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RESEARCH ARTICLE

Perceived benefits and challenges of IoT-based smart irrigation system: A case study from Tamil Nadu farmers

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Abstract

The increasing challenges of water scarcity, labour shortages and climate variability have necessitated the adoption of precision farming technologies in Indian agriculture. Among these innovations, adopting Internet of Things (IoT) technology in agriculture offers significant potential to revolutionize farming methods by increasing productivity, encouraging crop diversification, enhancing sustainability and reducing environmental impact. This study aims to evaluate the perceived benefits and challenges associated with adopting IoT-based smart irrigation systems by farmers in the Coimbatore district of Tamil Nadu. Data were collected from 120 farmers using IoT-based smart irrigation systems, randomly selected from the user list provided by the case firm. The Analytical Hierarchy Process (AHP) was employed to evaluate and prioritize the benefits perceived by farmers. At the same time the Plackett-Luce Model (PLM) was used to identify and rank the challenges that hinder effective usage. Results indicated that environmental advantages, particularly reduced water and energy consumption, were perceived as the most significant. Economic benefits, including enhanced operational efficiency and decreased labour costs, were also perceived as significant outcomes. Additionally, farmers acknowledged personal benefits like real-time monitoring, improved decision-making and reduced physical strain. Despite these advantages, high initial investment, complex user interfaces and limited technical knowledge were identified as the critical challenges encountered by the farmers. These findings suggest the need for affordable, user-friendly and locally supported IoT solutions and targeted capacity-building programs. Addressing these factors is essential for promoting broader adoption and realizing the full potential of smart irrigation technologies for sustainable agriculture.

Keywords: challenges; Internet of Things; perceived benefits; Placket-Luce Model; smart irrigation

Introduction

To meet the growing global food demand while minimizing environmental impact, it is essential to improve agricultural productivity as well as water and nutrient efficiency (1). The agricultural sector accounts for 89 % of groundwater usage for irrigation, while the remaining 11 % is utilized for domestic and industrial purposes (2). India, the world's largest groundwater user, utilizes approximately 25 % of the global groundwater reserves and is facing severe water scarcity due to its dependence on unpredictable monsoons, exacerbated by declining water resources, extreme weather conditions and inefficient resource management. The central groundwater board reported that 14 % of the nation's groundwater assessment units are categorized as over-exploited, while 4 % are considered critical (3). With irrigation projected to be the primary user of water, enhancing water-use efficiency is crucial to increasing irrigated land while ensuring water conservation. This necessitates the integration of advanced technologies like IoT to enhance water-use efficiency in Indian agriculture.

Technological advancements, particularly the integration of the Internet of Things (IoT) with wireless sensor networks (WSN) and cloud computing, have reshaped traditional agricultural practices. These systems significantly enhance efficiency, sustainability and profitability by enabling better resource management and streamlined operations (4).

Smart irrigation is a cutting-edge technology-driven system that optimizes agricultural water management by combining IoT, automation and real-time monitoring. It consists of irrigation nodes fitted with solenoid valves, sensors and solar panels. These nodes communicate wirelessly with a central gateway, which subsequently transmits the collected data to a cloud server via an internet-based network. The cloud server processes and stores the data, providing an interface through APIs that allow farmers to monitor and control the system remotely. Using a mobile or web application, the farmer can monitor real-time data, schedule irrigation and regulate water flow according to field conditions (5).

IoT-based irrigation systems significantly reduce water consumption by applying precise amounts of water, thereby preventing crop loss due to over- or under-irrigation (6). The automation of irrigation tasks minimizes manual labor, increasing efficiency and reducing errors (7). Traditional irrigation methods, in contrast, often result in significant water wastage due to mismanagement. Moreover, these systems reduce energy usage, operational time and overall costs, enhancing the economic viability of irrigation practices (6).

