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Integrated intelligent system for water quality monitoring and theft detection

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ABSTRACT

In India, water demands have risen inexorably over the last decade. The world's growing need for water has become a huge concern. The resource has been depleted due to wastewater, global warming, and industrialization. The importance of resource conservation and management must be prioritized. This work introduces an Internet of Things concept for water scanning and management in this work, which provides real-time feature extraction via the Internet. The suggested strategy addresses emerging needs within the aquatic sector, like gauging flow velocity and the imperative for scrutinizing water provision to minimize wastage and promote conservation. It also utilizes pH and conductivity sensors to examine the excellence of the aquatic that is distributed to every home. Traditional water metering methods necessitate consistent personal engagement for conservation, rendering them unwieldy and inefficient. To address the shortcomings of existing models, the proposed strategy employs wireless technology for smart quality sensing and information communication.

Key words: intelligent system, Internet of Things, quality assessment, theft detection

HIGHLIGHTS

- The goal of this project is to create and deploy a real-time system that uses GSM technology to track water quantity, detect leaks, monitor water quality, and bill users according to the quantity detected.
- The goal of the suggested system is to offer a complete answer to the problem of effective water management.
- The system's usage of GSM technology allows for real-time remote monitoring of water quality, accurate quantity measurement, rapid detection and relay of leaks, and automated payment based on those metrics.
- This holistic strategy promotes a more efficient and adaptable water supply system by assuring the ongoing evaluation of water quality and improving the general administration and longevity of water resources.

1. INTRODUCTION

In the water sector, consumers give an indisposed critical mass for influencing choices that effect in necessary improvements. Aquatic assets interact intricately with economic, societal, and environmental activities in the watery system (Bhatt & Patoliya 2016; Chowdury *et al.* 2019; Fuentes & Mauricio 2020). There are many participants in this arena, both public and private, ranging from large enterprises to tiny firms, and every one of them receives assistance from the federal, state, and local governments. The present market fragmentation in the water management system (WMS) is due to the diverse character of stakeholders as well as the many water governance plans that are constantly changing in each nation. Extreme trade fragmentation is a significant obstacle to modernization under the preferred model of integrated WMS, as it reduces the acceptance of public source models and principles (Chen & Han 2018; Saravanan *et al.* 2018; Odiagbe *et al.* 2019) This technique may facilitate interoperability, building it simple for researchers to increase current results and embrace innovative ones.

1.1. Need for study

The major problems must be overcome to create realistic and broad industrial standards for water management (WM) processes: (1) Water quality and waste management are not integrated. (2) A unified integrated WMS reference architecture for water managing manners that are currently insufficient.

There is a dearth of integration between existing systems. Local solutions can also be built and maintained, despite the fact that there are many worldwide suppliers who integrate WM solutions. For their solutions, global and local vendors use distinct standards, methodologies, information paradigms, and broadcasting routes. These responses are frequently complicated and, in some cases, unmanageable for their consumers. This stumbling block causes observing problems, which obstructs the crucial administrative process. It emphasizes the importance of shared considerations and techniques for efficient aquatic management.

By exploring distinct business, societal, and technical considerations, this work can include WMS with Internet of Things (IoT) capabilities (Maroli *et al.* 2021; Karthikeyan *et al.* 2023). The main benefits of using the IoT in water administration scenarios are as follows:

(i) Efficacy improves: Real-time operational control can help WM corporations and organizations can take intelligent trade choices then preserve funds. They use immediate information through actuators and detectors to observe and improve WM schemes, leading to greater efficiency, lower energy costs, and less need for human intervention.
(ii) Budget decreases: Improved asset utilization, operational efficiencies, and productivity can all help to lower WM expenses. Improved asset usage (for example, smart water irrigation devices) and service enhancements (e.g., remote monitoring) can benefit customers and companies.
(iii) Asset utilization: By enhancing the monitoring of assets (machines, equipment, tools, etc.) via sensors and connectivity, organizations can obtain visibility as well as understanding into their resource and supply chains (Rober H Smith 2021).
(iv) Throughput rises: Productivity is a significant factor that influences a company's profitability.

IoT permits real-time command, innovative schemes, course optimization, source maintenance, examination time lessening, and the ability of global control, decreasing the difference between mandatory vs. existing skills and enhancing employee efficacy (Sharma & Nayanam 2020).

1.2. Objective

The target of this work is to design and build a Global System for Mobile (GSM) communication-based scheme for:

- system for assessing the purity of water;
- water quantity assessment;
- leakage detection as well as real-time information transmission;
- billing based on the quantity measurement.

The remaining portion of the article is structured in the following manner: The first section presents the scheme and its purpose. The literature review is described in section 2, and the technique for proposed work is demonstrated in section 3. Results and discussion of the work are covered in section 4. The project work is finally concluded in section 5.

