Foundation University
Journal of Engineering and
Applied Sciences

FUJEAS
Vol. 5, Issue 2, 2025
DOI:10.33897/fujeas.v5i2.913

Research Article

Design and Construction of a Sustainable IoT based Solar Energy-Powered Smart Water Consumption Tracking System

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Article Citation:
Ali et al. (2025). "Design and Construction of a Sustainable IoT based Solar Energy Powered Smart Water Consumption Tracking System". *Foundation University Journal of Engineering and Applied Sciences*
DOI:10.33897/fujeas.v5i2.913

Abstract:

Water security and scarcity are major challenges in Pakistan, particularly in developing countries. There is a need for the sustainable implementation of a water consumption tracking system for control and monitoring using solar energy. This study aims to analyze water consumption to tackle the urgent worldwide concerns of water conservation and effective water resource management. By implementing solar-powered intelligent water-monitoring equipment, this prototype offers a new way to monitor and manage water usage. This scheme was controlled and monitored using an Arduino-based controller integrated with turbidity and water flow sensors to switch the motor using modern technologies. This prototype must be implemented because water security is a global challenge where freshwater is becoming increasingly rare. The goal of these systems is to transfer these parameters using an Internet of Things (IoT)-based system and control and monitor water resources via web applications. The system's real-time monitoring of consumption trends changes to sustainable water management. The system costs less compared to conventional SCADA-based systems. The proposed system achieved 92% efficiency without any external fossil fuel-based power sources. The comparative analysis shows that the proposed system prototype offers efficiency, cost-effectiveness, and scalability compared to traditional systems. The designed system delivers an economical and optimal solution for real-time data analytics for small-scale applications to advance the field. This sustainable technology enables people, communities, and organizations to play a significant role in protecting water supplies and maintaining their accessibility for future generations.

Keywords: Internet of Things; Water Security; Tracking System; Sustainable.

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1. Introduction

Innovations in IoT-based energy monitoring can detect and control industrial and domestic applications. This study provides a prototype design for energy management integrated with a microcontroller and sensors. The parameters were transmitted via an SQL-based network for monitoring [1]. The Internet of Things (IoT) has transformed the world's medical structure compared to traditional systems. Different stages of medical data analytics show innovations in the medical sector [2]. This study demonstrates the equipment's flow and construction parameters to secure the project scheme and shows further evaluation for future implementation [3]. The increase in smart electronics improves the efficiency of equipment in the domestic and industrial sectors. Smart devices must be implemented to access and control devices [4]. The implementation of an intelligent biometric identification system uses data analytics techniques to transmit data via an IoT-based system to verify fingerprints with a national data-based government record. The further utilization of AI models improves system efficiency [5]. The key reason for the water shortage is a decrease in the amount of water. The main concern of Pakistan is water shortage nowadays. This study provides a prototype design to integrate a microcontroller with sensors to manage photovoltaic-powered smart irrigation. An Arduino-based remote system to advance the automatic switching of irrigation systems by utilizing photovoltaic cells. The experimental results showed that the system is a sustainable solution for irrigation and farming [6]. Industrial wastewater can cause environmental pollution and public health problems.

Developing countries such as Bangladesh dump their wastewater into rivers and the sea, which affects the water quality. There is a need to implement an Internet of Things (IoT)-based system to collect and track water data parameters. Parameters including temperature, dissolved solids, potential of hydrogen, and turbidity need to be monitored and controlled. During this study, it was measured that the turbidity ranged from 170 to 360 parts per million (ppm), and the potential of hydrogen surpassed 7pH [7]. Laborers working in polluted environments are concerned with health-related problems. Internet of Things (IoT)-based systems are integrated with Arduino and sensors to monitor and control the water quality, air quality, pH value, temperature, and humidity to provide a sustainable environment. The global System for Mobile Communication (GSM) and Wireless Fidelity (Wi-Fi) integration was integrated with a system for real-time intelligent monitoring. This technology enables access to parameters from anywhere in the globe. This system measures and monitors daily weather and environmental changes [8]. Water is a basic source of living things. A lack of awareness regarding water management causes water pollution and diseases. It is important to design a scheme inspired by the latest Internet of Things (IoT)-based technologies to monitor and control parameters. The parameters included pH and turbidity. The procedure of the system control by the Arduino ATmega328P pH sensor calculates the acidity, and the turbidity sensor measures the turbidity level. A Low-power wide-area network system utilizes cloud management to save data. The proposed system attained a reliable accuracy of 99.73% for the pH sensor and 99.41% for the turbidity sensor [9].

The rise in population increases water demand. Due to climate change, water resources are decreasing, and water shortage is a major global challenge. Internet of Things (IoT)-based smart technologies are growing rapidly to control and track water consumption, quality, and forecast water demand using mathematical formulations. There is a lack of awareness across the globe regarding tracking the consumption and quality of water. This study analyzes and suggests the use of modern technologies, such as IoT and Artificial intelligence integration with controllers and sensors, to monitor and control real-time parameters [10]. Water management is one of the major global challenges. Many water monitoring systems require human operations to manage and control the process. In this study, an automatic system was designed utilizing Arduino to manage water discharge. A real-time monitoring system was developed to access the motor and valve at any location. Line water supplies face a greater number of environmental problems. To overcome these issues, a prototype was designed to connect IoT-based technologies to access each solenoid valve that operates automatically with a microcontroller [11]. This study focused on the design and development of a sustainable water management system to address water challenges worldwide. This study describes intelligent water control to improve water quality. Future directions for smart water management systems are considered for sustainable methodology [12]. This study focuses on a cloud-based irrigation scheme for monitoring and control using sensors. The Arduino Node MCU gathered data from the sensors and controlled the system. The sensor included humidity, and a soil sensor was used to save water. Internet of Things (IoT)-based technologies are integrated with systems to control and manage systems using web applications [13].