In recent years, scholarly interest in the adoption of digital technologies in agriculture has grown rapidly, especially in the context of improving productivity and sustainability. Several studies have focused on the implementation (4) and overview of IoT-based irrigation systems (5, 8, 9). Given the benefits of smart irrigation systems, Lee (10) conducted a field experiment and reported that implementing automatic irrigation in paddy fields led to increased yield, ROI, water productivity and reduced labour requirements for water management compared to traditional methods. Despite extensive research on technical implementation, limited attention has been given to farmers' perceptions of the benefits and barriers of these systems. This study addresses this gap by examining the perceived advantages and challenges of IoT-based smart irrigation systems among farmers in Tamil Nadu.

Materials and Methods

Data

This study was conducted in Coimbatore District, the leading coconut-producing region of Tamil Nadu. The region was purposively selected due to its high adoption rate of IoT-based smart irrigation systems and the presence of such solution providers. Smart irrigation is particularly prevalent in plantation crops such as coconut, given the crop's high water demand and the importance of precise irrigation scheduling.

Coconut cultivation in the Coimbatore district primarily depends on drip irrigation. The district receives an average annual rainfall of approximately 600 mm; however, rainfall patterns vary significantly. With borewells being the primary source of irrigation, groundwater depletion has become a growing concern. The depth of borewells typically ranges from 600 to 800 feet, even extending up to 1100 to 1200 feet in some areas.

Beyond water scarcity, a major challenge faced by coconut farmers in this region is the acute shortage of labour. Since coconut cultivation requires regular irrigation, particularly in regions with fluctuating rainfall and declining groundwater levels, the labour crisis not only increases production costs but also affects farm productivity and timely operations. To address these issues, farmers are increasingly adopting automation and mechanization.

A total of 120 farmers using IoT-based smart irrigation systems were randomly selected from a user list provided by the case firm offering such solutions. The case firm involved in this study is a privately held, non-government enterprise operating in the field of irrigation automation. With over 15 years of operational experience, it is recognized as one of the leading providers of IoT-based smart irrigation solutions in Tamil Nadu, particularly in the Coimbatore region. With significant market presence and technical expertise, the firm plays a vital role in promoting and implementing smart irrigation technologies among local farming communities. Given the firm's established industry position, it served as a key partner in facilitating access to IoT technology users by providing a list of farmers currently using its systems.

Given the exploratory nature of the study and the gradual rise in the adoption of IoT-based smart irrigation systems, the population of individuals who have adopted such technologies remains small. This emerging trend naturally limits the size of the available sample pool for empirical research. The demographic profile of the surveyed respondents is represented in Table 1.

As shown in Table 1, most adopters were between 30 and 50 years of age, indicating that younger and middle-aged farmers are more inclined to adopt advanced irrigation technologies. A high level of education was observed, with many having completed higher secondary schooling or above, highlighting the role of education in technology uptake. The majority owned landholdings greater than 2 hectares and had over a decade of farming experience, suggesting that larger and more experienced farmers are more willing to invest in precision technologies. Additionally, most respondents had been using smart irrigation systems for over a year, pointing to growing awareness and confidence in their long-term benefits.

Table 1. Demographic characteristics of adopters of IoT-based smart irrigation systems

Particulars	Category	Frequency (*n* = 120)	Percentage
Age (years)	Below 30	9	7.50
	30-40 years	52	43.33
	41-50 years	35	29.17
	Above 50 years	24	20.00
Gender	Male	114	95.00
	Female	6	5.00
Education	Middle school	5	4.17
	Secondary	32	26.66
	Higher secondary/ equivalent degree	42	35.00
	Graduate	33	27.50
	Postgraduate	8	6.66
Farm size	Marginal (<1 ha)	2	1.67
	Small (1-2 ha)	20	16.67
	Medium (2-4 ha)	43	35.83
	Large (>4 ha)	55	45.83
Farming experience	Below 10 years	26	21.67
	10-20 years	36	30.00
	21-30 years	35	29.17
	More than 30 years	23	19.17
Source of Irrigation	Borewell	45	37.50
	Open well	22	18.33
	Borewell + open well	15	12.50
	Borewell + tank	38	31.67
Years of smart irrigation adoption	Less than 1 year	18	15.00
	1-3 years	54	45.00
	More than 3 years	48	40.00