2. RELATED WORKS

Zhang *et al.* (2011) suggested a system framework for real-time aquatic feature assessment in aquaculture using the wireless sensor network (WSN) capabilities. The monitoring arrangement is a computerized, intelligent, and efficient device that ensures the excellence of aquaculture water. Zhenan *et al.* (2013) concentrated on water quality monitoring (WQM) and control in general water bodies such as reservoirs and ponds. Major technological issues like choosing sensors and wireless network management are examined, also relevant algorithms are chosen based on model requirements. Zanella *et al.*'s (2014) goal is to improve the utilization of government assets via improving the excellence of service provided to residents as well as lowering the public administration's operative amount. The major goal of this project is to provide communication infrastructure that allows citizens to have unified, simple, and cost-effective access to a variety of government services, thereby unlocking potential synergies and boosting transparency. Adamo *et al.* (2014) and his collaborators outlined a combination of intelligent sensors. These sensors were developed based on the real-time, continuous monitoring of surface water bodies, specifically those with a saline composition. The primary purpose of this system is to provide a valuable tool for WQM, serving as a dependable information source to inform strategic choices concerning significant ecological challenges. Cloete *et al.* (2016) suggested the strategy and improvement of a water standard-checking organism to inform users of real-time water quality data. The device can monitor speed, temperature, pH, conductivity, and oxidation-reduction potential, among other physicochemical indicators of water quality. Water pollutants can be detected using these physiochemical characteristics. The measuring node can send data to the warning node for vocal and video notifications through ZigBee.

Faustine *et al.* (2014) developed an experimental aquatic intelligence structure to facilitate WQM in the Lake Victoria Basin. The device measures the substance's pH, electrical properties, oxygen in solution content, and heat in real-time. It immediately distributes this information, which is presented in both pictorial and statistical forms, to key stakeholders via an internet-based user interface as well as smart phone applications. Sharath *et al.* (2014) and Tao *et al.* (2014) offered a solution to the issues with existing analog water meters, such as lower stream capacity accuracy, air valve issues, manual billing systems, and uneven aquatic dissemination. It uses a wireless connectivity with minimal power called ZigBee to automate the invoice system, and NI-LabVIEW to develop the human-machine interface. Fang *et al.* (2014) proposed a unique strategy for environmental monitoring and management that incorporates IoT, geo-informatics, and ecological science. Wiranto *et al.* (2015) suggested a technique to measure pH as well as oxygen concentration in a variety of seafood farm facilities in Indonesia. A handy, economical, and energy-efficient multi-sensor system for atmospheric and WQM is presented by Simić *et al.* (2016). To maintain a safe supply of drinking water, Pasika & Gandla (2020) presented a WMS based on IoT. Water quality should be monitored in real-time using sensors, and the measured data should be processed by a microcontroller in this manner. Mukta *et al.* (2019) offered an IoT-based intelligent WQM scheme that allows for real-time monitoring of aquatic conditions using four quality metrics: pH, temperature, contamination, as well as electrical conductivity. Konde & Deosarkar (2020) introduced an IoT-based programmable sensory connection module for tracking the quality of water.

The water quality parameter was used to construct a smart WQM model. The pH of water determines whether it is acidic or basic, and dissolved oxygen tells how much oxygen is dissolved in the water. The conductivity of water refers to its ability to carry a current of electricity. Turbidity is a measurement of how transparent the water is. Traditional methods have drawbacks such as difficult methodology, a long wait for results, low measurement precision, and high costs. This work proposes continuous monitoring of aquatic excellence characteristics in real-time utilizing an IoT framework that may be developed and designed at a minimal cost by focusing on the aforesaid challenges.

3. MATERIALS AND METHODS

Figure 1 shows an IOT-based system that includes a solenoid valve, various smart sensors and intelligent processor. The power supply unit is utilized to provide power to all of the blocks. The aquatic level is monitored by an ultrasonic sensor. The sensor sends out a sound pulse, which is reflected by the object being detected. The flow rate of the water is measured with a flow meter. Water quality is measured using pH and conductivity. In this work, an Atmega 328 controller with 28 pins was used. Transmission and reception of inputs to an external device can be used to control the inputs. Pulse width modulation (PWM) is included to enhance the efficiency of the scheme. The controller receives sensor data and uses GSM to update the information on the webpage. It also uses the driver to regulate the valve. If any parameter exceeds the predetermined level, the system actuates the solenoid valve as shown in Figure 2, and updates the information on the webpage.

The process of the recommended WQM system is shown in Figure 3. All components are fed by the power supply. It converts AC to DC voltage. The diode is connected to a transformer that converts 230 V into 12 V AC. The IN4007 diode converts AC to DC electricity. To keep the voltage constant, an LM 7805 regulator is employed. The regulated signal is passed on to the next capacitor, which filters out undesired AC components. If the output voltage exceeds the limit, the load LED with a voltage of 1.75 V will be dropped on the resistor. The Atmega328 controller is employed as the architecture's core in this work. The level of the water is determined employing the ultrasonic sensor, which is attached to controller port A0. The pH sensor is attached to port A2 of the controller, while the conductivity sensor is attached to port A1 of the controller as shown in Figure 4. These are used to determine the quality of the water. Port A3 is where the flow meter is connected. The controller accepts sensor data and uses a driving circuit (ULN2003) to regulate the solenoid valve. The controller also uses GSM to refresh the information on the web page. It uses serial link to connect to controller ports 2 and 3 and is utilized for serial communication between the controller and the GSM.

