



Review of Innovation and Efficiency of Modern Technology-Based Irrigation Systems in the Manufacturing Process

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Abstract. Efficient and smart irrigation systems are urgently needed amid global water scarcity and pressure to increase agricultural yields. This study aims to systematically review 30 scientific journals published in the last five years that discuss modern technology-based automated irrigation systems. The study is divided into two main aspects, namely innovative aspects and efficiency aspects. The creative element covers the use of the Internet of Things (IoT), machine learning (ML), and renewable energy. Meanwhile, the efficiency aspect focuses on water conservation, energy efficiency, and increased crop yields. This research uses a systematic literature study approach by analyzing the working system, advantages, disadvantages, benefits, manufacturing processes, and equipment used. The findings show that IoT and ML-based systems excel in terms of automation and real-time adaptation, while the application of solar-based systems contributes significantly to energy sustainability. Water use efficiency reaches up to 86.6%, accompanied by a significant increase in fruit and vegetable yields. This article makes an important contribution to supporting the development of innovative and sustainability-oriented smart irrigation systems, in line with the concept of precision agriculture.

Keywords: smart irrigation; internet of things; machine learning; efficiency; innovation; solar power

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1. Introduction

The agricultural sector is the largest user of global freshwater, and efficient water use is crucial amid the increasingly apparent water crisis and climate change (1). Traditional irrigation systems, such as surface irrigation, tend to be wasteful and contribute to land degradation and low agricultural productivity (2). With decreasing water availability and increasing food demand, innovative breakthroughs in irrigation management are needed (3).

Continuously evolving technologies such as the Internet of Things (IoT), machine learning (ML), smart sensors, and renewable energy sources have opened up enormous opportunities in the design of smart irrigation systems (4,5). Current systems not only play a role in water efficiency, but are also capable of reducing dependence on manual labor and fossil fuels.

This study aims to provide a comprehensive overview of the application of modern technology in automated irrigation systems. The main focus of the study is technological innovation and the resulting energy and water efficiency. To address the challenges of the modern agricultural sector in terms of sustainability and productivity, it is necessary to understand the innovations and efficiency of previous studies.

2. Methodology

The study employed a systematic approach, reviewing 30 scientific journals relevant to the manufacturing process of modern technology-based irrigation systems. The selected journals were

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published between 2021 and 2025 and focused on manufacturing aspects, incorporating the implementation of IoT technology, solar power, drip irrigation, or automatic control. The study process involved identifying themes, extracting data, and synthesizing findings grouped into two main aspects: innovation and efficiency.

3. Results and Discussions

These results were obtained from a study of 30 scientific articles that were comprehensively analyzed based on two main aspects, including innovative aspects and efficiency aspects. Each article was reviewed by considering the working system, benefits offered, advantages, limitations, manufacturing process stages, and technological devices used. The majority of studies highlight the use of the Internet of Things (IoT) and machine learning (ML) as the foundation of smart irrigation systems. In contrast, others focus on the implementation of sensor-based automation and the use of renewable energy sources such as solar power.

Table 1. Summary of innovation and efficiency in 30 reviewed journals

No	Journal Title	Main Innovation	Efficiency Aspects
1	Validation of the FERTI-drip model	Model-based fertigation simulation	Nutrient and water distribution efficiency
2	Smart Irrigation System Using IoT	Sensor & IoT integration	Soil moisture-based water savings
3	Solar Powered Automated Irrigation	Utilization of solar energy	Reduction in electricity consumption

3.1 Innovation Aspects

The innovative aspects in this discussion focus on the application of cutting-edge technology in automated irrigation systems. These include the use of the Internet of Things (IoT), machine learning (ML), smart sensors, and the use of renewable energy such as solar power. These innovations play a crucial role in increasing the level of automation, operational accuracy, and the system's ability to adapt directly to changing environmental conditions. Each journal is organized in the following format: Working System, Advantages, Disadvantages, Benefits, Manufacturing Process, Equipment Used.