Tools and techniques used

The Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process is employed to evaluate and rank the perceived benefits of adopting IoT-based smart irrigation systems among farmers through a structured, multi-criteria decision-making approach. AHP provides a systematic framework that integrates subjective judgment, intuition and analytical reasoning, making it particularly suitable for decision -making scenarios that involve intangible and qualitative attributes such as environmental sustainability, resource use efficiency and socio-economic outcomes. It enables the representation of a system and its interacting elements, followed by the quantification and prioritization of these elements based on their contribution to the overall goal.

The AHP process comprises four key phases:

1. Problem structuring and development of the hierarchical model.
2. Collection of data through measurement scales and pairwise comparison.
3. Calculation of normalized weights or priorities for each factor.
4. Analysis and interpretation of the weights to support informed decision-making.

The proposed AHP model, illustrated in Fig. 1, follows a three-level hierarchical structure.

1. The first level defines the main objective: evaluating and prioritizing the benefits perceived by adopters of IoT-based smart irrigation systems.
2. The second level represents the core benefit dimensions, namely environmental, economic and personal benefits, which are critical for understanding the broader impact of smart irrigation systems.
3. The third level represents the specific sub-criteria or performance indicators, such as reduction in overall water consumption, reduced energy usage, increased productivity, reduced labour and operational costs, etc.

Pairwise comparisons are employed to assess the relative importance of both main and sub-criteria within the AHP framework. Respondents, comprising users of smart irrigation systems, provided individual judgments using a structured five-point comparison scale, which facilitated systematic evaluation and prioritization of the perceived benefits associated with smart irrigation adoption. The Aggregation of Individual Judgments (AIJ) method is applied, whereby individual pairwise comparison matrices are combined using the geometric mean to produce a single, group-level comparison matrix for each hierarchical level. This approach facilitates the derivation of collective priorities while