The acoustic transducer in ultrasonic sensors vibrates at ultrasonic frequencies. The pulses are focused on a target item and emitted in a cone-shaped beam. The pulses are reflected by the target and detected by the

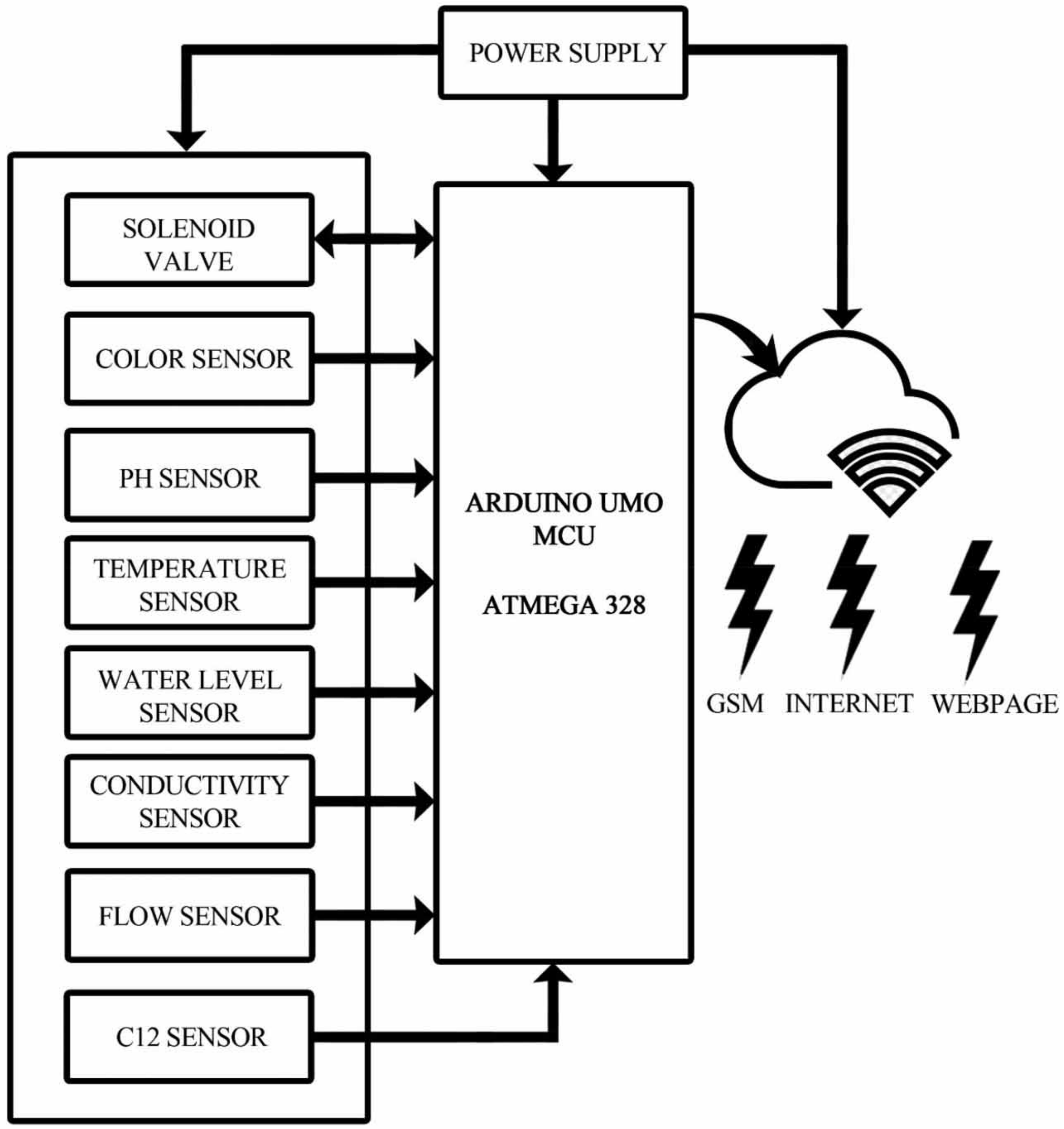

Figure 1 | Suggested integrated WQM system.

sensor. The sensor-to-target distance is reliably determined by measuring the time delay between each emitted and echo pulse.

Soil's volumetric water content is assessed using a conductivity sensor. A sample must be removed, dried, and weighed before being directly gravimetrically measured for free soil moisture. These sensors indirectly detect the volumetric water content by utilizing another attribute of the soil as a stand-in for the moisture level, such as electrical impedance, dielectric variable, or neutron contact. This DF Robot soil moisture sensor contains two probes that send electricity into the mud and then detect the impedance to determine the humidity level.

