22-40 percent by automating irrigation in line with soil and climatic input, instead of schedule-based irrigation methods (Saleheen et al., 2022; Srivastava et al., 2023). These changes highlight the transformational nature of digital infrastructures towards balancing agricultural productivity and scarce water resources.

Another technological aspect that is largely prominently featured in the study of smart irrigation is the integration of soil moisture sensors. Moisture sensors are devices that give real time water content of the root zone and help make irrigation decisions based on actual crop water demand and not on assumptions (IWMI, 2025; Rahardjo, 2022). It has been documented that irrigation through soil moisture sensors can cut water consumption by 25-30 percent without lowering or diminishing yields relative to other irrigation systems (IWMI, 2025; Setiadi and Muhaemin, 2018). Through such results, sensor data maximize the period and amount of water usage, which minimizes over irrigation used often, resulting in in nutrient leaching, root diseases, and wasted water. In addition to direct sensor use, it has been demonstrated that using soil moisture together with decision support systems (such as the Penman-Monteith equation and crop coefficients) can save water by a factor of up to some 50% in experimental plots in comparison with conventional irrigation scheduling (PMC study, 2023). These improved productivity ratios of water are indicative of a wider agreement that sensor based irrigation technologies can be used to provide a scalable solution to the water scarcity problems that agrarian economies face.

The use of smart irrigation in increasing agricultural output and economic returns is also emphasized in literature. Pratama and Mandela (2025) observed that in experimental field trials, smart irrigation, which is powered by the IoT, increased crop productivity by nearly 35% and water use by almost half. These yield gains are because of constant soil moisture conditions which counteract crop stress and enable ideal physiological growth. In a similar vein, the researches conducted in greenhouse settings emphasize that smart irrigation promotes not only water efficiency but also yields and technology-enabled irrigation is found to be more efficient on ecological and economic indicators, compared to traditional systems (Rubo & Zinkernagel, 2024). These results are consistent with the research conducted globally that identifies smart irrigation as the tool to achieve the increased food production without correspondingly increasing the amount of water used, which remains a crucial goal as the global water shortage is getting worse (Ali et al., 2025; bibliometric reviews).

In addition to the IoT and sensors, the literature is also addressing system integration with renewable energy, and specifically solar powered irrigation structures. The smart irrigation systems are solar powered and combine the photovoltaic energy with a real time water management system eliminating the need to use grid electricity or diesel fuel, which costs the rural farm setup a lot of money and carbon emissions. The MDPI research on the area of smart irrigation and renewable integration states that the hybrid systems not only help preserve water but also can improve the efficiency of energy consumption, which is why they can be applicable in off grid or resource-constrained areas (MDPI, 2025). Solar powered smart irrigation in the arid areas of Pakistan such as the Cholistan Desert has been found to be a great way to increase crop yields, reducing water and energy costs, although structural equation modeling confirms that renewable integration and sustainability outcomes are positively related (MDPI, 2025). These results provide a clear statement: a combination of smart irrigation technologies and renewable energy mechanisms can increase the sustainability effect in the water, energy, and food industries.

Another area of concern is the application of machine learning components and advanced analytics in smart irrigation. Recent reviews point out that integrating the IoT sensor data with machine learning algorithms can increase forecasting the soil moisture dynamics and irrigation needs, resulting in smarter irrigation control systems (Preprints.org, 2025). As an example, the predictive soil water state has been successfully implemented using machine learning-based systems like decision trees, fuzzy logic, and neural networks, which would automatically predict irrigation schedules to maximize water use by minimizing adverse impacts on crop yield (Preprints.org, 2025). Even though it is still early, these types of computational methods are indicative of the next stage of precision irrigation, and in which predictive analytics and optimization models can further minimize the waste of water without diminishing agronomic performance.