The implementation of a water-saving and sustainable computerized solution is required. In water areas, the water metering framework has been used to reduce key water and water access difficulties. In this study, the African city of Ghana was considered for the digital revolution of water infrastructure [14]. This study considers an IoT framework that empowers the quantitative and subjective estimation of water, as far as an updated rendition of the water infrastructure to improve water quality is concerned. The proposed strategy can be utilized in metropolitan and national regions for the utilization and quality monitoring of the water framework. The proposed framework, alongside the development of IoT interchanges and frameworks, can establish the groundwork for a water metering arrangement. Presenting a measurement framework to save and improve water. IoT-based techniques utilize artificial intelligence algorithms to track water consumption via the Web and mobiles [15]. Implementing a smart water network is thought to be a crucial step in addressing a number of water utility challenges, including primary break counteraction and pipe spill detection. This study developed an order-based model for acoustic wave records collected through the South Australian Water Partnership. This system uses co co-convolutional neural network to develop a visual math model. The findings indicated that 92.44% of the cautions generated by the developed models were accurate [16].

Energy conservation and water conservation are two important factors. The effects of climate change on Birmingham's water and energy systems require the development of energy and water security plans. Birmingham's water energy use might be significantly increased by adopting more intelligent and efficient decision-making for clean energy production [17]. Water tracking and control methodologies must be implemented for sustainable solutions. This study focused on tracking domestic water consumption [18]. Water tracking is important for checking the water quality. This study presents the plan and execution of smart structures for observing water utilization with an IoT-based system, where the utilization of water meters provides water information. The principal objective of such a framework is to provide an IoT-based sustainable solution. By introducing water meters, it is feasible to recognize utilization designs and evaluate the water consumption [19]. Conventional systems require large amounts of labor compared with automated systems for monitoring and control. In numerous regions of the world, the utilization of utilities such as power, gas, and water is checked manually by meter readers. Meter reading does not require the presence of a worker or delegate to visit the site. A digital system can be designed to show the meter parameters online [20].

Currently, there are many major problems associated with access to freshwater. Water assets are difficult to find in urban areas because of climate change. In emerging nations, water is kept manually in tanks, and due to human carelessness, water can leak out and be wasted. To resolve these issues, this study uses Internet-of-Things (IoT) equipment to proficiently track water leakage and automatic motor control. This system was designed to monitor parameters using web applications and mobile phones. This system was designed for both domestic and industrial applications. This system uses secure cloud storage for water [21]. Controlling water is the biggest global challenge. Humans use water daily; however, there is a lack of awareness regarding the tracking of water. Normal water usage was 150 L/person daily. This study focuses on water tracking in the city of Bangalore, India. Owing to an increase in population, the use of water has increased. To address these issues, this system was designed to be integrated with the latest Internet of Things (IoT)-based technologies to track water consumption worldwide [22].

Water is a natural resource for many living organisms. Management and security of water managed by the government. The current recording of usage is based on the size of the household, and there is a need to implement a smart water metering system to properly measure the usage of water. To monitor these parameters system was designed to address this major issue. This system uses a NodeMCU ESP8266 microcontroller integrated with sensors to control and monitor the actual water volume and different parameters for tracking and testing. The experimental error was 0.3%. This system was designed to track real-time parameters on an LCD screen [23]. Water quality and control are important factors for sustainable life. In this study, sensors were implemented to track the usage and quality of water. This study systematically inspected the water quality by filtering the water. This study fundamentally examined the development of data-storing models [24]. Sustainable development depends on different factors, such as economy, education, farming, energy, and industry; environmental factors are among the main factors. The main challenge is the use of water resources for industries and buildings. Sustainable Development Goals (SDGs) provide information on water security and sustainable development in the water sector. Digital transformation of the latest technologies must be implemented in the sense of water security. Modern technologies include the Internet of Things (IoT) and artificial intelligence systems with the integration of sensors and controllers [25]. The rapid increase in the population increases the water demand. The implementation of modern water sensor technologies provides water security solutions. This system tracks consumption and stores data. This study examines the future direction of smart sensors for household water consumption and tracking [26].

Energy utilization has become a standard and scholarly inclusion of renewable energy. Server hydro-farms produce drinking water. This study examined the water utilization of farms and the estimation of water utilization for sustainable solutions [27]. Water is a basic requirement of living operations. The increase in population increases the requirement for water. The main purpose of this system is to produce fresh and healthy water to provide clean water and maintain the reliability of our ecosystems. The Internet of Things (IoT)-and Internet communication technology (ICT)-based systems play a major role in monitoring and tracking water. In this study, IoT-based systems controlled the amount and quality of the water [28]. Water is a basic necessity for our lives. Water usage and control are major problems faced by society. Internet of Things (IoT)-based smart devices analyze and control water usage. An IoT-based intelligent meter system uses data storage algorithms to reduce water wastage. This system uses an Arduino Uno, a Wi-Fi module, and flow sensors to collect data efficiently. A simulation analysis was conducted using MATLAB software to model the algorithms [29].

