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Water Efficient Irrigation by Integrating Clay Pots, Drip Systems, and Internet of Things Monitoring: A Comprehensive Review

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Abstract: Water scarcity is a major challenge in agriculture, where nearly 70% to 80% of freshwater is used for irrigation. This study reviews clay pot irrigation and its integration with drip irrigation and Internet of Things (IoT)-based monitoring for improving water use efficiency. Previous studies have reported substantial irrigation water savings under clay pot irrigation systems up to 80% compared to conventional methods by supplying water slowly near to the root zone and reducing losses. It also provides good water use efficiency and maintains acceptable crop yield under limited water conditions. Previous studies have shown that the performance of the clay pot irrigation depends on pot design, including size and shape. A few studies suggested that storing water in clay pots and the water passing through the pot walls may lead to some improvement in water quality, although detailed data is still limited. However, the integration with drip irrigation and IoT-based control can further improve water distribution and reduce manual effort.

Keywords: Clay pot irrigation; Crop yield; Drip irrigation; Internet of Things; Pitcher irrigation; Water use efficiency

1 Introduction

Clean water is essential for life and has been a major concern around the world for many years. "Agriculture uses the largest share of freshwater, accounting for about 70%–80% of total global water withdrawals [1]. In addition, the use of poor-quality water can negatively affect plant growth and food production [2]. Simultaneously, increasing population growth has increased food demand and placed additional pressure on agricultural water use [3]." To deal with this situation, there is a need to use irrigation methods that can give higher yield with less water [4]. Therefore, drip irrigation is considered one of the most efficient irrigation methods and is known for using less water compared to traditional methods like furrow and sprinkler irrigation [5]. In this method, water is supplied directly to the plant in small amounts, which reduces losses due to evaporation and excess drainage. By using drip irrigation in crops such as cotton, sugarcane, grapes, and bananas, water savings of up to 60% and crop yield increases of up to 50% have been reported [6]. It also reduces labor work and can increase farmer income, making it useful in areas where water scarcity is a major issue [7].

Another method i.e. clay pot irrigation, also known as pitcher irrigation, is a traditional method that helps in saving water by reducing losses due to evaporation and deep percolation, while supplying water directly to the root zone [8]. In this method, clay pots filled with water are buried under the ground up to the neck. Water slowly moves through the pores of the pot and becomes available to plant roots in a controlled manner. Because of this gradual and steady release, the method is considered efficient, especially in areas where water availability is limited. Clay pots are made from natural clay soil and contain small pores in their walls, which allows water to seep out gradually. The simple design and low cost of clay pot irrigation make the system easy to use and effective in maintaining soil moisture near the root zone [9] compared to conventional drip irrigation [10], making it suitable for water-scarce regions. This method is mostly suitable for small areas at present, as the pots need to be filled again and again manually at regular intervals, which requires time and labour. In addition to saving water, clay pot irrigation can help improve soil physical conditions and may also contribute to slight improvements in certain water-quality parameters [8], although currently available evidence remains limited. As a result, it can reduce the pressure on groundwater resources and help limit the negative effects of excessive water extraction, especially in dry regions.

An additional concept used in this review study is the application of Internet of Things (IoT) in irrigation systems. IoT is gradually becoming a useful tool in modern irrigation, as it helps farmers use water more wisely and reduces the need for constant manual work [11]. In this system, sensors and controllers are used to keep track of field conditions like soil moisture, temperature, and water levels on a regular basis. Using this real-time information, the system can decide when irrigation is required and supply water automatically [11]. In recent years, there has been growing interest in IoT-based irrigation because it improves water use efficiency and reduces labour effort. The use of low-cost controllers such as Arduino, along with simple sensors, has made this technology easier to adopt in practical conditions [12].

Although clay pot irrigation and drip irrigation are effective when used separately [7], However, their combined use can provide better results. In such a system, water from a drip line can be supplied into the clay pot, and the pot gradually releases water into the soil. When this system is integrated with IoT-based monitoring, irrigation can be controlled based on real-time conditions.