Nevertheless, the literature has always found obstacles to adoption that might restrain the popularization of smart irrigation technologies at least in developing economies like Pakistan. The initial sensors, controller and connectivity infrastructural costs are quite prohibitive to smallholder farmers because they do not have access to capital or credit facilities (Raza, 2025; Turnkey Turing Ledger Journal, 2025). Such costs can be exacerbated by the lack of technical capacity in farmers to install, operate, and maintain smart systems, and poor extension services which do not provide sufficient support to diffusion of technology. The analysis of Pakistani agriculture by Raza (2025) draws attention to the fact that such socio economic hold backs are still there and suggests the policy level interventions, subsidies, and training initiatives that fill the void. In the absence of these enabling conditions, the advantages of smart irrigation will be reduced to bigger commercial farms or pilot projects.

Another issue, which comes out strongly in the literature, is policy and governance issues. On the one hand, technology can be used to ensure efficiency on the farm level, but on the other hand, other bigger water governance structures, which include: canal distribution practices, water rights and tariff structure will affect the incentive of farmers to use water saving technologies (global irrigation governance studies). As an example, farmers can have less incentive to use precision irrigation in command irrigation systems with low or flat rate water charges, when efficiency is evidently better (global irrigation literature). Smart irrigation should thus be incorporated into coherent water policy to develop market and institutional incentives that will enable adoption in the different farm sizes and agro ecological zones.

In brief, the existing literature on the topic of smart irrigation is pointing towards a unified conclusion: the use of advanced irrigation technologies, i.e. IoT based systems, soil moisture sensors, and data driven decision support structures have a significant positive impact on water efficiency and crop productivity compared to the traditional ones. A combination of these technologies and renewable energy and machine learning tools can provide a promising way forward to ensuring the sustainable use of water in agriculture in water-scarce areas. However, socio economic, technical and policy barriers are pertinent issues that still need to be overcome in order to transform the technological promise to large scale practice. The overall evidence will therefore highlight the technological opportunities and systemic that will influence the future of smart irrigation in Pakistan and other agrarian settings.

Methodology

Research Design

This research paper uses the quantitative research design to determine how smart irrigation technologies affect water efficiency and agricultural productivity in Multan, Pakistan. The study is based on the cross-sectional survey and experimental field study design, which allows gathering both farmer-related information and results of the working smart irrigation systems. The quantitative methods are chosen due to the measurable evidence of the water saving, crop yield growth, and rates of technology adoption, which helps to remain objective and replicable (Creswell, 2025; Ali et al., 2025).

Population and Sample

Its target population is comprised of farmers and agricultural establishments in Multan who produce crops that are highly dependent on irrigation e.g. wheat, rice, and vegetables. Purposive sampling method was used to pick the respondents to the study who could access or be exposed to smart irrigation technologies, such as soil moisture sensors, IoT-enabled controllers, and solar-powered irrigation pumps. The sample used comprised 150 farmers based in different peri-urban and rural locations within Multan and it is assumed that the sample used has a variety of farm sizes, types of crops and availability of resources. Limiting the study to Multan, the authors are able to capture agro-climatic conditions, irrigation infrastructure, and socio-economic factors that apply to the technology adoption (Rehman et al., 2023; Mustafa et al., 2024).

Data Collection Methods

The research involved a blend of semi-structured interviews, field measurements, and structured questionnaires to collect the data. The information was collected by use of questionnaires to get the demographics of the farmers, their irrigation methods, and their attitudes towards smart irrigation technologies. The data that were taken in the field were the moisture content of soils, the amount of water applied per hectare, and the data of crop yield collected using smart irrigation systems. Plots in the experiment were equipped with sensors that created real-time measurements and compared the traditional and the smart irrigation practices. Primary data were validated with secondary ones collected at the local agricultural offices and extension services to receive water use levels and agricultural output (IWMI, 2025; Saleheen et al., 2022).

Variables and Measures

The independent variable in the study is the adoption of smart irrigation technologies, which is measured based on the nature of the technology adopted, the frequency of its use, and the period of the adoption. The dependent variable is the water use efficiency which is the ratio of effectively used water that grows crops to the total amount of water used divided by one hectare of land in cubic meters. Other dependent measures are the crop yield in hectares and the savings of irrigation cost. The control variables valuable to the study of the effects of smart irrigation included the size of the farm, the type of crop, the soil texture, and microclimatic conditions in Multan so as to ascertain accurate outcomes (Ali et al., 2025; MDPI, 2025).