Water pollution is a major problem worldwide. Polluted water causes health problems for living organisms. If water is polluted, suitable measures can be taken to clean drinking water. The integration of sensors is considered in this system to examine the real-time parameters required to purify water. The sensors were integrated into an Arduino-based microcontroller to observe and control the system. This study proposes an economically intelligent Internet of Things (IoT)-based water quality observation system that continuously monitors quality parameters. The prototype was developed and tested, and further data were transmitted to the cloud for testing [30]. The progress of Internet of Things (IoT) technology has improved system monitoring procedures. The network of the controller, sensors, and actuators improves the stability of the system. Water quality in India is a major challenge. The industrial sewage produces water pollution to the maximum in lakes, rivers, and the sea. In a conventional system, the monitoring process involves manual calculations of samples from different regions. The sensors were integrated with Arduino Uno to monitor water parameters [31]. The system previously designed was high in cost and energy usage. The Internet of Things (IoT) system was considered in this study to measure parameters like pH, salinity, and turbidity. The smart water architecture integrated with IoT and machine learning is proposed in this study [32].

Freshwater resources are finite in the face of human threat. Although water-saving options have generally improved, these efforts are still far from conserving enough water to prevent future water shortages that might seriously affect our way of life. The public has to be aware of the risks associated with water quality and sustainable individual water usage due to the long-term increase in requests for high-quality new water [33]. This study introduces a Shrewd Watering System (SWS) that makes intelligent use of water in small- to medium-sized fields by using Android applications. The proposed architecture is based on a number of open and responsible sensors that continuously record data on plants and climate variables, such as air temperature and soil moisture level. After data is collected from sensors on a server, the suggested SWS uses the Fluffy Rationale and Blockchain approaches to interpret the data and decide on the watering schedule. In this study IoT system framework benefits greatly from the web applications for the Watering Framework (SWS) model [34]. Water security is a major problem in securing water resources for drinking water. Water scarcity and low water pressure pose a major threat to global population health. The conventional method of manual meter reading is badly arranged and tedious, but it also squanders assets. This strategy is additionally unfit to deal with the sustainable water assets since it requires productive, precise, and solid checking methods that empower the utilities area and buyers to know the degree of water utilization progressively. Continuous brilliant water meters that can be checked by the client are fundamental and comprise a critical part of the water management system. The conventional system uses manual measuring, which is unfit to secure the water assets. Since the water consumption requires a real-time smart system to monitor the water system. This system is designed to reduce the wastage of water and track the abnormal usage. The study uses wireless sensors with application development to monitor the system [35].

1.1. Objectives

The prototype contributes to the design of a smart water tracking system using Internet of Things (IoT) technology to enhance purity and reduce water waste. The main objectives of an intelligent system are as follows:

- To develop a system that can accurately and timely track water consumption and quality in real time, while continuously monitoring it.
- The primary goal of this system is to determine the consumption that identifies and reduces water waste.
- The main objective is to design a remote monitoring system so that users can view the consumption data from any location.

2. Material and Methods

The proposed system was constructed to control and observe water quality parameters such as pH, turbidity, and light intensity. This intelligent system measures and monitors environmental factors using IoT and sensor-based networks. The 12V DC motor pump, TDS sensor, and turbidity sensor were integrated with an Arduino ESP32 microcontroller. The water supply senses the flow using sensors. To ensure reliability, a turbidity sensor was installed in the water supply line. For testing purposes total dissolved solids (TDS) sensor was used in the water supply line. For cloud-access IoT-based systems, integrated microcontrollers and sensors collect data and transfer real-time information to web applications and smartphones. Digital data conversion was performed using an Arduino microcontroller. The data parameters included water flow, quality, and total dissolved solids.

2.1 Hardware Components

The hardware components are used for controlling, observing, and optimizing the watering system using an Internet of Things (IoT)-based intelligent water tracking system. Parameter control with sensors related to the environment. The hardware components were selected based on the energy consumption, atmospheric conditions, calibrations, and price.

2.1.1 Microcontroller

In this study, Arduino was used to synchronize all actions of the irrigation arrangement. The ESP 32D controller was designed with a combination of digital and analog (I/O) ports that may be interfaced with several development shields. The controller has 15 digital and analog I/O pins with a programmable controller.

2.1.2 Turbidity Sensor

A turbidity sensor is a device that evaluates the light scattering caused by particles to determine how cloudy or hazy a liquid, usually water, is. It is widely employed in various industrial processes, environmental monitoring, and water treatment to ensure water purity. Figure 1 shows a schematic of the turbidity sensor, and technical specifications are given in Table 1.

2.1.3 Total Dissolved Solid Sensor

A TDS (total dissolved solids) sensor is a device that is used to measure the amount of inorganic salts, minerals, and other dissolved materials in a liquid. Figure 2 shows a schematic of the TDS sensor, and technical specifications are given in Table 2.

2.1.4 DC Water Pumps TL-C01

The DC centrifugal pumps are driven by a brushless motor. Utilize garden-fresh water, saltwater, and

other waters friendly with the parallel viscosity of water. The motor uses solar power for operation and the system is integrated with an Arduino to control and monitor the system. Table 3 shows the technical specifications of DC Water Pump.