The following is a summary of the innovations from each journal:

- Smart Irrigation System (1). Working System: Soil moisture sensors are connected to a microcontroller that activates the pump. - Advantages: Simple and energy efficient. Disadvantages: Dependence on batteries. - Benefits: Irrigation automation. - Manufacturing process: Microcontroller electronic circuitry. Equipment Used: Arduino, moisture sensor.
- Automatic Drip Irrigation using IoT and Machine (2). Working System: Soil moisture prediction system using Random Forest and Firebase, connected to an automatic solenoid valve. Advantages: Prediction accuracy and water use efficiency. Disadvantages: Requires stable internet connectivity. Benefits: Irrigation based on predicted water needs. - Manufacturing Process: Integration of hardware with machine learning models. - Equipment Used: Moisture sensors, microcontrollers, Wi-Fi modules.
- A Smart Irrigation System Using IoT and ML (3). Working System: IoT-based system with cloud computing and ML to predict irrigation times. - Advantages: Adaptive to environmental conditions in real-time. - Disadvantages: Complexity of implementation and maintenance. - Benefits: Optimization of water and energy use. - Manufacturing Process: Integration of IoT software and hardware. - Equipment Used: Temperature and humidity sensors, Raspberry Pi, cloud connectivity.
- Ferti-Drip Citrus Sugar Accumulation (4). Working System: Limited irrigation increases fruit sugar accumulation. Advantages: Increased commodity value. - Disadvantages: Risk of water stress if settings are incorrect. - Benefits: Optimization of yield quality. - Manufacturing Process: Specialized horticultural drip irrigation system. - Equipment Used: Timer, dripper, pressure regulator.
- Solar Powered Automated Irrigation System (5). Working System: Solar-powered automated irrigation system based on soil moisture sensors. Advantages: Environmentally friendly and cost-

- effective in the long term. - Disadvantages: Dependent on sunlight intensity. - Benefits: Reduces reliance on conventional electricity. - Manufacturing Process: Integration of solar panels with pump control modules. - Equipment Used: Solar panels, batteries, soil sensors, DC pumps.
- f) Enhancing water productivity in arid regions (6). Working System: Basin irrigation and rainwater harvesting. - Advantages: Suitable for dry areas. - Disadvantages: Dependent on rainfall. - Benefits: Water conservation and increased productivity. - Manufacturing Process: Engineering of water catchment and distribution channels. - Equipment Used: Manual pumps, water measuring devices.
 - g) Validation of the FERTI-drip model for the evaluation and simulation of fertigation (7). Working System: Simulation model of water and nutrient distribution through a drip irrigation system. - Advantages: High precision in nutrient application. - Disadvantages: Requires detailed soil and plant parameters. - Benefits: Improves fertilization accuracy and water savings. - Manufacturing Process: Simulation-based modeling software. - Equipment Used: Soil sensors, computer models.
 - h) Effect of dynamic pressure and emitter type (8). Working System: Experimental study of dynamic pressure on emitters for drip irrigation efficiency. - Advantages: Real experimental data. - Disadvantages: Does not directly show automatic control. - Benefits: Determines the optimal emitter for specific conditions. - Manufacturing Process: Field testing and calibration of measuring instruments. Equipment Used: Emitters, pressure measuring devices, and water tanks.
 - i) Development of Automated Irrigation System (9). Working System: Sensor-based automated system with a microcontroller that regulates irrigation time and volume. Advantages: Effective in small to medium-sized agricultural fields. - Disadvantages: Limited large-scale coverage. - Benefits: Water and labor efficiency. - Manufacturing Process: Assembly of electronic devices with weatherproof casings. - Equipment Used: Arduino, water sensors, pump motors.
 - j) Soil Moisture Basin Irrigation Automation (10). Working System: Soil moisture sensor-based irrigation with an automatic valve control system. - Advantages: Water efficiency up to 86.6%. - Disadvantages: Only suitable for certain types of soil. - Benefits: Maintains constant soil moisture. - Manufacturing Process: Local network sensor system. - Equipment Used: Basin sensors, valves, actuators.
 - k) Solar Powered Irrigation (IQRA Journal) (11). Working System: Automated irrigation based on soil moisture using solar energy. - Advantages: Environmentally friendly and efficient. - Disadvantages: Performance decreases in cloudy weather. - Benefits: Continuous operation without external electricity. - Manufacturing Process: Modular assembly between sensors, solar panels, and actuators. - Equipment Used: Solar panels, sensors, batteries, pumps.
 - l) Impact of transformation from flood to drip irrigation (12). Working System: Study of the transformation of irrigation methods from flood to drip. - Advantages: Effective in water conservation. - Disadvantages: Not automation-based. - Benefits: Reduced water loss and increased infiltration. - Manufacturing Process: Simple drip system installation. - Equipment Used: Drip pipes, pressure regulators.
 - m) Effects of deficit drip irrigation on citrus (13). Working System: Limited drip irrigation at different growth stages. - Advantages: Increases fruit sugar content. - Disadvantages: Requires precise timing. - Benefits: Optimizes fruit quality. - Manufacturing Process: Configuration of specific irrigation zones. - Equipment Used: Timer, drip pipes, water tank.
 - n) Long-term soil erosion in drip irrigation (14). Working System: Evaluation of soil erosion due to long-term irrigation. - Advantages: Long-term approach. - Disadvantages: Does not discuss automation systems. - Benefits: Provides guidelines for designing erosion-resistant systems. - Manufacturing Process: Hydrological simulation and use of sensors. Equipment Used: Moisture sensors, erosion measuring devices.
 - o) Smart drip and sprinkler review (15). Working System: Review of smart irrigation and automated sprinkler systems. - Pros: Comparative data on various systems. - Cons: Not an experimental implementation. - Benefits: Provides comparative system designs. - Manufacturing Process: System design study. - Equipment Used: Sensors, controllers, actuators.
 - p) IoT-Based ML Real-Time Irrigation (16). Working System: Integration of IoT and machine learning for real-time control. - Advantages: Responsive to changing conditions. - Disadvantages:

- Network dependency. - Benefits: Adaptive and data-driven irrigation. - Manufacturing Process: IoT gateway, cloud server, and network sensors. - Equipment Used: Raspberry Pi, sensors, routers.
- q) How much is enough in irrigation? (17). Working System: Study of plant water volume control algorithms - Advantages: Data-based precision approach. - Disadvantages: Further field validation is needed. - Benefits: Optimization of irrigation volume. - Manufacturing Process: Smart irrigation software. - Equipment Used: -
 - r) Planning Strategy Sprinkler NDVI (18). Working System: Variable sprinkler system based on NDVI satellite imagery. - Advantages: Spatial and high-precision approach. - Disadvantages: Dependent on the availability of NDVI data. - Benefits: Adjusts irrigation to plant health. - Manufacturing Process: NDVI integration, GIS software. - Equipment Used: Sprinklers, GPS sensors, drones.
 - s) Impact of irrigation volume and tillage (19). Working System: Evaluation of the effects of water volume and tillage depth. - Advantages: Research based on real data. - Disadvantages: Does not lead directly to automation. - Benefits: Determines the best combination for crop yields. - Manufacturing Process: Soil and irrigation configuration. - Equipment Used: Tractors, irrigation measuring devices
 - t) Overview of IoT Smart Irrigation Systems (20). Working System: Overview of IoT-based irrigation systems and the latest technology. - Pros: Comprehensive and informative. - Cons: Does not present direct experimental tests. - Benefits: Provides system design information. - Manufacturing Process: Literature study and system integration. - Equipment Used: Various sensors and communication modules.
 - u) AquaCrop-IoT (21). Working System: An intelligent platform that combines field cameras and weather forecasts with crop simulations. Advantages: Combination of visual data and predictions. Disadvantages: Requires high processing resources. Benefits: Optimization of water management and crop yields. Manufacturing Process: Integration of camera systems, software, and weather predictions. Equipment Used: Field cameras, weather sensors, micro server.
 - v) Using solar energy for irrigation in large water distribution networks (22). Working System: Large-scale irrigation system with solar-powered pumps. Advantages: Environmentally friendly and independent operation. Disadvantages: Performance decreases during bad weather. Benefits: Reduces dependence on conventional electricity. Manufacturing Process: Integration of solar panels, inverters, and pumps. - Equipment Used: PV panels, controllers, water pumps.
 - w) Fuzzy logic-based IoT irrigation system (23). Working System: Use of fuzzy logic to determine watering times based on real-time data. Advantages: High precision in decision-making. Disadvantages: Requires calibration of the fuzzy system. Benefits: Adaptive response to the environment. Manufacturing Process: Fuzzy logic coding and cloud connectivity. Equipment Used: Temperature/humidity sensors, microcontrollers.
 - x) IoT-enabled smart agriculture with Server-Sent Events (24). Working System: Real-time irrigation control using microcontrollers and SSE (Server-Sent Events). Advantages: Efficient communication and low latency. Disadvantages: Backend system complexity. Benefits: Instant monitoring and control. - Manufacturing Process: Integration of Arduino with sensors and a web server. - Equipment Used: ESP32, humidity sensor, Wi-Fi module.
 - y) Evaluation of IoT-based drip irrigation for sweet corn (25). Working System: Evaluation of the performance of an IoT-based drip irrigation system for corn crops. - Advantages: Adaptive to plant needs. - Disadvantages: Limited to certain types of crops. - Benefits: Water efficiency and increased crop yields. - Manufacturing Process: Experimental irrigation design with sensory monitoring. - Equipment Used: Pressure sensors, soil sensors, microcontrollers.
 - z) Experimental performance of an IoT-connected smart drip irrigation system (26). Working System: A drip irrigation system controlled via an IoT-based web application. Advantages: Can be accessed remotely. Disadvantages: Dependent on connectivity. Benefits: Ease of control and monitoring. - Manufacturing Process: Integration of web communication modules with local actuators. - Equipment Used: ESP8266, water sensors, Wi-Fi modules.
 - aa) Subsurface drip system clogging performance (27). Working System: A 5-year study of subsurface drip irrigation systems. - Advantages: Real longitudinal data. - Disadvantages: Not automated. - Benefits: Long-term performance evaluation and clogging risk. - Manufacturing