The main objectives of this study are to review the geometry and materials of irrigation pots, compare pot irrigation with conventional irrigation methods in terms of crop yield and water use efficiency, evaluate reported water-quality aspects associated with clay pot irrigation, examine the integration of clay pot irrigation with drip irrigation and IoT-based monitoring systems

Research gap

Most of the existing studies on clay pot irrigation and drip irrigation have been conducted independently, with limited attention to their combined use as a single system. The use of IoT-based automation in clay pot irrigation has also received limited research attention.

The influence of pot design parameters, such as size and shape, has not been extensively optimized for different crops and field conditions. In addition, only limited quantitative information is available on the reported water-quality aspects in clay pot irrigation systems.

This gap shows the need for an integrated approach that integrates clay pot irrigation, drip irrigation, and IoT-based monitoring to develop a simple and efficient irrigation system.

Scope of the study

This study focuses on clay pot irrigation and examines how it can be used to conserve water in agricultural practices. It discusses the functioning of this method in relation to water-use efficiency and crop performance, particularly in regions where water availability is limited. Attention is also given to the use of low-quality or saline water, and the reported performance of clay pot irrigation under such conditions.

The study further discusses the possibility of combining clay pot irrigation with drip irrigation and IoT-based systems. The purpose is to understand how these approaches can function as an integrated irrigation system to improve water use efficiency, reduce the need for manual effort, and support more effective and practical irrigation management.

2 Types of Pots Used for Irrigation

Different types of pots are used in agriculture and gardening, and their material and design can affect plant growth and water use. In irrigation applications, the selection of pot type is important because it affects water distribution, root growth, and soil physical properties. Clay pots are widely used in irrigation because of their porous nature [13]. Clay pots are generally low cost, locally available, and considered environmentally friendly, although their performance may vary with soil type, water quality, and climatic conditions.

Another type of pot used for irrigation is biodegradable pots because they are environmentally friendly and made from natural waste materials such as wood fibers, bamboo, husk, and recycled paper [14]. Some studies indicated that biodegradable pots may help reduce environmental impact, as they follow the principles of reduce, reuse, and recycle [15]. However, their durability is limited, and they are mainly suitable for short-term use.

Based on previous studies, biodegradable and clay pots have shown promising performance in terms of water distribution, aeration, and environmental sustainability compared with other types of pots such as plastic, concrete, and metal pots [16]. In contrast, plastic and concrete pots may have limitations such as poor aeration, heat build-up, and restricted water movement, which can negatively affect plant growth [17, 18].

Therefore, the selection of pot material should consider both irrigation performance and environmental impact, with biodegradable and clay pots generally considered more suitable under such conditions. However, further research is needed on biodegradable pots, particularly from environmental and economic perspectives.

3 Effect of Pot Geometry and Design Parameters

Previous studies have shown that the shape and size of clay pots play an important role in plant growth and water use. In one study, various shapes such as conical, spherical, round, and cylindrical were used for testing. The results indicated that cylindrical pots showed comparatively better performance than other shapes. They helped to reduce soil salinity, achieved higher water use efficiency (8.6 kg$\cdot$ m^{-3}), and saved up to 82% water [19]. Pot size is another important factor. Increasing the pot size can improve plant growth. However, the suitable pot size depends on the type of plant, and very small pots can limit root growth [20]. Pot depth and shape also affect soil physical properties and temperature. Tall and narrow pots tend to have lower water content, higher evaporation, and more temperature changes. One study reported that short and wide pots can hold more water and maintain better temperature conditions for plant growth [21]. The study of pot geometry is important because the shape, size, and depth of the pot control how water is distributed in the soil and reaches the plant root zone. Different pot designs can influence soil moisture distribution and root growth conditions. This directly affects water use efficiency and crop yield. Understanding these factors helps in selecting suitable pot designs and also supports the development of improved irrigation systems. Based on previous studies, the main findings regarding pot geometry parameters such as shape, size, and depth are summarized in Table 1.