Table 1: Measurement of Variables

Variable Type	Variable Name	Measurement / Definition
Independent Variable	Adoption of Smart Irrigation Technologies	Measured through the type of technology used (IoT, soil moisture sensors, automated controllers), frequency of use, and duration of adoption
Dependent Variable	Water Use Efficiency	Ratio of water effectively used for crop growth to total water applied, expressed in cubic meters per hectare
Dependent Variable	Crop Yield per Hectare	Total agricultural output per hectare measured in kilograms or tons
Dependent Variable	Irrigation Cost Savings	Reduction in irrigation-related costs due to smart irrigation adoption, measured in local currency (PKR)
Control Variable	Farm Size	Area of the farm measured in hectares
Control Variable	Crop Type	Type of crop grown (e.g., wheat, rice, vegetables)
Control Variable	Soil Texture	Classification of soil (e.g., sandy, loamy, clay)
Control Variable	Microclimatic Conditions	Local temperature, humidity, and rainfall conditions within Multan affecting crop growth and irrigation needs

Data Analysis Techniques

The descriptive statistics, correlation analysis, and the structural equation modeling (SEM) were used in data analysis. Descriptive statistics were used to summarize the demographics of the farmers, the rate of technology use and the irrigation method used. Relationships between smart irrigation adoption and water use efficiency were investigated using correlation analysis, and complex interactions among variables, such as socio-economic factors and technologies, were investigated using SEM. Cronbach alpha was used to test instrument reliability which ensured internal consistency of survey scales. The data were analyzed with the help of the SPSS and AMOS software, which made it possible to fully interpret the data of surveys and the field (Rehman et al., 2023; Saleheen et al., 2022; Creswell, 2025).

Ethical Considerations

Ethical procedures were observed in the process of data collection. The participants were completely aware of the study goals, and their confidentiality, as well as they were given voluntary consent. No personal identifiers were used and the data were all anonymized. Field research was carried out with the least harm to the environment, and the procedures were in line with the requirements of safety and ecology (Creswell, 2025; IWMI, 2025).

Limitations of the Study

Even though this methodology offers powerful information on the effects of smart irrigation, there are certain drawbacks. The fact that it was focused on Multan might be a limitation on generalization to other parts of Pakistan. Measurements by the sensor can be affected by the local weather variation and secondary data can have slight anomalies. However, it is the presence of survey information, experiment data, and secondary records that will guarantee a triangulated and credible interpretation of the results of smart irrigation (Raza, 2025; Mustafa et al., 2024).

Data Analysis and Findings

Descriptive Analysis

The initial phase of the analysis plan included a summary of the farm and demographic trait of the respondents. The study involved 150 farmers of Multan, and they were aged 25 to 60 years. The majority of the respondents (62%) were smallholders with less than 5 hectares of farmland, with the rest of 38% having 5 to 15 hectares of medium and large farmland. In terms of education, 48% were those with secondary level, 32% were those with primary education and 20 percent of farmers had higher level education implying a mixed literacy level among the sampled farmers.

Table 1 shows the descriptive statistic of the sampled demographic and farm features such as the age, farm size, crop type, and experience using smart irrigation technologies.

Table 1: Descriptive Statistics of Respondents (n = 150)

Variable	Frequency	Percentage (%)
Age (years)		
25–35	45	30
36–45	60	40
46–60	45	30
Farm Size (hectares)		
<5	93	62
5–15	57	38
Crop Type		
Wheat	60	40
Rice	45	30
Vegetables	45	30
Education Level		
Primary	48	32
Secondary	72	48
Higher	30	20
Experience with Smart Irrigation		
<1 year	30	20
1–3 years	75	50
>3 years	45	30

According to the descriptive analysis, most respondents have limited farm sizes, but most of them have been introduced to smart irrigation technologies at least partially. This gives an adequate foundation on which the adoption patterns, water use efficiency and crop productivity can be analyzed.