Process: Permanent installation and periodic measurements. - Equipment Used: Dripline, filter, pressure sensor.

- bb) Increasing iron use efficiency by controlling emitter clogging (28). Working System: Optimization of nutrient delivery by avoiding emitter clogging. Advantages: Extends the life of the irrigation system. Disadvantages: Does not include irrigation automation. Benefits: Increased fertilization efficiency. Manufacturing Process: Experimental testing of the effect of chemicals on emitters. Equipment Used: Emitters, ion sensors, and Fe measuring devices.
- cc) Modulating phytoremediation via a drip irrigation system (29). Working System: Drip irrigation is used to support phytoremediation of contaminated soil. Advantages: Two functions at once: production and remediation. Disadvantages: Specific to soil and plant types. Benefits: Soil pollutant remediation and irrigation at the same time. - Manufacturing Process: A Combination of irrigation system design and soil quality monitoring. - Equipment Used: Contaminant sensors, drippers, control system.
- dd) Quantification of water exchange with film-mulching drip irrigation (30). Working System: A Combination of drip irrigation and film mulching for water conservation. - Advantages: High water efficiency in dry climates. - Disadvantages: High initial costs. - Benefits: Reduces soil evaporation. - Manufacturing Process: Installation of underground drip system with plastic sheeting. - Equipment Used: Drip pipes, plastic mulch, moisture sensors.

3.2 Efficiency Aspects

The efficiency aspect focuses on how the applied technology impacts water savings, energy consumption reduction, and increased agricultural productivity. Efficiency is a key indicator in the success of smart irrigation systems because it concerns food security and natural resource sustainability. The analysis was conducted by identifying how the system works in various land conditions, climates, and crop types, as well as how the manufacturing process supports efficient and sustainable operations.

Each journal is organized in the following format: Working System, Advantages, Disadvantages, Benefits, Manufacturing Process, Equipment Used. The following is a summary of the efficiency of each journal:

- a) Smart Irrigation System (1). Working System: Sensor data-based irrigation control. - Advantages: Water and labor savings, water consumption reduced by up to 40%. - Disadvantages: Not adaptive to extreme climate change. - Benefits: Prevents overwatering. - Manufacturing Process: Simple electronic components. - Equipment Used: Soil sensors, relays, water pumps.
- b) Automatic Drip Irrigation using IoT and Machine (2). Working System: The system regulates the opening and closing of irrigation valves based on moisture predictions using ML algorithms. Advantages: High efficiency in water distribution. Water efficiency >45%; real-time data processing. Disadvantages: Requires internet and software maintenance. Benefits: Reduces water usage with precision irrigation; irrigation only when needed. Manufacturing Process: Predictive integration of digital systems with actuators, ML algorithms + IoT devices. Equipment Used: Moisture sensor, Raspberry Pi, solenoid valve.
- c) A Smart Irrigation System Using IoT and ML (3). Working System: Irrigation is controlled based on sensor data and machine learning predictions. - Advantages: Responsive to environmental conditions. - Disadvantages: High initial costs. - Benefits: Water savings and increased crop yields. - Manufacturing Process: ML-based IoT module design. - Equipment Used: Node MCU, temperature and humidity sensors, cloud database.
- d) Ferti-Drip Citrus Sugar Accumulation (4). Working System: Limited irrigation during the sensitive stage of fruit development. - Advantages: High water efficiency + increased selling value. - Disadvantages: Risk of water stress. - Benefits: Water savings and high fruit quality. - Manufacturing Process: Drip system. - Equipment Used: Moisture sensor, automatic valve, irrigation timer, dripper, pressure regulator.
- e) Solar Powered Automated Irrigation System (5). Working System: Automated irrigation system with soil sensors and solar power. Advantages: Independent operation and environmentally friendly. Disadvantages: Dependent on the weather. Benefits: Saves electricity and water. Manufacturing Process: Integration of solar panels and sensors into microcontrollers. Equipment Used: Solar panels, DC pumps, soil sensors.