Table 1. Summary of the effect of pot geometry on irrigation performance

Sr. No.	Findings	Implications	Ref.
1	Higher surface area-to-depth (S/D) ratio reduces plant growth under saline conditions	Use pots with lower S/D ratio	[22]
2	Cylindrical pots reduce salinity and provide higher water-use efficiency	Cylindrical shape is preferred	[19]
3	Larger pot size increases biomass, while small pots limit growth	Optimize pot size according to crop type	[20]
4	Tall and narrow pots lose more water and show higher temperature variation	Use wider pots with moderate depth	[21]

4 Water Use Efficiency and Crop Yield Response under Different Irrigation Methods

In this study, the water use efficiency and crop yield responses of selected crops such as potato, cabbage, and tomato under different irrigation methods were reviewed to evaluate the performance of clay pot irrigation compared with furrow, drip, and sprinkler irrigation methods, which are discussed in the following sections.

4.1 Water Use Efficiency under Different Irrigation Methods

To understand the effect of clay pot irrigation on water use efficiency, data for potato, cabbage, and tomato crops were collected from previous studies and are presented in Table 2. However, these studies were conducted under different soil, field conditions, fertilizer application, and environmental conditions. For example, silt loam soil was used in study [23], sandy loam soil in study [24], sandy soil in study [25], and sandy clay loam soil in study [26], while some studies did not mention the soil type [27, 28]. These variations may influence the reported results.

The values presented in Table 2 and Table 3 were compiled from different published studies conducted under varying soil characteristics, climatic conditions, irrigation scheduling practices, crop varieties, and experimental methodologies. Therefore, the reported values should be interpreted as indicative comparisons rather than direct one-to-one performance evaluations among irrigation methods. Variations in environmental and management conditions may significantly influence crop yield and water-use efficiency outcomes.

Table 2. Water-use efficiency under various irrigation methods

Crop	Furrow (kg$\cdot$m^{-3})	Sprinkler (kg$\cdot$m^{-3})	Drip (kg$\cdot$m^{-3})	Pot (kg$\cdot$m^{-3})	Ref.
Potato	6.63	8.03	9.47	NR*	[25]
Cabbage	11.96	15.05	25.4	36.17	[26, 28, 29]
Tomato	16.22	NR*	22.9	33.62	[23, 24, 27]

Notes: 1. NR* indicates that relevant data were not available in the reviewed studies. 2. The reported values were obtained from different independent studies conducted under varying environmental, agronomic, and experimental conditions; therefore, direct comparisons among irrigation methods should be interpreted cautiously.

Generally, drip irrigation provides higher water use efficiency compared with several other irrigation methods. However, findings from the reviewed studies indicate that pot irrigation may achieve higher water-use efficiency than several conventional irrigation methods under certain conditions, as presented in Figure 1. Therefore, more research is needed to better understand the performance of pot-based irrigation systems under different field conditions.

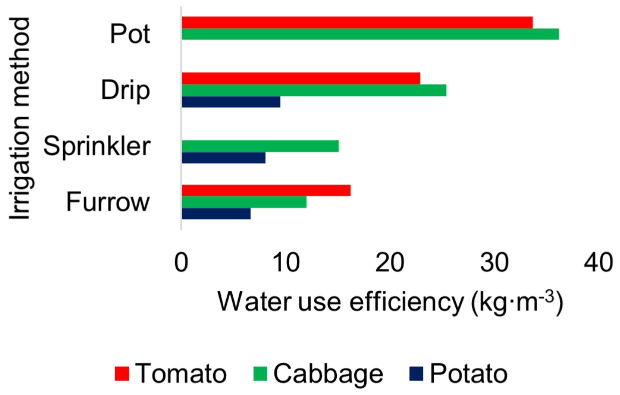

Figure 1. Water use efficiency of potato, cabbage, and tomato under different irrigation methods

4.2 Crop Yield Response under Different Irrigation Methods

Use of drip and sprinkler irrigation methods generally produces higher crop yield than traditional furrow irrigation because they distribute water more evenly and use it more efficiently [30]. However, previous studies suggest that clay pot irrigation may improve crop yield under certain experimental conditions. For example, in tomato, a yield of 48.30 t· ha^{-1} is reported under clay pot irrigation, which is higher than furrow irrigation (Figure 2 and Table 3).