The water's flow detector, which usually has a pinwheel type to measure water travel, is linked to the water supply. The sensing element has three connections: black (ground), yellow (Hall Effect signal response), and red (5–24 V DC power). The output of the sensor must be used to calculate pulses in order to determine the flow of water. About 2.25 milliliters of volume are represented by each pulse.

Automated information accumulating, chronicling, and data investigation are all advantages of the pH sensor. Common uses of pH sensors comprise acid-base iterations, analysis of domestic acids and bases, observing pH variation through organic responses or in an aquarium as a consequence of photosynthesis, studies of acid fall, and investigation of aquatic purity in rivers and ponds.

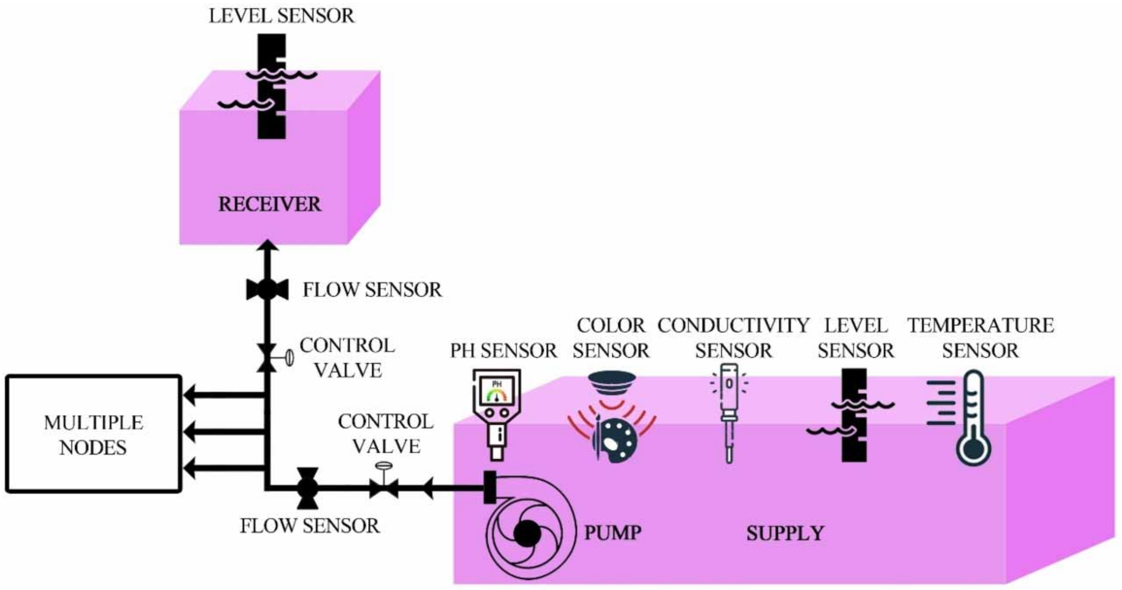

Figure 2 | Representation of a proposed workflow.

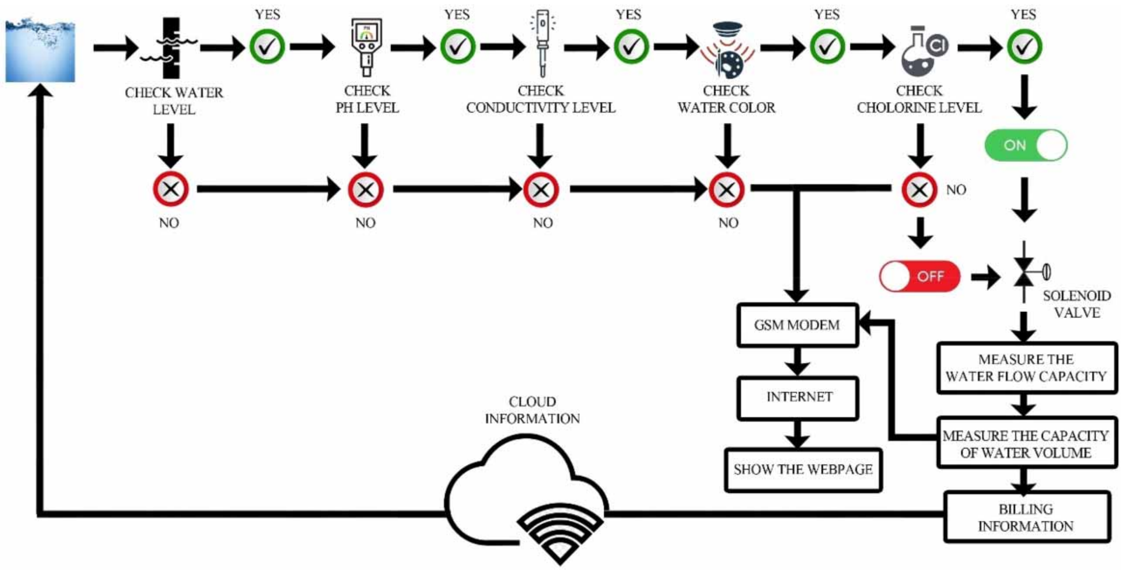

Figure 3 | Process depicting stream illustration.