2.1.5 Flow sensor YF-S201

The water flow sensor contained a PVC regulator body. It is a water sensor. When water flows through the rotor, it reels. Its speed variations changed with the amount of flow, and the Hall effect sensor produced pulse signals with respect to speed, which is appropriate for sensing the flow in water in pipes.

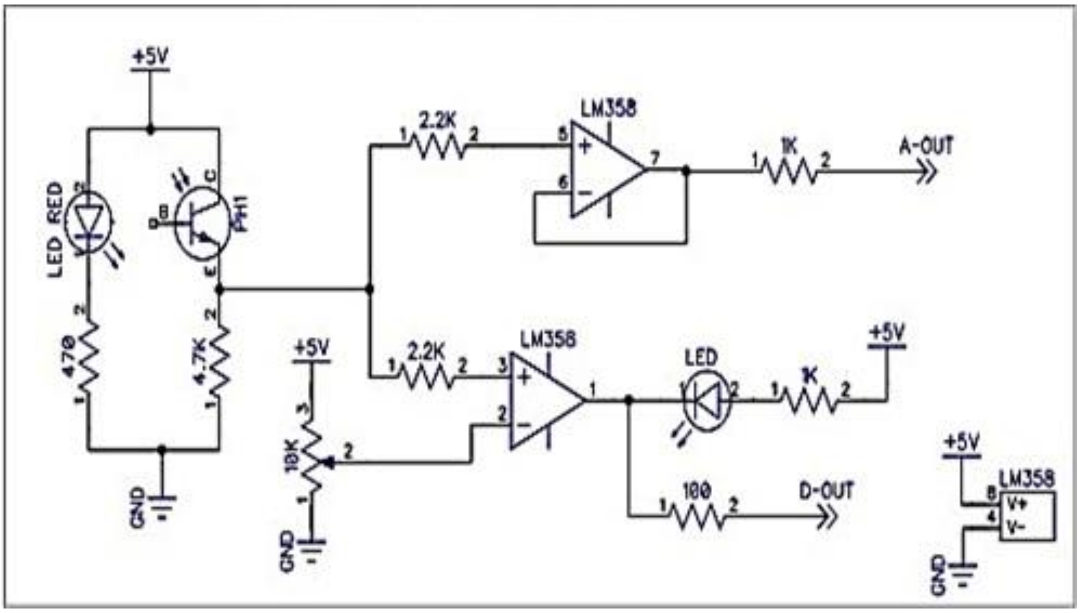

Figure 1: Schematic diagram of turbidity sensor

Table 1: Turbidity sensor technical specification

PIN Number	Description
Data	Measure water quality by light scattering caused by suspended particles
V_{cc}	5 volts
Ground	Connected the ground to the main circuit

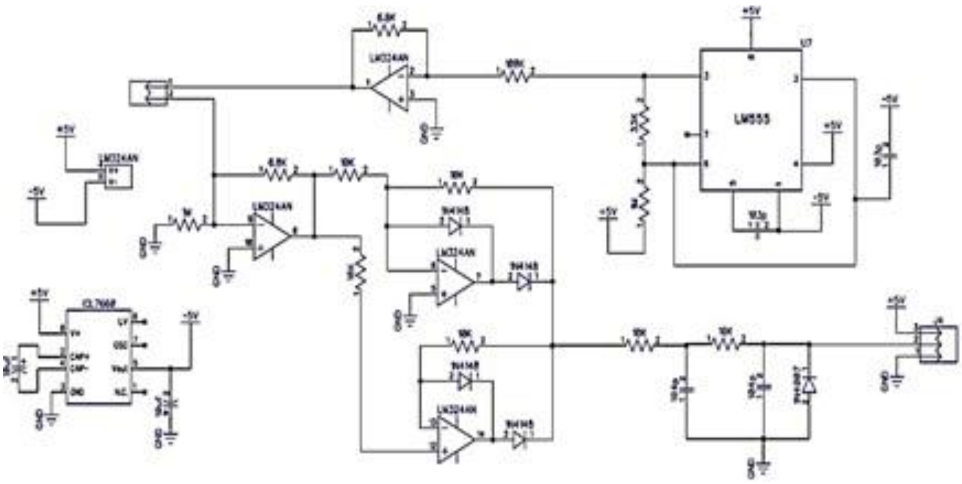

Figure 2: Schematic diagram of TDS sensor

Table 2: TDS sensor technical specification

PIN Number	Description
Data	Measure the amount of inorganic salts, minerals, and other dissolved materials in a liquid
V_{cc}	5 volts
Ground	Connected the ground to the main circuit

Table 3: DC pump technical specification

Parameters	Description
Power	12 VDC
Current	2 A
Protection	Overvoltage and current protection
Type	Centrifugal pump
Life	22000 hours
Flow	18 l/min to 22 l/min

Table 4: Flow sensor technical specification

Parameters	Description
Power	4.5-24 VDC
Current	10mA
Flow rate	1-30 L/min
Pressure	≤1.75MPa

2.2 Schematic Diagram

The hardware prototype schematic diagram was designed using Dip trace software. Different components were linked in the construction of the proposed system to design a model for monitoring water parameters. A schematic diagram is shown in Figure 3, which demonstrates the hardware flow of the proposed system.

2.3 Block Diagram

Figure 4 shows a block diagram of the proposed system strategy for the designed prototype.