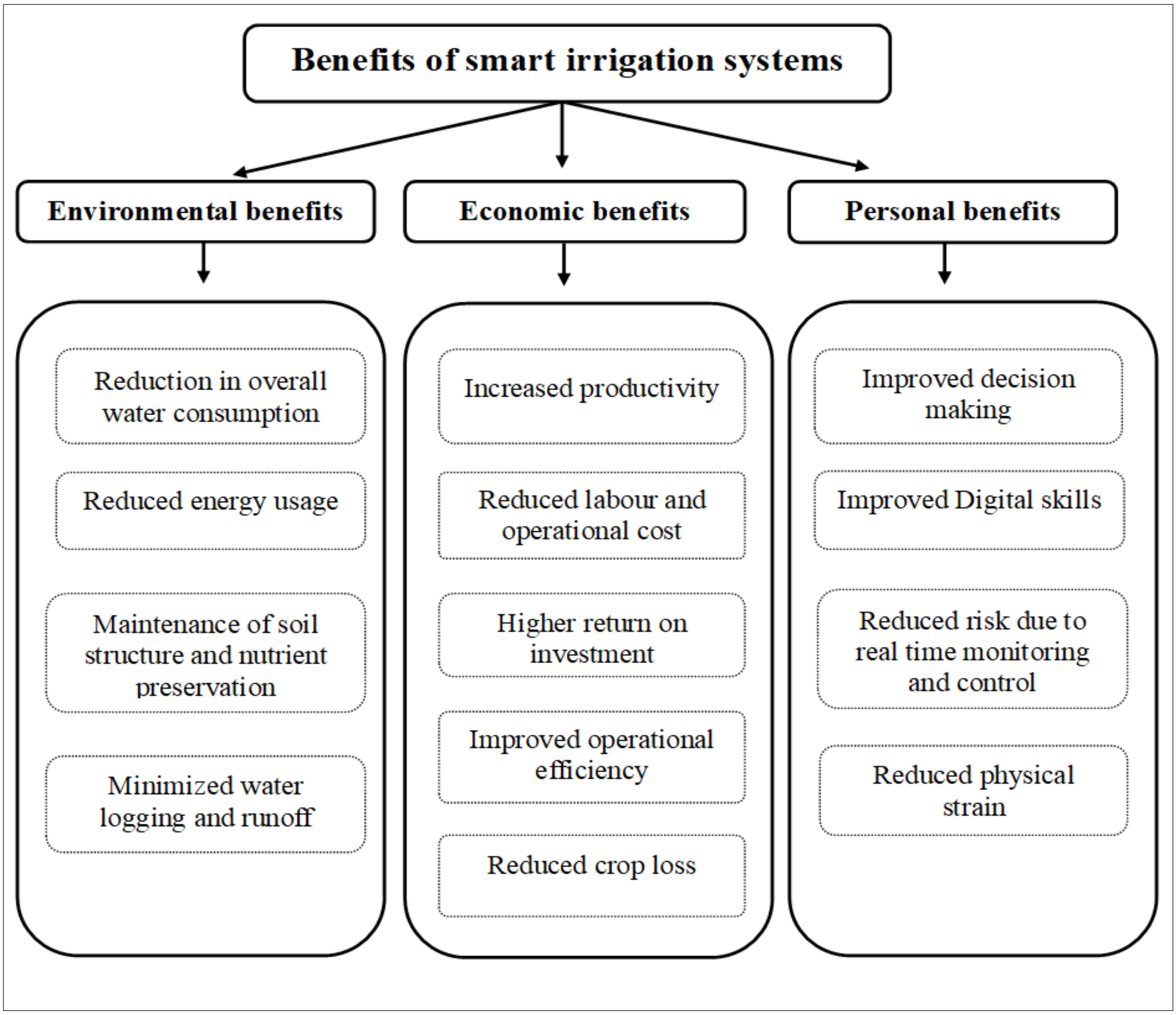

Fig. 1. Benefits of IoT-based smart irrigation systems.

preserving the logical consistency of judgments. Final local and global weights are computed based on the aggregated matrices. To ensure methodological rigor, only matrices exhibiting a Consistency Ratio (CR) less than 0.1 are included in the final analysis, in alignment with established AHP guidelines.

Plackett-Luce Model (PLM)

PLM is employed to assess and rank the challenges encountered by farmers in the adoption of IoT-based smart irrigation systems. This model is particularly well-suited for analysing ranked data, where respondents are asked to order a set of challenges from most to least significant.

Given a set of n items, let θ_i indicate the worth parameter associated with item *i*. The probability of obtaining a specific ranking sequence ($i_1, i_2, ..., i_n$), where i_1 is the highest-ranked item i_n is the lowest-ranked item, is given by Equation 1

$$P(i_1, i_2 \ldots\ldots, i_n) = \prod_{j=1}^{n} \frac{\theta_{ij}}{\sum_{k=j}^{n} \theta_{ij}} \qquad \text{(Eqn. 1)}$$

Equation 2 shows the log-likelihood function based on N observed rankings ($R_1, R_2, \ldots, R_n$)

$$L(\theta) = \sum_{m=1}^{N} \sum_{j=1}^{n_m} (\log \theta_{ij}^{j} - log \sum_{k=j}^{nm} \theta_{ik}^{m} \qquad \text{(Eqn. 2)}$$

Where,

R_m indicates the rank assigned in the m^{th} observation.

ij^m denotes the item occupying the rank j^{th} in the m^{th} observed ranking.

n_m represents the total number of items included in the m^{th} observed ranking.