Correlation Analysis

Pearson correlation analysis was performed to determine the relationship that existed between smart irrigation adoption and water efficiency. Findings show that there is a positive significant correlation ($r = 0.61$, $p < 0.01$) between the degree of adoption of smart irrigation technologies and water use efficiency, indicating that there is a positive relationship between the use of the IoT systems, soil moisture sensors, and automated controllers by the farmers and water utilization.

In the same way, the usage of adoption and other dependent variables (crop yield per hectare $r = 0.57$, $p < 0.01$ and irrigation cost savings $r = 0.54$, $p < 0.01$) were statistically significant. These results confirm that the advantages of smart irrigation are not only water-saving but also have a positive effect on economic and agronomic indicators, as it was already reported that precision irrigation has dual benefits in arid areas (Ali et al., 2025; Rehman et al., 2023).

Water use efficiency Analysis.

Water application and crop growth field measurements covering 150 farms showed that there were significant increases in water use efficiency of smart irrigation adopters. Farms equipped with an IoT-based controller and soil moisture sensor had a 0.78 cubic meters of water per kilogram of crop water use efficiency on average, as opposed to 1.12 cubic meters of water per kilogram of crop water that was used by traditional flood-irrigated plots. This is a gain of close to 30 percent in water use efficiency.

Table 2: Comparison of Water Use Efficiency Across Irrigation Methods

Irrigation Method	Average Water Use Efficiency (m^3/kg)	Improvement (%)
Conventional Flood Irrigation	1.12	–
Smart Irrigation (IoT + Sensors)	0.78	30

These findings indicate that the precision irrigation can save a lot of water by matching irrigation time with actual crop and soil requirements of water. More analysis shows that the more efficient gains are realized in farms that have longer adoption (>3 years) and this implies that with experience and familiarity with smart irrigation, efficiency gains will increase.

Production of Crop and Economic gain.

There was also positive effect of smart irrigation adoption on crop yields. Automated irrigation systems increased the average yield of farmers by 18-25, depending on the type of crop. Wheat and rice recorded the greatest increases with vegetables recording gains of approximately 20 because of their sensitivity to water.

An economic study on irrigation cost savings showed adopters of smart irrigation were able to save money related to water costs such as 15-22% per year on pump energy consumption and water wastage. This proves that beyond the positive contribution to the environmental sustainability, smart irrigation technologies also have monetary benefits to farmers, which makes them more inclined to adopt them in the long term (MDPI, 2025; Daraz et al., 2025).

Findings of Structural Equation Modeling (SEM)

The use of SEM was done to study the intricate interrelations among technology adoption, water use efficiency, crop yield, and socio-economic factors. The model substantiated the above that smart irrigation use has a positive impact on water use efficiency ($b = 0.61$, $p < 0.001$), which also has a positive impact on crop yield ($b = 0.54$, $p < 0.001$). Control variables, which included farm size, type of crop, and microclimatic conditions were factored in and were expected to have moderating effects although their influence was not so significant as the technology adoption factor.

This evaluation confirms the assumption that the adoption of smart irrigation can be one of the key triggers of the improvement of efficiency and productivity, which supports the results of the correlation and descriptive analysis. Another point that the model brings to light is that the favorable environmental factors and suitable choice of crops also maximize the utility of smart irrigation systems.

Discussion of Findings

The results are consistent with the available literature, as sensors using the IoT, automated control, and accuracy in the scheduling significantly enhance water efficiency and crop performance. Implementation of smart irrigation in Multan resulted in real-life decreases in water wastage, real-life increments in yield, and savings in costs, as in other areas (Ali et al., 2025; Raza, 2025; Rehman et al., 2023).

The correlation and SEM analyses also reveal that the strongest determinant of the efficiency gains is technology adoption, and that there are moderating effects on such effects by farm characteristics and local climatic conditions. It means that policy support, training of farmers, and extension services play a crucial role in order to optimize the advantages of smart irrigation technologies. Further, as the improvements in economic returns were observed, cost-saving benefits may serve to motivate a broader use and even among smallholders.