Table 3. Crop yield response under different irrigation methods

Crop	Furrow (t·ha^{-1})	Sprinkler (t·ha^{-1})	Drip (t·ha^{-1})	Pot (t·ha^{-1})	Ref.
Potato	19.16	34.45	34.46	NR*	[31, 32]
Cabbage	48.41	37.00	34.30	NR*	[28, 33]
Tomato	15.68	46.81	96.70	48.3	[24, 27, 34–36]

Notes: 1. NR* indicates that relevant data were not available in the reviewed studies. 2. The reported values were obtained from different independent studies conducted under varying environmental and experimental conditions; therefore, direct comparisons among irrigation methods should be interpreted cautiously.

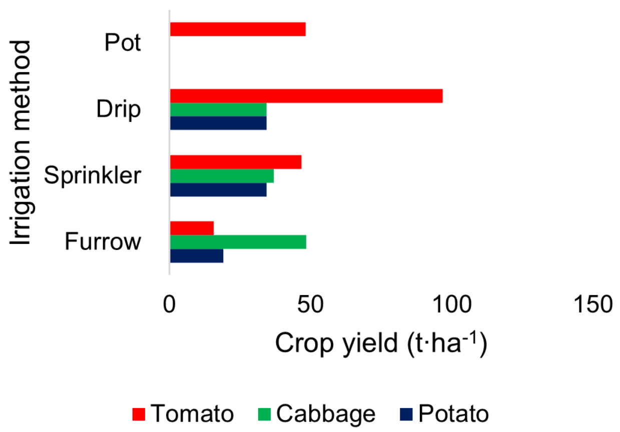

Figure 2. Crop yield under different irrigation methods

Findings discussed in Sections 4.1 and 4.2 suggest that clay pot irrigation may achieve relatively high water-use efficiency and satisfactory crop yield under controlled water application conditions. These findings indicate the potential of pot irrigation to reduce water use while maintaining acceptable yield levels. However, the reported outcomes may vary depending on soil properties, climatic conditions, crop type, and irrigation management practices.

5 Impact of Clay Pot on Water Quality

Water quality is another important factor in irrigation, especially in areas affected by salinity [37]. Improving irrigation water quality is often costly and not affordable for many farmers. In this context, clay pot irrigation can be considered a simple and low-cost alternative. It was reported that storing water in a clay pot for 7 days may improve certain water-quality parameters to some extent [38]. The reported results are presented in Table 4 and Figure 3. The study showed that dissolved oxygen (DO) increased from 6.17 ppm to 7.52 ppm, while total hardness (195 to 178 ppm) and total dissolved solids (TDS) (338 to 275 ppm) decreased, suggesting possible improvement in certain water-quality parameters.

Table 4. Changes in water quality after storage in a clay pot

Parameter (ppm)	Before Storage	After Storage	Ref.
DO	6.17	7.52	[38]
Total hardness	195	178	[38]
TDS	338	275	[38]

Note: DO, dissolved oxygen; TDS, total dissolved solids.