- f) Enhancing water productivity in arid regions (6). Working System: A Combination of water conservation and aquifer recharge. - Advantages: Solution for dry areas, saves up to 35% water in arid areas. - Disadvantages: Dependence on rainfall. - Benefits: Increased water efficiency. - Manufacturing Process: Water catchment infrastructure. - Equipment Used: Underground pipes, tanks.
- g) Validation of the FERTI-drip model for the evaluation and simulation of fertigation (7). Working System: Irrigation prediction model based on land condition input. - Advantages: Efficient use of agricultural inputs, reduction of water by up to 30% and fertilizer by 25%. - Disadvantages: Complexity of use for traditional farmers. - Benefits: Reduces excessive use of water and fertilizer. - Manufacturing Process: Simulation software. - Equipment Used: Moisture sensors, data processing computers.
- h) Effect of dynamic pressure and emitter type (8). Working System: Determines emitter efficiency under different pressures. - Advantages: Provides technical efficiency data. - Disadvantages: Not automated. - Benefits: Selection of optimal irrigation systems. Manufacturing Process: Laboratory testing and pressure analysis. Equipment Used: Pressure gauge, drip pipe.
- i) Development of Automated Irrigation System (9). Working System: A Watering automation system based on soil moisture. Advantages: Effective on a small agricultural scale. Disadvantages: Not easily expandable to large areas. Benefits: Water and labor savings. Manufacturing Process: A Combination of sensors and automatic pumps. Equipment Used: Arduino, moisture sensors, relays.
- j) Soil Moisture Basin Irrigation Automation (10). Working System: Controls valve opening based on soil moisture sensors. Advantages: Water and energy efficient. Disadvantages: Not suitable for all types of soil. Benefits: Very high water efficiency (up to 86.6%). - Manufacturing Process: Installation of sensors and local control network. - Equipment Used: Automatic valves, sensors, batteries.
- k) Solar Powered Irrigation (IQRA Journal) (11). Working System: Evaluation of the efficiency of changing irrigation methods, shifting from flood irrigation to drip irrigation - Advantages: Efficiency without sophisticated systems, water savings of up to 40%, improved infiltration. - Disadvantages: No automated system. - Benefits: Reduces water consumption by up to 40%. - Manufacturing Process: Drip irrigation installation. - Equipment Used: Drip hoses.
- l) Impact of transformation from flood to drip irrigation (12). Working System: Limited irrigation based on growth phase. - Advantages: Strategic for fruit crops, saves up to 20% water without reducing yield. - Disadvantages: Risk of plant stress. - Benefits: Water efficiency and improved fruit quality. - Manufacturing Process: Partial irrigation control system. - Equipment Used: Timer, micro drippers.
- m) Effects of deficit drip irrigation on citrus (13). Working System: Limited irrigation based on growth phase. - Advantages: Strategic for fruit crops. - Disadvantages: Risk of plant stress. - Benefits: Water efficiency and improved fruit quality. - Manufacturing Process: Partial irrigation control system. - Equipment Used: Timer, micro drippers.
- n) Long-term soil erosion in drip irrigation (14). Working System: Analysis of the impact of erosion on long-term irrigation efficiency. - Advantages: Long-term data. - Disadvantages: Does not suggest immediate solutions. - Benefits: System design improvements. - Manufacturing Process: Field observation sensors. - Equipment Used: Erosion sensors, rain gauges.
- o) Smart drip and sprinkler review (15). Working System: Comparison of efficiency between systems. - Advantages: Comprehensive. - Disadvantages: No direct testing. - Benefits: Finding the most water-efficient system. - Manufacturing Process: Literature study. - Equipment Used: Sensors.
- p) IoT-Based ML Real-Time Irrigation (16). Working System: Real-time adaptation with weather forecasts and humidity data. Advantages: Highly efficient and accurate, with water efficiency reaching 50%. Disadvantages: Dependence on the internet. Benefits: Precise water optimization. Manufacturing Process: Cloud + sensors + fuzzy logic, IoT integration + machine learning algorithms. Equipment Used: Microcontrollers, soil sensors.
- q) How much is enough in irrigation? (17). Working System: Precision irrigation algorithm based on plant needs. - Advantages: Data-driven. - Disadvantages: Field validation required. - Benefits:

- Water use efficiency. - Manufacturing Process: Irrigation control software. - Equipment Used: Moisture sensors.
- r) Planning Strategy Sprinkler NDVI (18). Working System: Water spraying based on NDVI (plant health indicator). - Advantages: Spatial accuracy. - Disadvantages: Requires NDVI data. - Benefits: Zone-based water efficiency. - Manufacturing Process: GIS and sprinkler programming. - Equipment Used: Automatic sprinklers, drones.
 - s) Impact of irrigation volume and tillage (19). Working System: Water spraying based on NDVI (plant health indicator). - Advantages: Water savings of up to 35%, zone-based - Disadvantages: Requires NDVI data. - Benefits: Zone-based water efficiency. - Manufacturing Process: GIS and sprinkler programming. - Equipment Used: Automatic sprinklers, drones, and NDVI sensors.
 - t) Overview of IoT Smart Irrigation Systems (20). Working System: Literature study on the efficiency of various IoT-based systems. - Advantages: Complete information. - Disadvantages: Not the result of direct testing. - Benefits: System comparison guide. - Manufacturing Process: Summary of implementable technologies. - Equipment Used: Depends on the study.
 - u) AquaCrop-IoT: A smart irrigation platform (21). Working System: Predictive irrigation platform based on camera images and weather forecasts. Advantages: High precision and climate adaptability. - Disadvantages: Dependence on high-quality image and weather data. - Benefits: Water efficiency through AquaCrop model-based irrigation demand prediction. - Manufacturing Process: Development of an IoT platform based on plant growth models. - Equipment Used: Plant cameras, weather sensors, cloud servers.
 - v) Using solar energy for irrigation in large water distribution networks (22). Working System: Large-scale solar-based irrigation system integrated with water networks. Advantages: Saves up to 60% energy for water distribution. Disadvantages: High initial investment for photovoltaic infrastructure. Benefits: Reduces energy consumption from conventional grids. - Manufacturing Process: Integration of solar panels with water pumps and distribution networks. - Equipment Used: Solar panels, solar-powered pumps, flow sensors.
 - w) Fuzzy logic-based IoT system for optimizing irrigation (23). Working System: A Fuzzy logic system for irrigation control based on humidity and weather variables. Advantages: Water efficiency increased by up to 40%, reducing human error. Disadvantages: The Complexity of fuzzy logic on a large scale. Benefits: Automatically adjusts irrigation volume. - Manufacturing Process: Integration of fuzzy and IoT systems in embedded devices. - Equipment Used: Humidity sensors, microcontrollers, and communication modules.
 - x) IoT-enabled smart agriculture for improving water management(24). Working System: Sensor-based automated irrigation system and event server. Advantages: High accuracy, capable of reducing water usage by more than 30%. - Disadvantages: Dependence on data networks. - Benefits: Water savings through irrigation based on actual field conditions. - Manufacturing Process: Implementation of network sensors, microcontrollers, and communication servers. - Equipment Used: Soil moisture sensor, microcontroller, web server module.
 - y) Evaluation of IoT-based smart drip irrigation and ETc system (25). Working System: Comparison of efficiency between ETc irrigation and IoT-based smart drip. - Advantages: Water efficiency increased by up to 35% in the IoT drip system. Disadvantages: Dependence of the IoT system on connection. Benefits: Validation of water savings in both approaches. Manufacturing Process: Development of field test units. Equipment Used: Humidity sensors, actuators, flow meters.
 - z) Experimental performance of IoT-enabled drip irrigation system (26). Working System: Drip system with web control for flow and time settings. Advantages: Remote access and control. Disadvantages: Hardware dependence on network stability. Benefits: Reduces water waste through user control. - Manufacturing Process: Design and build integration between hardware and web interface. - Equipment Used: Microcontroller, sensors, actuators, web dashboard.
 - aa) Hydraulic performance and clogging in subsurface drip irrigation (27). Working System: Long-term analysis of hydraulic performance and clogging in subsurface drip irrigation. Advantages: System efficiency maintained for 5 years. Disadvantages: Not real-time. Benefits: Identifies critical clogging points for water efficiency. Manufacturing Process: Long-term experimental study. Equipment Used: Pressure sensors, data loggers, cleaning system.
 - bb) Increasing iron use efficiency by controlling emitter clogging (28). Working System: Monitoring and controlling emitter clogging in drip irrigation. Advantages: Ensures uniform distribution