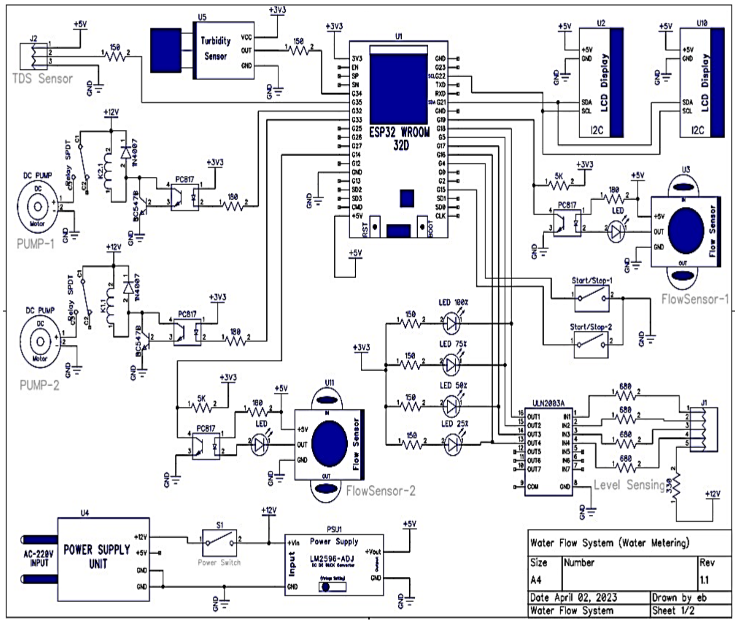

Figure 3: Schematic diagram smart water tracking system

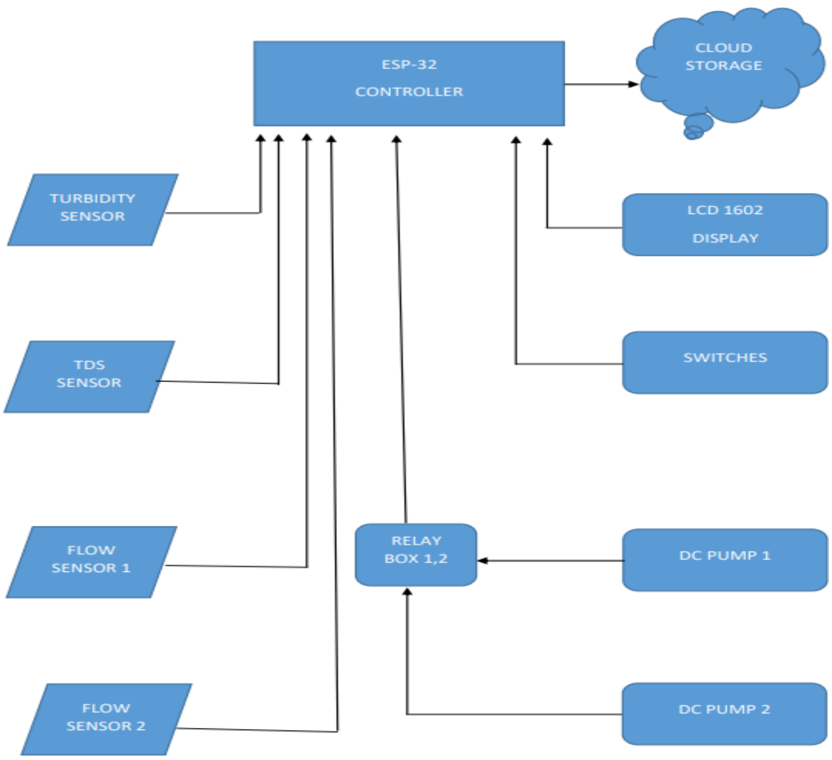

Figure 4: Block Diagram for proposed system

2.4 Software Implementation

Figure 5 shows the Arduino IDE Interface used to implement a smart water tracking system. Microcontroller programming is designed to switch the motor, and water flows through the flow sensor, which senses the flow of water. The turbidity and TDS sensors were already dipped in the water tank to read the quality of the water, and the level sensor to determine the level of the tank. The sensor transmits data to the controller, demonstrates the display, and transmits the data to the cloud server (Google Firebase), where a user application is connected to visualize the data.

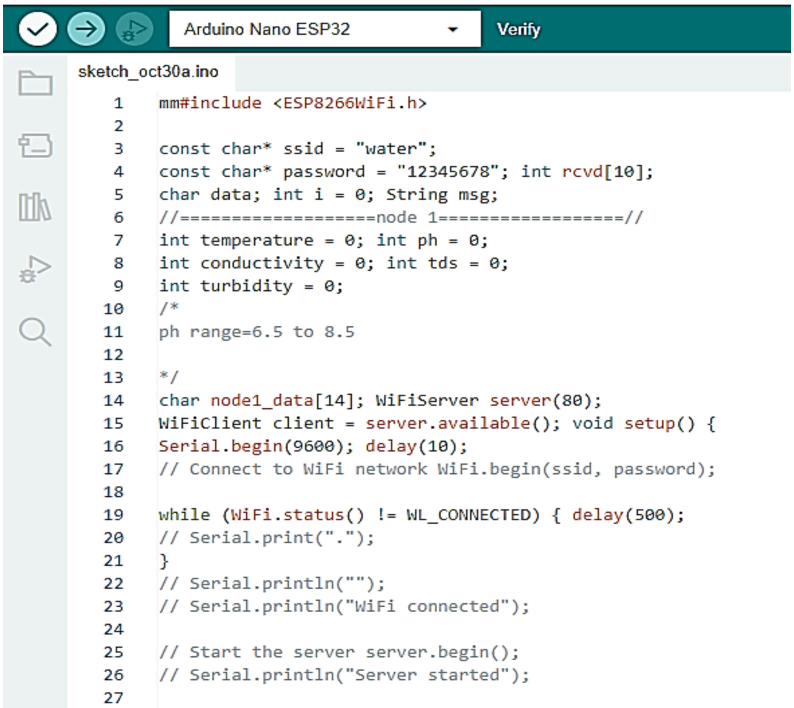

Figure 5: Software implementation (Arduino IDE programming interface)