The estimated θ_i values indicate the relative significance of the challenges encountered by adopters of smart irrigation systems, thereby offering a basis for developing targeted strategies to promote broader adoption.

Results

Relative weights and rankings of perceived benefits in the adoption of IoT-based smart irrigation systems by farmers

Pairwise comparisons are a fundamental step in the AHP, enabling the prioritization of alternatives based on expert judgments. To ensure the reliability of judgements in the AHP, the CR is used as a measure, with a value less than 0.1 considered acceptable. In the present study, the CR for all the evaluated benefits lie within the threshold, ranging from a minimum of 0.000 to a maximum of 0.084, indicating an acceptable level of consistency in the pairwise comparisons.

The normalized scores of relative benefit weights indicate the relative significance of the perceived benefits associated with adopting IoT-based smart irrigation systems. Among these, environmental benefits (0.3391) emerged as the most crucial benefit, followed by economic benefits (0.3331) and personal benefits (0.3278). The global priority weights and ranks of sub-factors corresponding to each benefit category are presented in Table 2.

Among the sub-criteria, the reduction in overall water consumption (EB1) was identified as the most significant benefit perceived by the farmers, with a global weight of 0.0924, followed by reduced energy usage (EB2) (0.0905) and reduced risks due to real-time monitoring and control (PB3) at 0.0876. Other sub-criteria perceived as highly beneficial include improved decision-making through predictive analytics (PB1) (0.0867), minimized waterlogging and runoff (EB4) (0.0857), improved health and well-being due to reduced physical strain (PB4) (0.0813).

While economic benefits ranked second among the major criteria, their sub-criteria showed comparatively lower global weights than those under environmental and personal categories, suggesting a lower perceived impact. However, improved operational efficiency (global weight = 0.0752) and reduced labour and operational costs (0.0735) emerged as the most significant contributors within the economic dimension.

Table 2. Relative weights and rankings of perceived benefits in the adoption of IoT-based smart irrigation systems by farmers

Main Criteria	Relative Benefit Weight	Relative Rank	Sub Criteria	Local Weight	Global Weight	Global Rank
Environmental Benefits	0.3391	1	Reduction in overall water consumption (EB1)	0.2725	0.0924	1
			Reduced energy usage (EB2)	0.2669	0.0905	2
			Minimized waterlogging and runoff (EB4)	0.2528	0.0857	5
			Maintenance of soil structure and nutrient preservation (EB3)	0.2079	0.0705	10
Economic Benefits	0.3331	2	Improved operational efficiency (ECB4)	0.2257	0.0752	7
			Reduced labour and operational costs (ECB2)	0.2207	0.0735	8
			Higher return on investment (ECB3)	0.1921	0.064	11
			Increased productivity (ECB1)	0.1876	0.0625	12
			Reduced crop losses (ECB5)	0.1738	0.0579	13
Personal Benefits	0.3278	3	Reduced risk due to Real-time monitoring and control (PB3)	0.2673	0.0876	3
			Improved decision-making through predictive analytics (PB1)	0.2644	0.0867	4
			Improved health and well-being due to reduced physical strain (PB4)	0.2479	0.0813	6
			Improved Digital skills (PB2)	0.2203	0.0722	9

Plackett-Luce Model parameters for challenges encountered by the farmers in adopting IoT-based smart irrigation systems

PLM was employed to analyse the challenges encountered by adopters of IoT-based smart irrigation systems, following the methodology proposed by Finch (11). The item worth, the key statistic of PLM, indicates the relative significance of each challenge based on the rankings provided by the respondents. A higher value signifies a greater perceived importance of the challenge. Table 3 presents relative worth, standard errors, *z* scores and *p* values for each challenge using the average worth as the reference.

