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An IoT-Based Smart Irrigation System with Cloud Analytics for Precision Agriculture

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ABSTRACT

Agriculture consumes the largest share of freshwater, and inefficient irrigation wastes both water and energy while sometimes harming yield. The Internet of Things, combined with cloud analytics, offers a way to irrigate precisely according to the actual needs of the crop. This paper presents an IoT-based smart irrigation system that uses soil-moisture sensors and weather information, processed through a cloud platform, to control irrigation automatically. Soil-moisture readings and rainfall forecasts are sent to the cloud, where an irrigation decision combines a moisture threshold with the expected weather, actuating drip valves only when needed. The system was evaluated in a field trial against a conventional fixed schedule over a four-month tomato-growing season. The smart system reduced water use by about thirty-seven percent and the number of irrigation events by a similar margin, while slightly increasing yield. The results show that combining IoT sensing with cloud analytics enables substantial water savings without compromising productivity, supporting more sustainable precision agriculture.

KEYWORDS: *smart irrigation, Internet of Things, precision agriculture, cloud analytics, soil moisture, water conservation*

INTRODUCTION

Freshwater is a scarce and increasingly stressed resource, and agriculture accounts for most of its use, so improving irrigation efficiency has both economic and environmental importance. Conventional irrigation often follows a fixed schedule that ignores the actual moisture in the soil and the weather, leading to over- or under-watering (1). Precision agriculture seeks to apply water, and other inputs, in the right amount at the right time (2).

The Internet of Things makes precision irrigation practical by connecting soil and weather sensors to controllers that can act automatically, while the cloud provides the storage and analytics to turn sensor data into irrigation decisions. By irrigating according to measured need rather than a calendar, such systems can save water while maintaining or improving yield (3). The combination of sensing, connectivity, and cloud analytics is central to this capability.

This paper presents an IoT-based smart irrigation system that uses soil-moisture sensors and weather forecasts, processed in the cloud, to control drip irrigation automatically. The system is evaluated in a field trial against a conventional fixed schedule, with water use, irrigation events, and yield as the outcomes (4).

LITERATURE REVIEW

Smart irrigation has been studied widely, using soil-moisture sensing, weather data, and various control strategies. The integration of IoT devices with cloud platforms is a common theme, enabling remote monitoring and data-driven decisions (5).

IoT and Cloud-Based Irrigation

Studies report that moisture-based irrigation, which waters only when soil moisture falls below a threshold, saves water compared with fixed schedules, and that incorporating weather forecasts avoids irrigating before expected rain. Cloud platforms add the ability to store historical data, run analytics, and control the system remotely, though connectivity and sensor reliability in the field remain practical concerns (6).

- Fixed irrigation schedules ignore actual soil moisture and weather.
- Moisture-threshold control saves water relative to calendar-based irrigation.
- Weather forecasts prevent irrigation before expected rainfall.
- Cloud platforms enable storage, analytics, and remote control of irrigation.

Even so, many studies report simulated or short-term results, and field trials that quantify water savings and yield together against a conventional baseline over a full growing season are less common (7).

RESEARCH GAP

Although IoT-based irrigation is well studied, season-long field trials that combine moisture-threshold control with weather forecasts via a cloud platform and quantify both water savings and yield against a conventional schedule are relatively scarce. The joint reporting of resource and productivity outcomes is essential to justify adoption (8).

This study addresses the gap by deploying a cloud-connected smart irrigation system in a season-long field trial and comparing its water use, irrigation events, and yield against a conventional fixed schedule.

OBJECTIVES

- To design an IoT-based smart irrigation system with cloud analytics.
- To combine soil-moisture thresholds with weather forecasts for irrigation decisions.
- To deploy the system in a season-long field trial on a tomato crop.
- To compare water use, irrigation events, and yield against a conventional schedule.

METHODOLOGY

The system was built from soil and weather sensing, a microcontroller-based actuator, and a cloud platform, and was deployed on a field plot. Its performance was compared with an adjacent plot irrigated on a conventional schedule.

System Architecture

The components of the system are summarised in Table 1. Capacitive soil-moisture sensors at several depths and local weather inputs fed a microcontroller with a cellular module, which relayed data to a cloud platform. The platform stored the data, ran the irrigation logic, and sent commands back to solenoid valves on the drip lines, enabling fully automatic operation.

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Table 1: Smart irrigation system components

Component	Description
Soil sensors	Capacitive moisture, multiple depths
Weather inputs	Temperature, humidity, rainfall forecast
Controller	Microcontroller with cellular module
Actuator	Solenoid valves on drip lines
Cloud platform	Data storage and irrigation analytics

Field Trial Setup

The field trial configuration is summarised in Table 2. The smart system irrigated only when soil moisture fell below a crop-specific threshold and no significant rainfall was forecast, whereas the comparison plot followed a conventional fixed schedule typical of local practice. Water use, the number of irrigation events, and the final yield were recorded for both plots over the four-month season.