2.5 Hardware Implementation

The main component of the prototype is an ESP-32D microcontroller. All the hardware components of this project were connected to this microcontroller. This controller received the flow, Turbidity & TDS sensor signals, and sent the data. The quality of water was demonstrated to the LCD display module and the user app through cloud storage. The turbidity sensor senses the water quality. There were three terminals in the turbidity sensor. Terminal 1 for the DC supply, Terminal 2 attached to the controller, and Terminal 3 for the ground. The TDS sensor measures the water quality. The sensor includes three terminals. Terminal 1 is for the DC supply, Terminal 2 signals the controller, and Terminal 3 signals the ground. Two pumps were used in our prototype, both of which were connected to the DC power relays. DC power relays were connected to an Arduino. The LCD panel module displayed the water flow parameters. Two 5V flow sensors were used in this project. The flow sensors were connected to the controller. The flow sensors include three wires for supplying the DC supply, the second is connected to the ground, and the third is connected to the controller pin. Figure 6 shows the hardware flow for the smart water-tracking system. IoT comprises hardware components integrated to analyze data via applications. This system was designed to better manage water using an eco-friendly system.

2.6 Mathematical Calculations

This system is based on a water sensor and two water DC pumps to monitor the water flow and quality. In this study, we measured and tracked the water flow, and the sensor calculated the water amount. The calculations during testing were as follows.

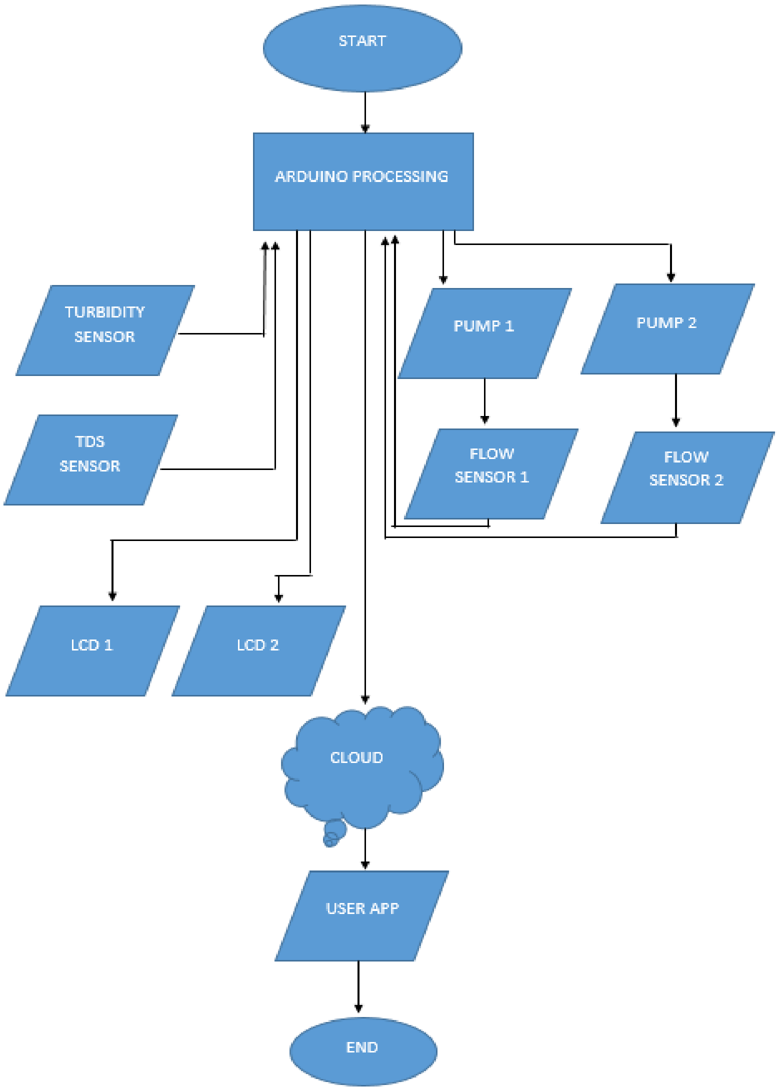

Figure 6: Hardware flow

Current calculation of the Solar panel at the maximum power point:

P = V I

P = 20 watts

V = 18.9 V

I = 1.58 A

P = V x I

20 watt = 18.9 V x I

Now, solve for I_{mp}

$I_{mp} = \frac{20\ W}{18.9}$

DC pumps current equation:

$I = \frac{P}{V}$

V= 12V

$I = \frac{6}{12}$

$I = 0.5$ A

The proposed system uses a 20 watts photovoltaic panel and two 12VDC water pumps to implement the water management scheme. The panel rated power 20 watts and 18.9 V drawn 1.06A current under operational conditions. The DC water pump rated 6 watts and 12VDC draws 0.5 A during the operating condition.