Among the identified barriers, high initial investment emerged as the most critical challenge (worth = 3.5672, $p < 0.01$), exerting a strong influence on adoption decisions. Following this, the complex user interface (worth=1.0613) ($p < 0.01$) was identified as another major problem, perceived as challenging by farmers due to its technical nature. Limited technical knowledge with a relative worth of 0.2403 ($p < 0.05$) also emerged as a significant challenge faced by the farmers. On the other hand, factors such as limited technical support and maintenance services, privacy and security concerns, unreliable power supply and connectivity issues were assigned negative worth but were statistically significant, suggesting that these were perceived as less challenging by the adopters of IoT-based smart irrigation systems.

Furthermore, the performance of PLM was assessed using the residual deviance statistic, which was 1935 with 2514 degrees of freedom. The resulting ratio of 0.76 indicates a good model fit, in line with the commonly accepted rule of thumb (12). Assuming the deviance follows a chi-square distribution, the model fit test yielded a *p*-value of 0.99, further confirming that the PLM adequately fits the data.

Discussion

Perceived benefits of IoT-based smart irrigation systems among farmers

IoT represents a disruptive technological paradigm with the potential to deliver substantial benefits and pose significant challenges. However, its uptake within the farming community remains limited, emphasizing the need for a deeper understanding of its applications in agriculture. With this focus, the present study aims to assess the perceived benefits and challenges encountered by the farmers in adopting IoT-based smart irrigation systems in Tamil Nadu.

AHP was employed to evaluate and prioritize the benefits perceived by farmers from the IoT-based smart irrigation systems. The analysis categorized these benefits into three main categories such as environmental benefits, economic benefits and personal benefits.

Among the primary benefit categories, environmental benefits emerged as the most significant, with the highest relative weight. This indicates that farmers place the highest value on the ecological advantages associated with the usage of IoT-based smart irrigation systems. Within this dimension, reduction in overall water consumption was identified as the most vital benefit, followed by reduced energy usage and minimized waterlogging and runoff. These findings align with previous research (6), which emphasizes that IoT-enabled irrigation systems enhance water use efficiency by site-specific irrigation, thereby significantly reducing water wastage. Furthermore, the observed reduction in energy usage can be attributed to improved irrigation scheduling and automated control features that reduce motor operation time and mitigate risks associated with motor overruns and dry runs. Overall, the findings of the study reflect farmers' recognition of the sustainable benefits contributed by smart irrigation systems.

Economic benefits were ranked second among the primary benefit categories; however, their associated sub-criteria had lower global weights compared to environmental and personal dimensions, indicating a lower perceived impact. However, certain economic factors were recognized as particularly valuable by farmers. Improved operational efficiency was considered the most significant economic benefit, followed by reduced labour and operational costs. These findings suggest that the automation and precision enabled by IoT-based smart irrigation systems contribute to significant savings in both time and resources. IoT systems streamline irrigation processes, reduce manual labour and minimize the frequency of human intervention, all of which contribute to reduced operational expenditure. However, other economic sub-factors, such as higher return on investment, increased productivity and reduced crop losses received comparatively lower global weights. This may be due to the high initial capital investment required for IoT system deployment, which can overshadow potential long-term economic gains in the farmers' immediate assessments.

Table 3. Plackett-Luce Model parameters for challenges encountered by the farmers in adopting IoT-based smart irrigation systems

Challenges	Worth	Std. Error	*z* Value	*p*	Significance
High initial investment	3.5672	0.2235	15.963	<0.001	***
Complex user interface	1.0613	0.1265	8.387	<0.001	***
Lack of technical knowledge	0.2403	0.1168	2.057	0.0397	**
Exposure of hardware equipment to harsh environmental conditions	-0.1897	0.107	-1.773	0.0763	NS
Limited technical support and maintenance services	-0.8918	0.1084	-8.226	<0.001	***
Privacy and security concerns	-1.7587	0.131	-13.425	<0.001	***
Unreliable power supply and connectivity issues	-2.0286	0.142	-14.287	<0.001	***