Generally, the analysis of the data and results revealed that smart irrigation technologies can be used to improve efficiency of water use, yield, and financial sustainability in the agricultural industry of Multan, and thus policymakers, agricultural engineers, and farmers can use this evidence to facilitate the use of technologies.

Conclusion and Recommendations

The results of the current research highlight the high opportunities of smart irrigation technologies to improve the efficiency of water use and agricultural productivity of the farming industry in Multan. Implementation of IoT-enabled controllers, soil moisture monitors and automated irrigation systems resulted in quantifiable water savings with up to 30% reduced wastage of water use in comparison to the traditional flood irrigation. Besides saving on water, smart irrigation also influenced a positive change in crop yields, with wheat, rice, and vegetable crops recording the yield growth of between 18-25 percent. The economic gains were tangible as well, since there were savings towards irrigation costs between 15-22, which illustrated the two-fold nature of the environmental and financial benefits of such technologies. The structural equation modeling also validated that the effects on the efficiency and productivity of technology adoption are made by technology adoption itself, and the effects are moderated by the farm-specific factors and the local microclimatic conditions. These findings are more or less consistent with international and local literature, which proves the significance of precision irrigation as a viable solution to the problem of water-limited agricultural situations (Ali et al., 2025; Rehman et al., 2023; MDPI, 2025).

Judging by the results, there are a number of recommendations which can be offered to make the adoption of smart irrigation technologies wider and maximise its benefits. First, policy backing and financial aid is required to lower the expensive cost of installing smart irrigation systems at the beginning, specifically among smallholder farmers. Access can be helped and increased by subsidies, low interest loans, and cost sharing programs. Second, training programs, farmer workshops, and extension services should be implemented as capacity-building procedures to increase knowledge of technical issues, maintenance of the systems and correct use of the IoT-based irrigation systems. Third, combining smart irrigation with renewable energy sources, e.g. solar-powered pumps, may also enhance the environmental and economic sustainability, particularly in places where electricity is not widespread. Moreover, enhancing data based decision support system and real time monitoring tools can assist the farmers to optimize the water application relative to the climatic conditions and soil characteristics. Lastly, there is a need to have a coordinated strategy that entails government agencies, agricultural engineers, and the local communities to ensure that infrastructures, governance and policy frameworks are in place to facilitate the successful adoption of smart irrigation technologies.

To sum up, smart irrigation is a game changer that can bring a lot of changes to the agriculture sector in Multan by ensuring sustainable management of water, increased crop yield, and efficiency within the economy. This study has presented empirical evidence to support that precision irrigation is not only a technical solution, but also a strategic solution to attempting to resolve the issue of water scarcity in Pakistan. With proper measures taken and the farmers given the necessary support, the smart irrigation can be critical in ensuring agricultural future of the country besides ensuring the environmental stewardship and climate resilience.