3. Results and Discussion

The experiment was conducted with all sensors working properly to sense environmental parameters. This prototype was inspired by clean solar power energy technology. This prototype is based on saving water resources using strategies for improving the management system and reducing water waste. The system is designed to monitor the water consumption and quality with the help of an Arduino controller and sensors like turbidity, TDS and water level sensors, and flow sensors to measure the quality and consumption.

3.1 Experimental Setup

The YF-S201 sensor was used to check the flow rate. The water supplied by the TL-C01 DC pump was allowed to pass through the water to check the flow rate. The output pulses were recorded by the microcontroller, while the turbidity sensor and TDS measured the light scattering and dissolved material to verify the water quality. The microcontroller was integrated with a Wi-Fi module for real-time parameter monitoring. The collected data size indicates the sensor accuracy and water system efficiency. Table 5 shows the sensor accuracy, system energy performance, and water usage efficiency datasets.

Table 5: TDS sensor technical specification

Component	Range	Accuracy	Power Source
YF-S201 Flow Sensor	0–30 L/min	±2%	5V
Turbidity Sensor	0–1000 NTU	±3%	5V
TDS Sensor	0–2000 ppm	±2%	5V
TL-C01 Pump	18–22 L/min	--	12 V DC

Table 6 shows the sensitivity, speed, and other parameters. These gaps were addressed by implementing an IoT-based water management system.

Table 6: IoT and Traditional System Comparison Analysis

Article	Cost	Real-time monitoring	Speed
IoT Based	Less	Advance	Faster
Traditional System	More	Basic	Slower

For comparative and quantitative outcomes, the microcontroller IoT-based model included cloud data communication time. The evaluation indicated that the water management of the system was more advanced than that of the manual electromagnetic relay-based scheme. The discovery time and statistical consequences of the projected system are presented in Table 7.

Table 7: Quantitative Results

Components	Detection	Accuracy	Power
Arduino + IoT prototype	120 – 150 ms	High	8W
Electromagnetic Relay	200-500 ms	Low	1W

3.2 Application Interface

The user app was designed using an Ionic platform. This framework can utilize Web browsers and mobile applications. This framework utilizes web technologies such as HTML, CSS, and JavaScript to construct high-quality mobile apps that can operate on various platforms, including iOS, Android, and other websites. Figure 7 shows the web application results for controlling and monitoring the system.

Figure 7: Web application interface

3.3 Developed Model

The device can be used in small household applications. The proposed system application is extensible. The brain-box system for the control hardware implementation is shown in Figures 8 and 9. A solar panel was installed in the prototype to power the smart water-tracking model. Two switches were installed at the front to start the pumps. Two LCDs were manually placed to monitor the water usage. A tank was placed at the back of the prototype to store water. The circuit contains an Arduino controller as the brain of the system. The turbidity and TDS sensors were placed at the center of the prototype board. The water level sensor was placed in the tank, two pumps were installed in the tank, and two flow sensors were connected to them and placed outside the tank. Switching can be managed by various applications. The real-time parameters of the motor, valve, and level were demonstrated using the IoT system.

The implementation of the developed intelligent water management system has provided numerous positive outcomes. Some potential results are as follows:

- **Water Conservation:** A smart water-tracking system optimizes the water delivery system. This