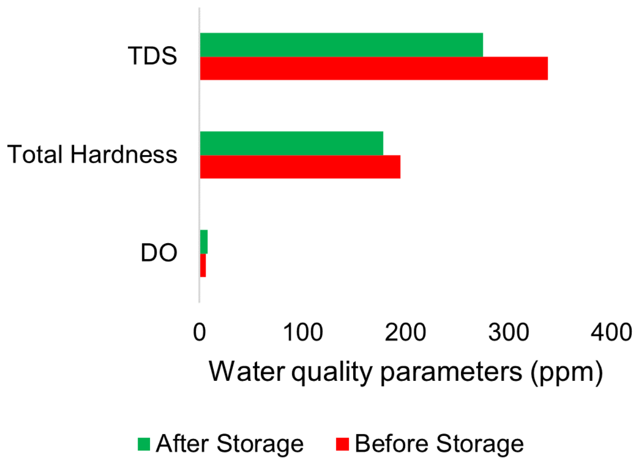

Figure 3. Comparison of water quality parameters before and after clay pot storage

Notes: 1. TDS, total dissolved solids; DO, dissolved oxygen. 2. DO values are comparatively lower than other parameters.

Although studies suggest that both stored and percolated water from clay pots may show improvement in certain water-quality parameters, limited quantitative data is available in this regard. Therefore, more research is needed to better understand and quantify these improvements.

6 Conceptual Framework of Integration of Clay Pot, Drip Irrigation, and Internet of Things

The conceptual framework for the integration of clay pot irrigation, drip irrigation, and IoT monitoring is discussed as follows.

6.1 Proposed Working Principle of the Integrated Clay Pot, Drip Irrigation, and Internet of Things System

In this proposed system, clay pots will be buried in the soil close to the root zone. Each pot will be covered with a cap, and a small hole will be made at the top of the cover to fix the emitters or drippers. A drip irrigation system, along with necessary filters, will be installed to fill the clay pots with water. The drip system will ensure a controlled water supply into the pots.

To automate the process, capacitive water level sensors will be installed at the bottom and top of one selected clay pot. Capacitive sensors are suitable because they are low-cost, reliable, and provide stable readings for water level measurement [39]. When the water level drops, the bottom sensor will detect a low level and will send a signal to the controller. When the water reaches the top sensor, it will indicate that the clay pot has reached the full water level. An Arduino Uno microcontroller will be used as the main controller of the system [40]. It will receive signals from the sensors and will control the operation of the motor through a relay. When the bottom sensor detects a low water level, the Arduino will automatically start the motor. When the top sensor detects the full level, the Arduino Uno microcontroller will stop the motor. This will ensure a continuous and steady water supply to the root zone without manual intervention [41].

To reduce system cost, sensors will be installed in only one reference pot. As shown in Figure 4, the reduced level (RL) of all other pots in the field will be maintained using an auto level [42, 43]. This will ensure that all pots are at the same elevation and will be filled uniformly under the same operating conditions.

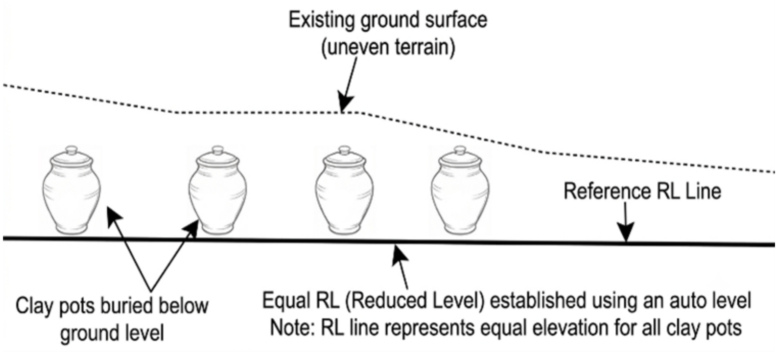

Figure 4. Establishment of equal reduced level (RL) for clay pot placement using an auto level

This integrated approach shown in Figure 5 will combine traditional clay pot irrigation with drip and IoT technology to improve water-use efficiency, reduce labor requirements, and support controlled irrigation management.