Table 2: Field trial setup

Parameter	Value
Crop	Tomato
Plot area	0.5 hectare per treatment
Trial duration	4 months
Irrigation logic	Moisture threshold plus rainfall forecast
Comparison	Conventional schedule vs smart system

RESULTS AND FINDINGS

The smart system used markedly less water than the conventional schedule while maintaining yield. The monthly water usage of the two approaches over the trial is shown in Figure 4. The season totals for water use, yield, and irrigation events are summarised in Table 3.

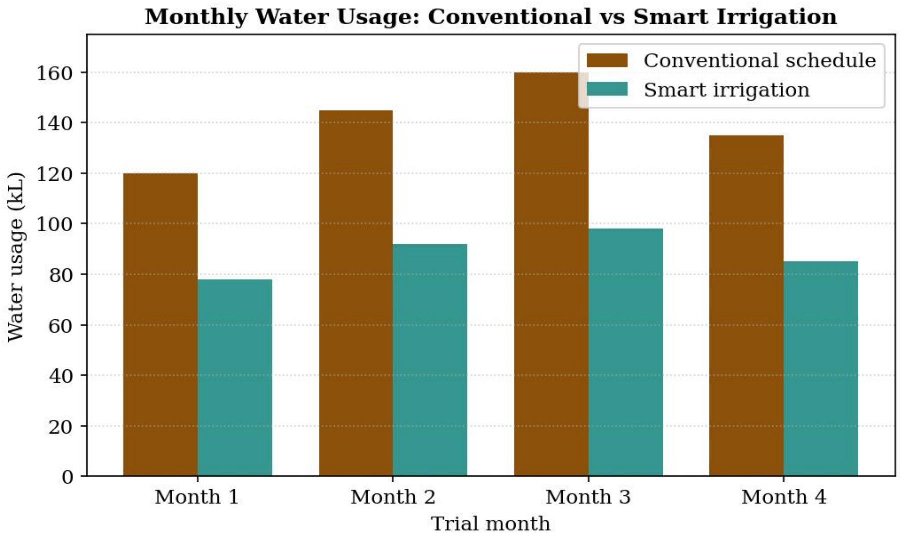

Figure 1: Monthly water usage for conventional and smart irrigation

As shown in Figure 4, the smart system used less water than the conventional schedule in every
month of the trial, with the difference reflecting irrigation events that were skipped when the soil was already moist or rain was expected. As reported in Table 3, over the season the smart system reduced water use by about thirty-seven percent and irrigation events by a similar margin, while yield rose slightly, indicating that the crop was watered according to need rather than excess. The water saved came without any productivity penalty.

Table 3: Season totals for the two irrigation approaches

Metric	Conventional	Smart system	Improvement (%)
Water used (kL)	560	353	37.0
Yield (t/ha)	42.0	45.6	8.6

Metric	Conventional	Smart system	Improvement (%)
Irrigation events	96	61	36.5

DISCUSSION

The water savings achieved by the smart system stem from irrigating in response to measured soil moisture and expected rainfall rather than a fixed calendar, which inevitably waters at times when the soil needs none. The slight increase in yield suggests that the conventional schedule was over-watering, which can stress the crop, so applying water more precisely benefited both resource use and productivity (9).

The role of the cloud was to turn raw sensor readings and forecasts into timely irrigation decisions and to allow remote monitoring of the field, which is valuable for farmers managing dispersed plots. The principal practical risks are sensor drift and connectivity loss, either of which can disrupt automatic control, so robust sensing and a sensible fallback when connectivity fails are important. Extending the system to more crops and larger areas, and adding nutrient management, are natural next steps (10).

CONCLUSION

This paper presented an IoT-based smart irrigation system with cloud analytics that combines soil-moisture thresholds with weather forecasts to control drip irrigation automatically. In a season-long field trial on tomato, the system reduced water use by about thirty-seven percent and irrigation events by a similar margin while slightly increasing yield, compared with a conventional fixed schedule. The results demonstrate that integrating IoT sensing with cloud analytics enables substantial water savings without compromising productivity, supporting sustainable precision agriculture.

LIMITATIONS

- The trial covered a single crop and location over one growing season.
- Sensor drift and connectivity loss were not stress-tested during the trial.
- The economic cost of the system and its return on investment were not analysed.

FUTURE SCOPE

- Extending the system to multiple crops, soil types, and climatic regions.
- Adding fertiliser and nutrient management to the cloud analytics.
- Incorporating predictive models of crop water demand from historical data.
- Evaluating the cost and return on investment for smallholder adoption.

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