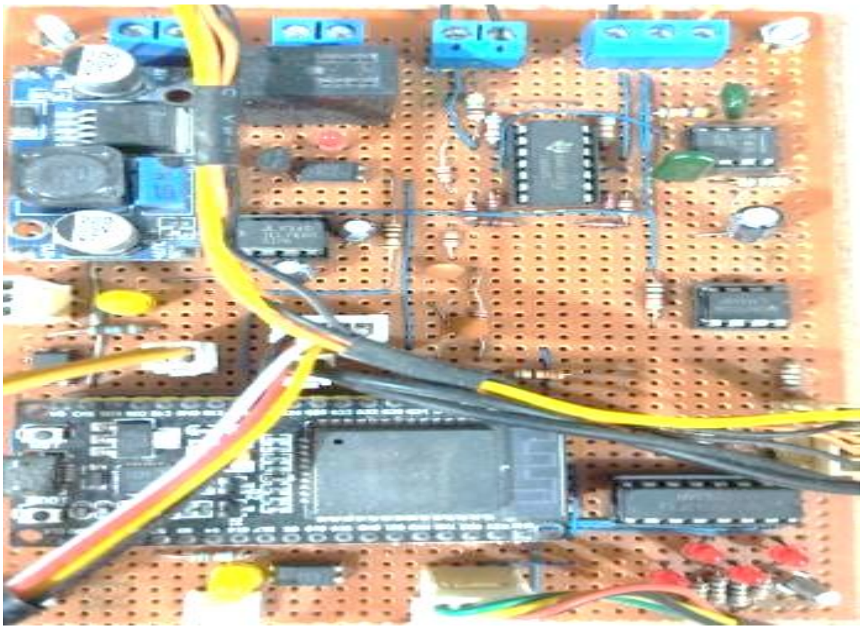

Figure 8: Experimental setup

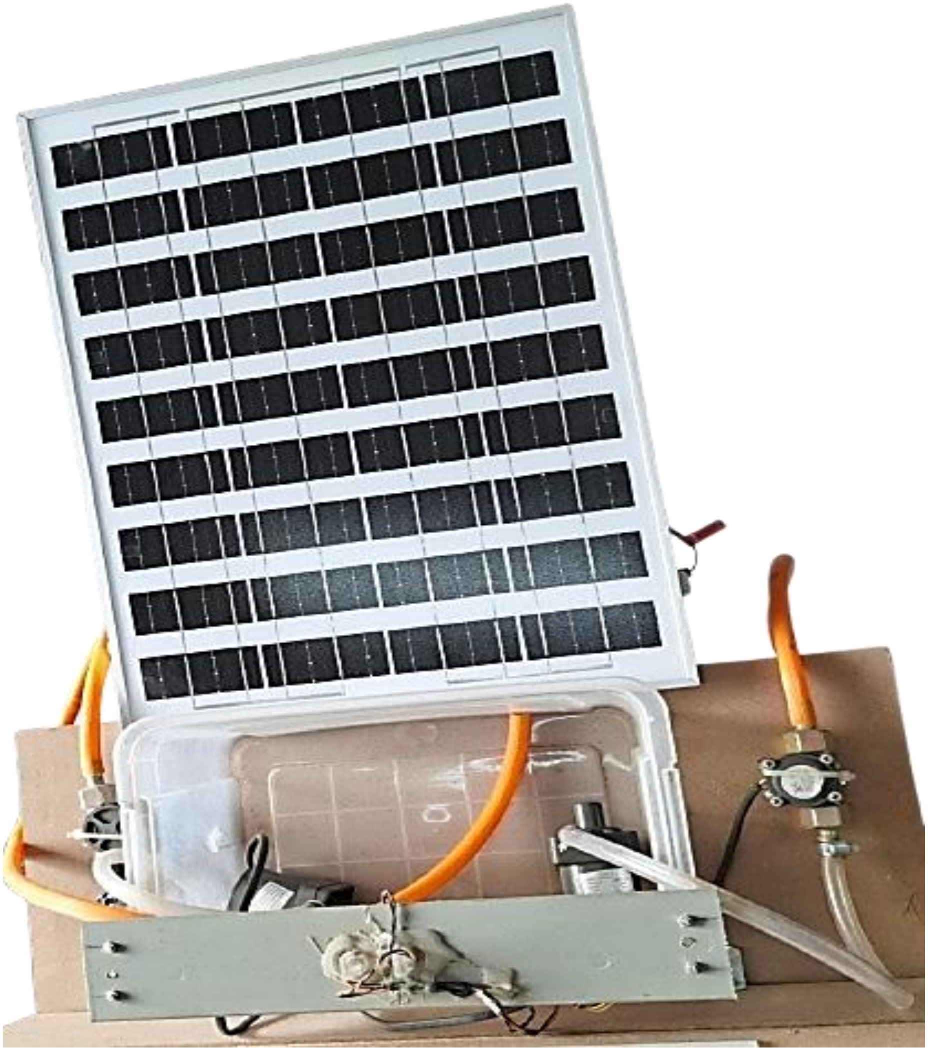

Figure 9: Experimental setup

system provides an optimum solution for reducing wastage of water and energy.

- **Energy Saving:** The developed smart water management system was inspired by clean energy technology. This system uses solar power to operate the prototype.
- **Eco-friendly System:** This system provides an environment-friendly scenario for both water and energy. Economic: This system reduces the water and energy bills for utilities compared to a conventional system.

Overall, an intelligent water system utilizing IoT technology can result in water conservation, energy savings, environmental sustainability, and low cost. These results demonstrate the potential of IoT-based upgradation in water practice and promote renewable energy-based systems for sustainable solutions.

3.4 Comparative Analysis

A comparison with conventional water management systems is summarized in Table 8 in terms of cost, efficiency, and scalability.

Table 8: Comparative Analysis

System Type	Power Source	Cost (PKR)	Efficiency	Scalability
Proposed System	Solar 12 W + 12V Battery	55,900	92%	High (IoT Tracking)
Conventional System	Grid Power	≈ 180,000–220,000	92%	Fixed Installation

4. Conclusions

Due to the cumulative increase in water and energy shortages, a solar-powered smart water consumption tracking system was designed for water management. This system has access to data accuracy, real-time data collection, and active status through IoT-based cloud technology. This technology significantly reduces water waste by managing water pumps using real-time flow-rate data. This leads to significant cost savings and environmental benefits. Moreover, the system reduces labor costs. Although significant progress has been made in tackling important water management challenges with this prototype, the implementation of this system might have a sustainable and long-lasting effect on the management of water resources, eventually supporting environmental sustainability and economic feasibility in both urban and rural areas. The results showed that the implementation of the water-tracking system saved water and energy and reduced manual human interaction. The implementation of this prototype can enhance the efficacy of water management systems by 92%. The designed system costs 55,900 PKR with high efficiency and scalability. The future large-scale implementation of this study will improve Pakistan's critical challenges and problems for sustainable water management.

Acknowledgment

The authors greatly thank the Department of Electrical Engineering, Nazeer Hussain University, Karachi, Pakistan, for the hands-on support to this research work.

Conflict of Interests

Publication of this research article has no conflict of interest.

Funding Statement

This research article is not a product of a funded research project.

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