The TCS3200 GBB has an arrangement of photo detectors, each with a red, green, or blue filter, or no filter. To remove position preference among the colors, the filters for every color are scattered uniformly through the arrangement. An oscillator inside the device generates a square-wave response with a frequency proportionate to the concentration of the selected color.

The chlorine sensor is a membrane-covered two- or three-electrode sensing mechanism. Working and reference electrodes are protected from direct contact with the measurement water by a membrane cap supplied with a specific electrolyte. Ionic chemicals in the water are kept back by the membrane in this measurement method, while chlorine can travel through without restriction.

4. RESULTS AND DISCUSSION

Figure 5 depicts the hardware connections for an IoT-based WQM scheme, which include flow sensors, pH sensors, conductivity sensors, level sensors, color sensors, and chlorine sensors. As illustrated in Figure 5, all of the

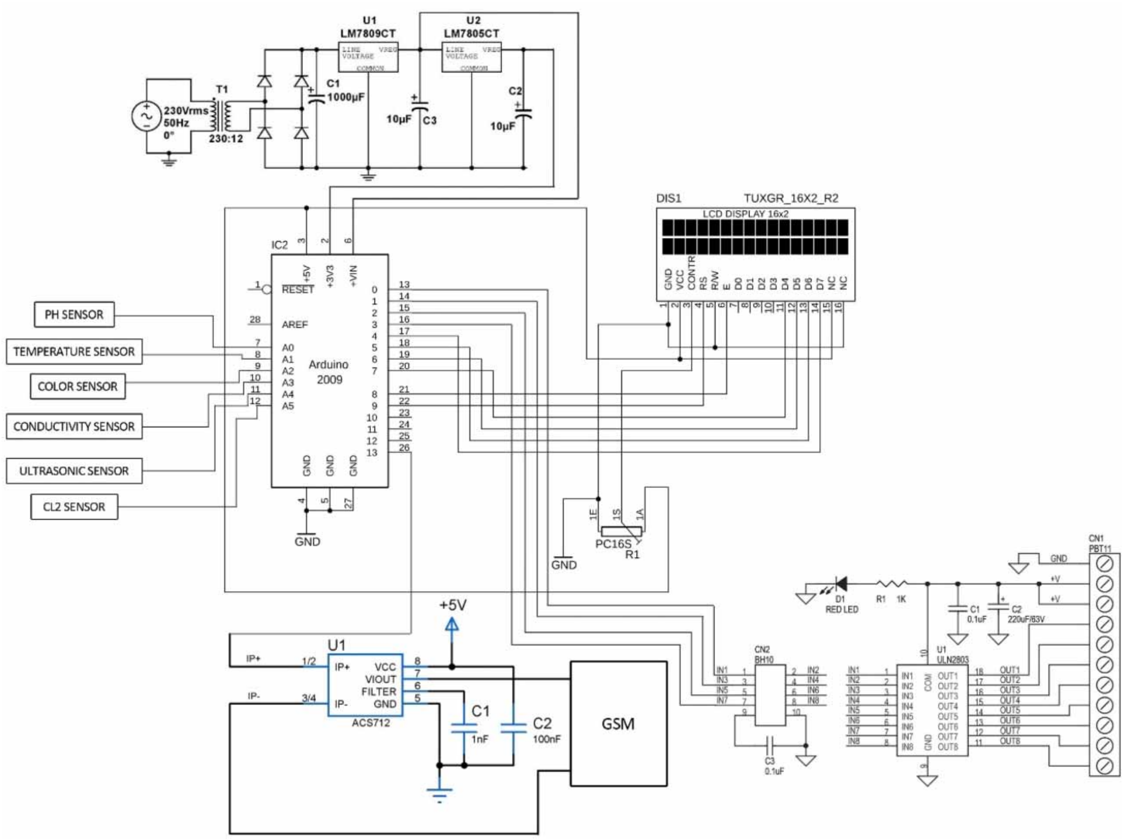

Figure 4 | Interconnection of the hardware modules.