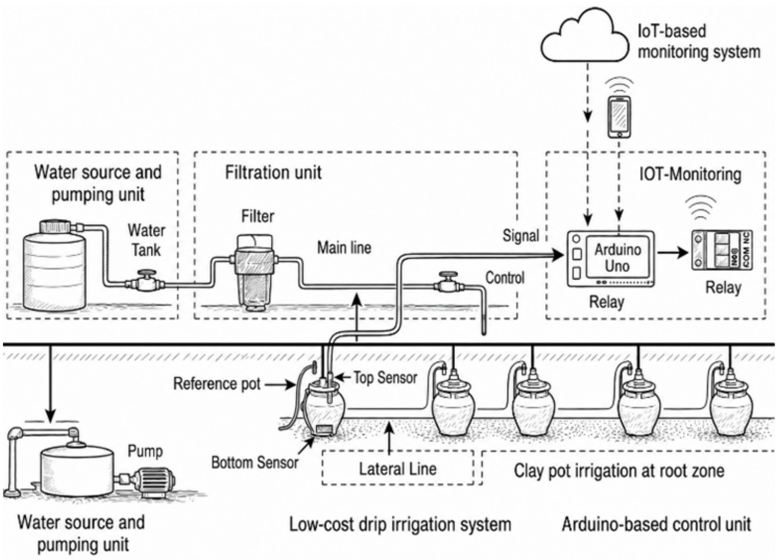

Figure 5. Conceptual framework of the integrated clay pot, drip irrigation, and Internet of Things (IoT)-based control system

7 Environmental Impact of the Proposed Integrated System

The proposed integrated clay pot irrigation, drip irrigation, and IoT monitoring system may provide environmental benefits by using water more efficiently and reducing wastage. In this system, clay pots are buried near the plant roots, allowing water to move slowly into the soil, which helps to reduce losses due to evaporation and deep percolation [8]. When combined with drip irrigation, water is supplied in a controlled manner, improving its distribution and overall water-use efficiency [5]. The use of IoT-based control further supports this process by supplying water only when it is needed, which helps to avoid over-irrigation [44]. As a result, the system can reduce excessive use of groundwater and lower the energy required for pumping. This clay pot-based integrated system may help maintain suitable moisture around the root zone and may also help control soil salinity and support better soil conditions [37].

At the same time, some environmental concerns should be considered. The use of sensors and electronic devices may lead to electronic waste if they are not properly handled after use. Clay pots may also require occasional replacement due to damage over time. Even with these limitations, the system may still be considered environmentally friendly because it is simple and supports better management of water resources. It can also support sustainable farming practices, especially in areas facing water scarcity.

A few previous studies have quantitatively demonstrated the environmental benefits of clay pot irrigation systems under different climatic and agricultural conditions. Reported findings include reductions in irrigation water losses, improved water-use efficiency, potential reductions in groundwater extraction, and reduced energy requirements associated with irrigation pumping. Selected quantitative environmental indicators reported in the available literature are summarized in Table 5.

Table 5. Quantitative environmental benefits reported for clay pot irrigation systems

Clay Pot Irrigation System	Environmental Indicator	Quantitative Environmental Benefit	Ref.
Clay pot irrigation under semi-arid conditions	Irrigation water savings	Up to 69% reduction in irrigation water use compared with furrow irrigation	[27]
Clay pipe irrigation systems	Reduction in water losses	Nearly 80% reduction in irrigation water consumption due to minimized evaporation and runoff losses	[8]
Bar-shaped clay pot irrigation system	Water-use efficiency improvement	Water savings increased by 40.6% for Swiss chard, 41.2% for tomato, and 41.7% for pepper crops	[8]
Clay-based subsurface irrigation	Water-use efficiency	14.6% higher water-use efficiency compared with conventional drip irrigation	[8]

Although a few studies have quantitatively reported water-saving potential and irrigation efficiency improvements associated with clay pot irrigation systems, limited published data are currently available regarding direct groundwater conservation and energy-saving impacts under field-scale conditions. Therefore, additional long-term experimental investigations are required to establish comprehensive environmental performance indicators for integrated clay pot irrigation systems.