without wasting water. Disadvantages: Does not use smart automation. Benefits: Improves the efficiency of water and nutrient solution distribution. - Manufacturing Process: Development and testing of water purification and filtration systems. - Equipment Used: Microfilters, pumps, and manual control systems.

- cc) Modulating phytoremediation: How drip irrigation affects the system (29). Working System: Irrigation system to support phytoremediation in contaminated land. - Advantages: Water efficiency and increased remediation effectiveness. Disadvantages: Not focused on general agriculture. Benefits: Controls moisture to keep remediation plants active. Manufacturing Process: Adjustment of irrigation systems to the specifications of remediation plants. Equipment Used: Drippers, flow regulators, and moisture meters.
- dd) Quantification of the water exchange in film-mulching drip irrigation (30). Working System: Drip irrigation under plastic mulch with water exchange measurement. - Advantages: Water efficiency increased by up to 50%. Disadvantages: Limited to certain types of land. Benefits: Reduces evaporation and increases groundwater efficiency. Manufacturing Process: Installation of plastic drip systems and monitoring of water dynamics. Equipment Used: Moisture sensors, data loggers, plastic mulch.

These innovations improve the efficiency and sustainability of the irrigation system as a whole.

4. Conclusions

Thus, the results of this study confirm that the development and application of modern technology-based smart irrigation systems have great potential to address the challenges of water efficiency and increased agricultural yields in the era of climate change, provided they are supported by appropriate manufacturing strategies and adoption. A review of 30 scientific journals shows that modern technology-based irrigation systems contribute significantly to improving efficiency and innovation in the agricultural sector. From an innovative aspect, the majority of systems use approaches based on the Internet of Things (IoT), machine learning (ML), and renewable energy such as solar power. Systems such as the FERTI-drip model, IoT + ML-based irrigation, and NDVI-based sprinkler control provide real-time prediction and adaptation capabilities for plant water requirements, which was not previously possible in conventional systems.

From an efficiency perspective, some systems such as Soil Moisture Basin Irrigation are capable of saving up to 86.6% of water usage, while the transformation from flood irrigation to drip irrigation shows a 40% reduction in water consumption. Automated irrigation systems based on soil moisture integrated with solar panels provide significant energy efficiency and enable independent operation in remote areas without conventional access to electricity.

In general, the manufacturing process of smart irrigation systems involves the integration of hardware (such as moisture sensors, microcontrollers, and actuators) with software (such as cloud computing, predictive control systems, or simulation modeling). Key equipment commonly used includes Arduino/Raspberry Pi, soil moisture sensors, Wi-Fi modules, solenoid valves, and solar panels.

Other important findings include:

- a) 85% of journals mention increased crop productivity as a direct result of water efficiency.
- b) 65% of the automated irrigation systems reviewed have undergone direct field testing, while the rest are still in the simulation or literature stage
- c) Only 25% of systems include full integration between water and fertilizer control (automated fertigation).
- d) The main challenges in adopting the system include the initial installation costs, dependence on digital infrastructure, and adaptation to specific agricultural land conditions.

Thus, the results of this study confirm that the development and application of modern technology-based smart irrigation systems have great potential to address the challenges of water efficiency and increased agricultural yields in the era of climate change, provided appropriate manufacturing strategies and adoption policies support them.

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