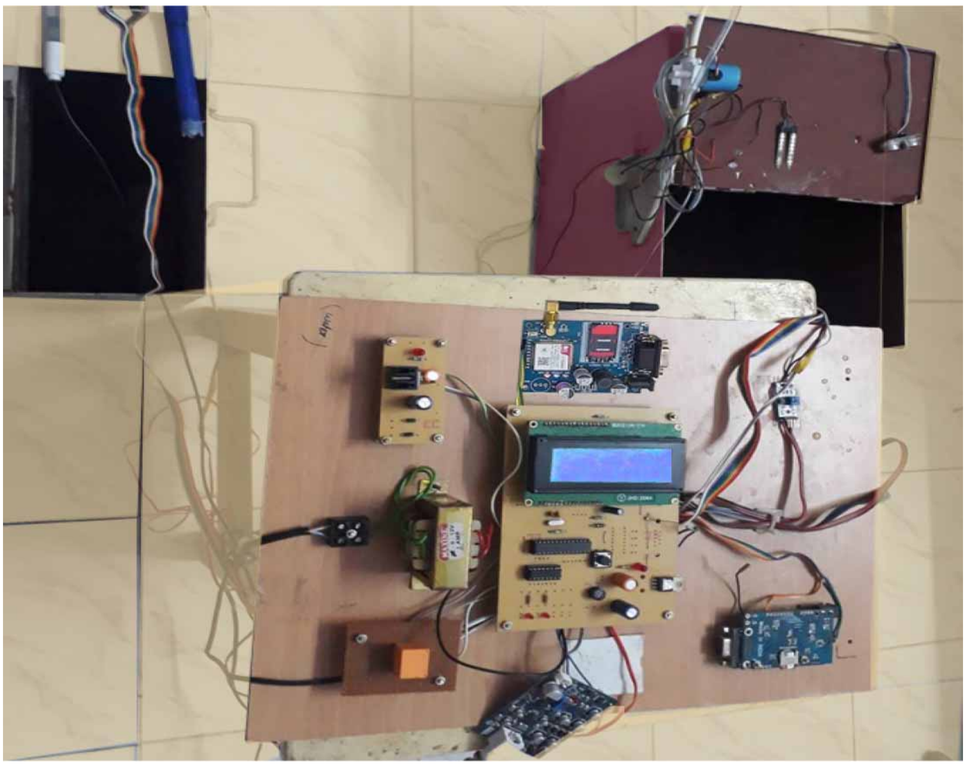

Figure 5 | Full hardware package of the work.

sensors are linked to the ARDUINO board. Two tanks were built to observe the water purity in real-time. The information from each sensor is presented on the display screen in the hardware setup. Through IoT, the same readings were also published on the site. The chemical and physical characteristics of the water are examined based on the readings. Furthermore, within the given resource, the consumption pattern of water may be estimated. Water leakage or theft is also identified, and water waste is avoided.

4.1. Experiment 1: Testing of normal water sample

As illustrated in Figure 6, all of the sensing elements were assembled in the fabricated tank for continuous water purity assessment. Sensors measured the values of normal water in the tank. As seen in Figures 6 and 7, the readings were displayed on the LCD display as well as on the Website. The water quality was tested to ensure that it was safe to drink. Aquatic is inflated from the source reservoir to the reception tank after it has been checked for purity. If the obtained measures are within the specified safe limit, the safe drinking water will be pumped into the tank for consumption. If the value exceeds the threshold, water pumping is halted to improve water quality or alter the water.

Figure 6 | Testing kit setup for normal water.

4.2. Experiment 2: Testing of chlorinated water

As indicated in Figure 8, this highly chlorinated water is added to the source tank, and the sensor reading from the kit is checked for accuracy.

To get high chlorine water, chemical dust is added to the water. The chlorine level in the drinking water is kept at 4.21 ppm. Excess chlorine is thought to cause skin problems. Manual testing showed the results to be satisfactory. As seen in Figure 9, all of the values were presented on the LCD and the web page. After adding the solvent, chlorinated water showed a chlorine range of (2–3) ppm, which was cross-checked with the online measurements. The operations of the solenoid valve were also tested, and valve conditions were displayed.

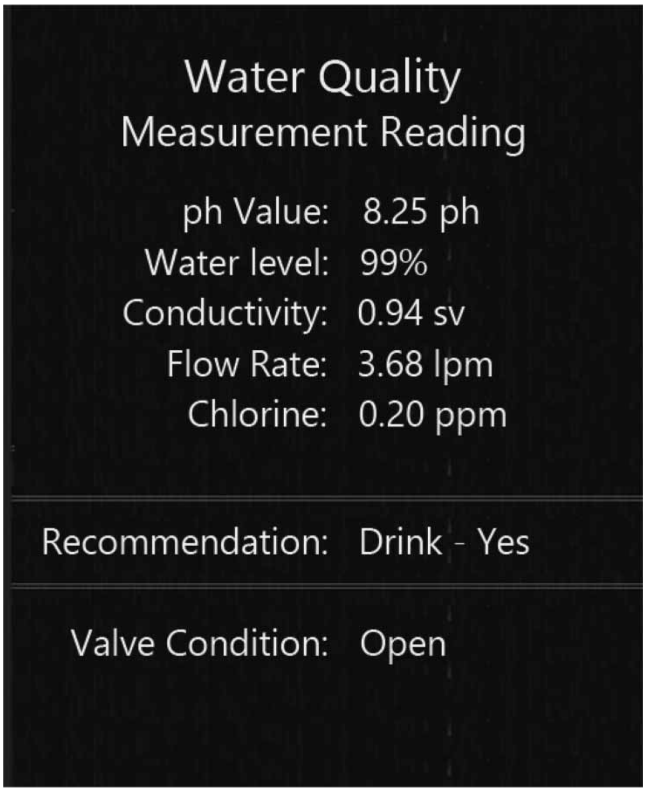

Figure 7 | Web page results of normal water.