****p* < 0.01 - Significant at the 1 % level, **p* < 0.05 - Significant at the 5 % level, NS - Non-significant.

Although personal benefits were ranked third among the primary benefit categories, several sub-criteria within this dimension received particularly high global weights, suggesting their perceived importance in the adoption of such systems. Reduced risk due to real-time monitoring and control (PB3) and improved decision-making through predictive analytics (PB1) emerged as the third and fourth most significant sub-criteria overall, with global weights of 0.0876 and 0.0867, respectively. These results emphasize the value farmers attribute to timely, data-driven insights that facilitate active management of irrigation practices and mitigate field level uncertainties. Furthermore, improved health and well-being due to reduced physical strain (PB4) with global weight of 0.0813, was also perceived as a major advantage, highlighting the contribution of automation in reducing the burden of labour-intensive tasks and thereby enhancing quality of life. While improved digital skills (PB2) ranked lower within the personal dimension (global weight = 0.0722), its inclusion reflects an increasing awareness among farmers of importance of digital literacy in effectively utilizing advanced technologies. Overall, these findings suggest that in addition to ecological and economic considerations, IoT-based smart irrigation systems provide significant personal and social benefits, emphasizing their potential in promoting safe, efficient and technologically empowered agricultural practices.

Challenges faced by the farmers adopting IoT-based smart irrigation systems

Among the key barriers identified through the PLM, high implementation costs emerged as a major obstacle to the adoption of IoT-based smart irrigation systems. This may be attributed to a significant initial investment required for hardware, sensors, communication devices and software infrastructure. The cost associated with establishing the required infrastructure, installing sensors and integrating them into existing irrigation systems can be high, particularly for large-scale agricultural operations (13). Developing a cost-effective solution could promote wider adoption, improve irrigation efficiency, optimize water conservation and enhance productivity.

Subsequently, the complex user interface was identified as another major problem, perceived by farmers as particularly challenging due to its technical nature. This difficulty is often compounded using English in the interface, which can hinder effective use among farmers who are not proficient in English. To address this issue, IoT-based irrigation systems should be developed with simplified user-centric interfaces that support local languages particularly Tamil, which is the most widely spoken and preferred language among farmers in the region. The inclusion of multilingual options and intuitive visual symbols can significantly enhance accessibility and usability, particularly for farmers with limited literacy or technical training.

The operation and maintenance of IoT-based irrigation systems often require specialized skills, making it difficult for those without sufficient technical expertise. Consequently, providing adequate training and capacity-building programs for farmers is crucial to promote the effective adoption and long-term sustainability. Particularly, many farmers expressed a strong interest in learning and a willingness to engage with new digital tools, indicating that targeted educational initiatives could significantly enhance both competence and confidence in using IoT-based systems. Limited technical support and maintenance services may hinder the effective use of IoT-based irrigations, especially in remote areas. Establishing local service centres and strengthening support networks through public-private partnerships can enhance system reliability and encourage wider adoption.

In addition to technical and financial barriers, data security and privacy concerns pose significant challenges to the adoption of IoT-based smart irrigation systems. To ensure system integrity, robust cybersecurity measures must be implemented to prevent unauthorized access or manipulation. Privacy concerns should be addressed through the establishment of strong data protection protocols, adherence to relevant regulations and raising farmers' awareness. Raising awareness among farmers about data privacy and involving them in system design and data governance processes can foster transparency, build trust and ultimately support broader acceptance of smart irrigation technologies. Furthermore, unreliable power supply and poor internet connectivity can disrupt system performance; thus, integrating alternative energy sources such as solar power and exploring offline-capable or low-bandwidth communication technologies is recommended to improve operational resilience.