8 Limitations of the Proposed System

The proposed integrated system consisting of clay pot irrigation, drip irrigation, and IoT-based monitoring may have the following limitations.

1. Initial Cost

One of the main challenges of this system is the initial investment required. Farmers need to invest in clay pots, drip irrigation components, sensors, and controllers before they can start using it. The total cost can vary depending on how easily clay pots are available locally and their market price.

2. Limited Crop Suitability

This method works better for long-duration crops such as fruit orchards, where the system can remain in place for several years. Still, it is not very suitable for short-duration crops because regular farming practices like ploughing and hoeing can disturb or even damage the buried clay pots.

3. Maintenance Requirement

Clay pots may crack or break over time and may need replacement. Similarly, drip pipes and filters can get clogged and need periodic cleaning to ensure proper water flow.

4. Need for Proper Levelling

For the system to work effectively, all the pots must be placed at the same level using the auto level concept as discussed in Section 6.1 (as shown in Figure 4).

5. Not Suitable for Uneven Land

This system is not ideal for fields that are uneven or sloping. In such conditions, it becomes difficult to maintain proper levelling and ensure uniform water distribution, which can limit the overall performance of the system.

9 Conclusion

Clay pot irrigation has shown potential for agricultural water conservation, with reported water savings of up to 80% compared with conventional furrow irrigation systems. Previous studies have also reported water-use efficiency values reaching 33.62 kg·m^{-3} for tomato and 36.17 kg·m^{-3} for cabbage. While drip irrigation generally provides higher crop yields, the evidence suggests that clay pot irrigation can still maintain acceptable productivity while significantly reducing irrigation water demand.

Pot geometry and design also influence system performance. Available studies indicate that appropriate selection of pot size and shape can improve soil moisture distribution and may affect water quality during storage, including reductions in TDS and increases in DO. However, these observations are limited in number and require further validation under varied soil and field conditions.

The principal contribution of this review is the development of an integrated irrigation concept combining clay pot irrigation, drip irrigation, and IoT-based monitoring. This hybrid framework links a traditional low-cost water-saving technique with modern precision irrigation and automation tools. The integration enables controlled water delivery, real-time monitoring of field conditions, and reduced dependency on manual irrigation management, thereby improving overall irrigation efficiency.

Despite these advantages, the proposed system is constrained by higher initial installation costs, maintenance requirements, and limited suitability for short-duration crops due to field operations that may disturb buried pots. Further field-scale studies are required to optimize the system design and evaluate its long-term performance across different agro-climatic conditions.

10 Future Scope

Future research needs to move beyond laboratory-scale or controlled experiments and focus more on testing the integrated system under real field conditions. Evaluating its performance across different types of soil and varying climatic conditions will provide a more comprehensive understanding of its practicality and reliability for everyday agricultural use. In addition, there is a need to carefully study how factors like pot size, spacing, and placement can be adjusted for different crops so that both water use efficiency and crop yield can be improved in a balanced way.

Further, more detailed work is required to understand how clay pot irrigation influences water quality under different environmental conditions. This will help in assessing its broader benefits beyond irrigation alone. Along with technical improvements, attention should also be given to reducing the overall cost of the system. Making it more affordable and easier to adopt will be important, especially for small and marginal farmers who often have limited resources.

Author Contributions

Conceptualization, S.S.N. and S.K.; methodology, S.S.N. and S.K.; validation, S.K. and A.B.; formal analysis, S.S.N. and A.B.; investigation, S.S.N.; resources, S.K.; data curation, S.S.N. and A.B.; writing original draft preparation, S.S.N.; writing review and editing, S.K. and S.S.N.; supervision, S.K. All authors have read and agreed to the published version of the manuscript.

Data Availability

Not applicable.

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Conflicts of Interest

The authors declare no conflict of interest.

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Nomenclature

IOT	Internet of Things
S/D	Surface area to depth
TDS	Total dissolved solids, ppm
DO	Dissolved oxygen, ppm