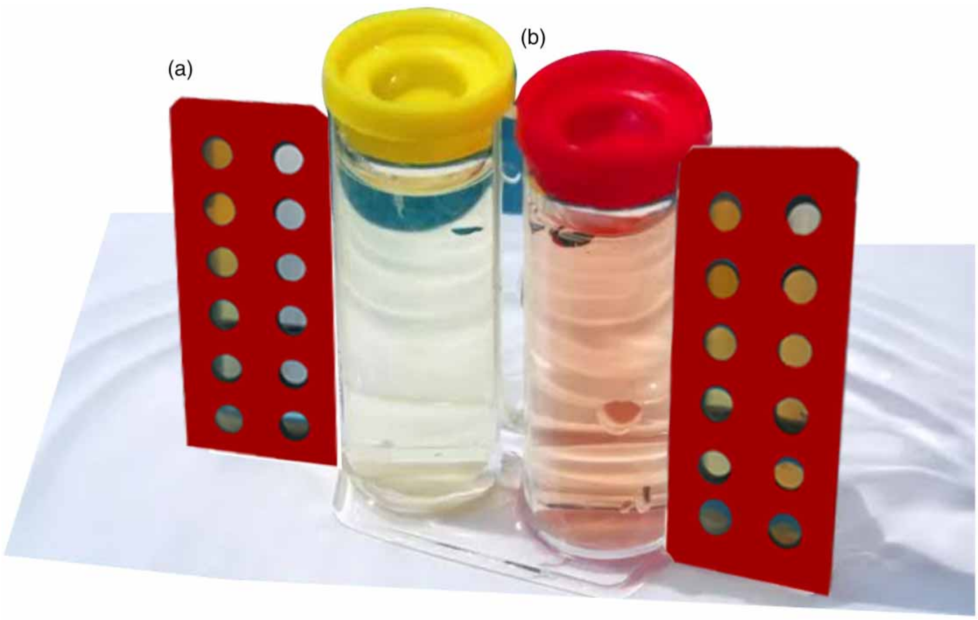

Figure 8 | (a) Before adding solvent and (b) after adding solvent.

4.3. Experiment 3: To detect the water leakage/theft

Two flow sensors were added in this test setup, as illustrated in Figure 10, to determine the quantity of water for billing purposes. Pumping water from one tank to another was made possible by a pumping engine with a tripping circuit. If no leak is discovered, the two sensors' readings of the flow rate may be identical, also the flow amount may be computed in the water distribution.

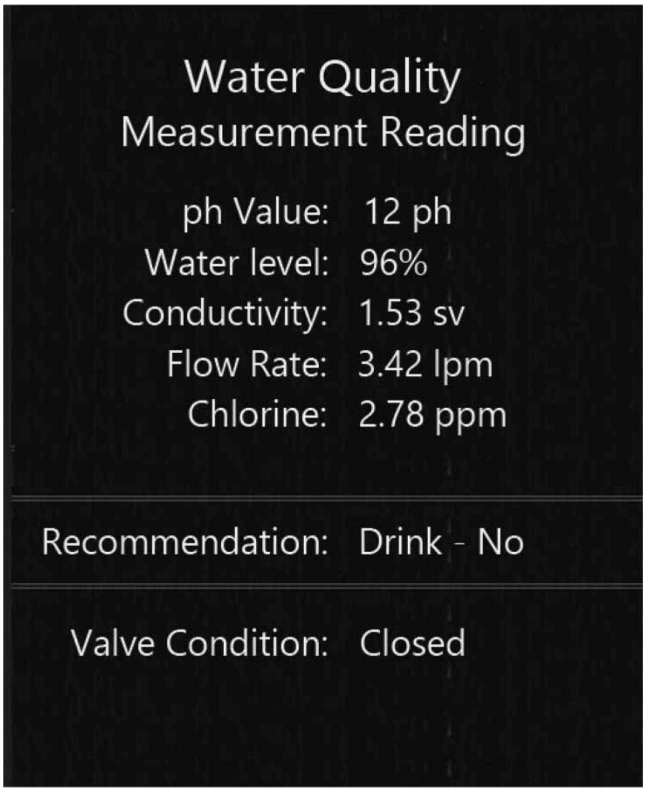

Figure 9 | Web page results for chlorinated water.

Figure 10 | Experimental results of water flow detection – no leak.

Two flow sensors are attached between the sending and receiving ends to detect water leakage or theft. Water is pumped between two tanks using a motor. The water is pushed from one end to the other, using flow rate sensors on both sides. If the flow rates of both are equal, it is determined that there is no leak or theft between the transmitting and receiving ends. If there is a leak or theft of water, one of the flow sensors sees a value lower than the sending end flow (68 and 94) as shown in Figure 11, and the motor is tripped. After that, fix the problem and start pumping water. Since water has become a limited resource, the above kit is mostly used for billing and to prevent water waste.