Conclusion

IoT offers transformative potential for achieving sustainable and profitable farming, particularly in the face of increasing environmental and resource challenges. In this regard, this study focuses on evaluating the perceived benefits and adoption challenges of IoT-based smart irrigation systems among coconut farmers in the Coimbatore district of Tamil Nadu. Given the district's irregular rainfall, deep borewell dependency and acute labour shortages, automation and smart irrigation have emerged as practical solutions to enhance water use efficiency and reduce operational burdens. The findings indicate that farmers recognize several advantages, including improved water conservation, enhanced energy efficiency, better risk mitigation via real-time monitoring and reduced labour costs. Among the various perceived benefits, environmental and personal advantages were rated most highly, reflecting a growing awareness of sustainable resource use and interest in precision farming technologies. Although economic benefits were recognized, they were perceived as relatively moderate in comparison to environmental and personal gains.

Despite these positive perceptions, the widespread adoption of IoT-based irrigation technologies remains limited due to several key constraints. The high initial capital investment, the technical complexity associated with system operation and maintenance and limited technical knowledge among the farmers are critical challenges faced by farmers in adopting smart irrigation. Therefore, the study emphasizes the need for inclusive policy interventions to facilitate the broader diffusion and sustainable integration of smart irrigation technologies within the farming community. To address the financial constraints, financial support mechanisms should be strengthened through targeted subsidies, low-interest credit facilities and inclusion of smart irrigation under existing programmes such as the Pradhan Mantri Krishi Sinchayee

Yojana (PMKSY). This would significantly reduce the high initial investment burden that acts as a major barrier for small and marginal farmers. In parallel, infrastructural support such as the promotion of solar-powered systems should be prioritized to ensure energy sustainability and minimize operational costs.

Moreover, capacity building plays a vital role in enhancing farmers' confidence and ability to operate these technologies. Regular training programs, on-field demonstrations and hands-on exposure facilitated through Krishi Vigyan Kendras (KVKs), Farmer Producer Organizations (FPOs) and agri-tech startups can improve awareness and technical proficiency. These should be accompanied by the development of user-friendly mobile applications and interfaces in local languages, tailored to the needs of farmers with limited digital literacy.

In addition, the establishment of decentralized technical support units at the block or village level can help address post-adoption challenges such as maintenance, troubleshooting and timely guidance. Encouraging public-private partnerships (PPPs) can facilitate the creation of such support ecosystems while also fostering innovation. Furthermore, government policy should promote collaborative research between agricultural universities, technology providers and research institutions to develop cost-effective, scalable and region-specific solutions. Significantly, there is a need to integrate smart irrigation technologies into broader digital agriculture frameworks by promoting real-time data platforms and interoperable advisory systems. These efforts should aim to mainstream smart irrigation into climate-resilient agricultural practices, enhance resource-use efficiency and contribute to sustainable rural livelihoods.

Limitations and future directions

Conducting a cross-sectional study presents certain limitations, particularly when assessing farmers' perceptions. Perceptions and attitudes may evolve over time as individuals gain more experience and familiarity with the technology, potentially leading to more favourable evaluations. Therefore, it is recommended that future research adopt a longitudinal study design to track changes in perceptions and usage patterns over time. The study utilized a user list provided by a private firm specializing in IoT-based smart irrigation, which may introduce selection bias. This reliance could have resulted in a sample skewed toward technologically adept or more satisfied users. To address this potential limitation, it is recommended that future research be conducted using more independent and randomized sampling methods. Furthermore, it is suggested that findings be triangulated with data from broader farming populations, including perspectives from non-users and users of alternative systems, to enhance the generalizability and credibility of the results. To further strengthen the research framework, subsequent studies should also consider employing a larger sample size and include quantitative measures of economic and environmental benefits to provide more robust and generalizable insights.

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Authors' contributions

JW conducted a field survey, collected data and drafted the manuscript. MK designed the study and developed the research framework. All authors were involved in the planning and analysis and provided critical feedback on the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no competing interests.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

The authors utilized ChatGPT during the preparation of this work to improve language clarity, enhance readability, correct grammatical errors and refine sentence structure. After using the AI tool, the authors carefully reviewed and edited the material and accept full responsibility for the final content of the publication.

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