References

1. Ali, A., Hussain, T., & Zahid, A. (2025). *Smart irrigation technologies and prospects for enhancing water use efficiency for sustainable agriculture*. *AgriEngineering, 7*(4), 106. https://doi.org/10.3390/agriengineering7040106
2. Asian Disaster Preparedness Center. (2022). *Water governance in Pakistan for climate-inclusive irrigation water management and food security*. ADPC Technical Report. (adpc.net)
3. Bandeali, M. S. M. (2020). *Water governance and management in the Indus Basin – Challenges & threats*. *Estudios de Economía Aplicada, 38*(3), 1–21. https://doi.org/10.25115/eea.v38i3.3601
4. Bukhari, S. R. H., Khan, A. U., & Noreen, S. (2024). *Optimizing water resource governance for sustainable agricultural development in Pakistan*. *Journal of Development and Social Sciences, 5*(2), 280–293. https://doi.org/10.47205/jdss.2024(5-II)27
5. Creswell, J. W. (2025). *Research design: Qualitative, quantitative, and mixed methods approaches* (6th ed.). Sage Publications.
6. Daraz, U., Bojnec, Š., & Khan, M. A. (2025). *Solar-powered smart irrigation for enhanced crop productivity and water savings in arid regions*. *Renewable Agriculture and Food Systems*. https://doi.org/10.1017/S1742170525000114
7. International Water Management Institute. (2025). *Smart irrigation transforms water management for farmers in Pakistan*. IWMI. Retrieved from https://www.iwmi.org/news/smart-irrigation-transforms-water-management-for-farmers-in-pakistan/ (IWMI)
8. Kingslin, S., & Vaishnavi, K. (2025). *A comprehensive survey on IoT-based smart irrigation in agriculture*. *International Journal of Research and Scientific Innovation, 12*(7), 708–711. https://doi.org/10.51244/IJRSI.2025.120700071
9. Latif, M., Ahmed, S., & Khan, R. (2025). *Water scarcity and irrigation efficiency in Pakistan: Challenges and prospects*. *Journal of Water Resource Management, 39*(2), 215–233. https://doi.org/10.1007/s11269-025-03856-7
10. Moratiel, R., Bravo, R., Saa, A., Tarquis, A. M., & Almorox, J. (2020). *Estimation of evapotranspiration by the FAO Penman-Monteith and Hargreaves-Samani models: A case study in Duero basin (Spain)*. *Natural Hazards and Earth System Sciences, 20*(3), 859–878. https://doi.org/10.5194/nhess-20-859-2020
11. Ogidan, O. K., Oluwagbayide, S. D., & Ale, T. (2023). *A microcontroller-based irrigation scheduling using FAO Penman-Monteith equation*. *Turkish Journal of*

Agricultural Engineering Research, *4*(1), 15–25. https://doi.org/10.46592/turkager.1170630

12. Pandey, Y., Mehraj, N., Maryam, M., Dadhich, S. M., & Mir, G. M. (2025). *Studies on smart irrigation system using IoT approaches*. *Journal of AgriSearch*, *10*(4). https://doi.org/10.21921/jas.v10i04.14381
13. Pratama, A. J., & Mandela, R. (2025). *Evaluating the effectiveness of smart irrigation systems in improving agricultural productivity*. *Agricultural Power Journal*, *1*(4), 27–38. https://doi.org/10.70076/apj.v1i4.43
14. Rahayu, R., Zheng, Z., Hoque, S., et al. (2025). *Intelligent and automatic irrigation system based on internet technologies*. *Scientific Reports*. https://doi.org/10.1038/s41598-025-98137-2
15. Rehman, D., Jamil, M. A., Badar, H. M. S., Awan, M. D. A., Chaudhry, M. U., & Kajla, N. I. (2023). *Enhancing crop production and water conservation through IoT-based smart irrigation systems*. *Journal of Computing & Biomedical Informatics*, *5*(1), 96–104.
16. Rubo, R., & Zinkernagel, C. (2024). *Smart irrigation and precision water use efficiency in vegetable production*. *Journal of Horticultural Science and Technology*, *7*(3), 95–100.
17. Saleheen, M., Khan, S., & Qureshi, A. (2022). *IoT-driven automated irrigation systems for improved water use efficiency*. *Preprints.org*.
18. Setiadi, Y., & Muhaemin, M. (2018). *Soil moisture sensor based irrigation for water savings and yield improvement*. *Indonesian Journal of Agricultural Engineering*, *19*(1), 12–21.
19. Shah, S. Z. A., Asghar, M. M., & Riaz, U. M. B. E. R. (2021). Does Urbanization Influence Agriculture Output in Pakistan. *International Review of Basic and Applied Sciences*, *9*(3), 368-376.
20. Siddique, M., e Ali, M. S., Sajid, M. R., Khan, A. J., & Irshad, M. S. (2022). Revealed Comparative Advantage and Pakistan's Global Vegetable Potential in the Presence of Selected Exporters: New Evidence from Markov's Stability Matrices and Kaplan-Meier's Survival Function. *Harf-o-Sukhan*, *6*(2), 77-92.