Figure 11 | Experimental results of water leak/theft detection.

All the performances of the sensor were independently checked before being meticulously attached to the main kit. To ensure the accuracy of the readings, every individual finding was cross-checked with the predefined original values. Finally, the findings were uploaded on real-time basis via the GSM module and displayed on the web page.

4.4. Discussion

This section provides a contemporary performance analysis of the suggested WQM system against conventional methodologies. The comparative analysis mainly considers three factors, which are the precision of the WQM scheme, the overall time taken by the system, and the implementation cost of the system.

The authors Alam & Zohura (2020) used the Arduino mkr100 module in water quality measurement, it is a vintage approach; the apparatus is expensive compared to the proposed processor. In some of the conventional water quality assessment schemes, the researchers used specific sensors for water quality measurement, like fabricated buoy-type sensor nodes (Kageyama *et al.* 2016), solar cell-facilitated sensors (Yue & Ying 2011), TiO_2-centered thick film pH resistive sensors (Simić *et al.* 2016), and fabricated turbidity sensors (Lambrou *et al.* 2014). Due to this specific sensor utilization in the IoT water quality system, the overall implementation cost of the system increases. But the proposed system utilized commercially available low-cost color sensor, conductivity sensor etc., which minimize the total amount of the presented system. Prior studies concentrated on alerting customers to changes in the water's purity via text messages. For the Global Positioning System unit connected to the processor, these methods (Jiang *et al.* 2009; Wang *et al.* 2011; Dehua *et al.* 2012; Li 2014) call for an additional subscriber identity module (SIM). These techniques' drawbacks include additional costs for using SIM cards. Additionally, there is a constraint on how much information may be stored and retrieved at the user's location. This additional cost is minimized by the in-built GSM operation in the proposed system.

Khatri *et al.* (2019) proposed a minimal-cost, wireless WQM arrangement using the Arduino and ZigBee modules. The water excellence metrics under scrutiny for their inquiry have been designated by the Central Pollution and Control Board situated in New Delhi, India. The water surveillance setup employed by Jiang *et al.* (2009) included an alert mechanism that informs responsible staff upon detecting water pollution. The processor will take 500 ms to complete the single event. The four water stations were monitored continuously for five days to verify the performance of the suggested system. Throughout this duration, examination data were saved within the database at 10-minute intervals. Several factors can lead to fluctuations in this timeframe like processor speed, wireless device connectivity, environmental conditions, and so on. Each of the reasons is studied separately with respect to time. Within this study, our focus lies on determining whether the system can execute all tasks devoid of errors, or if the IoT system will signal its incapacity to sustain a higher workload. The proposed system produces a data rate of 76.8 kbps, which minimizes communication among the processors and reduces the delay to less than 5 ms. The Wifi (IEEE 802.11) connectivity among the sensors will provide a higher data rate and longer distance coverage, but it needs a generalized architecture for higher power management (Mahmoud & Mohamad 2016), but the proposed system achieves the optimal delay with minimal power requirement.

The World Health Organization provides the standard metric ranges for the water quality units, like turbidity 5–10 NTU, pH 6.5–8.5, conductivity 300–800 μS/cm, and a chlorine level not greater than 5 mg/L. The proposed system precision is tested by adding contaminants in a range so that it can provide a considerable change in the measured quality metric. When compared with the Geetha & Gouthami (2016) WQM system, the proposed system produced improved performance, which is represented in Table 1.

Table 1 | Observed metrics after integrating pollutants (soil)

	Volume of auxiliary soil contaminant (mg)								
Quality assessment metric	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
Turbidity (NTU)	6	7	11	13	16	18	27	34	39
pH	6.6	6.7	6.8	7.0	7.2	7.3	7.4	7.6	8.0
Conductivity (μS/cm)	516	560	584	604	678	758	812	926	984
Chlorine level (mg/L)	3.1	4.8	5.1	6.3	7.5	8.2	8.7	9.2	9.4

Since applications for the IoT are likely to run on batteries, consuming energy is a significant restriction. The transmission of data consumes a significant amount of energy. The transfer of information takes place in two phases for activities like intelligent water quality assessment. The first is the interaction among detectors and a controller, and the second is the interaction involving the operating system and an application. To minimize the use of energy, the processor is set to operate in one out of four energy modes: Hibernate, Minimal Power Deep Sleep, Sleep, or Active.

5. CONCLUSION AND FUTURE SCOPE

This paper demonstrated the design and deployment of a low-cost, sophisticated intelligent WMS. This work begins by examining the limitations and drawbacks of existing approaches and then moves on to a state-of-the-art outcome in water purity observation that helps in the finding of contaminations/pollutants. Through the hardware setup, this project checks the conductivity, tank level, pH value, color, chlorine level, and flow rate of the flowing water. The observed parameters were uploaded via IoT and presented on the web page. When water purity benchmarks stray from predetermined optimal criteria, the system dispatches an alert to a distant user. These techniques aid in the enhancement and optimization of system performance. Water measurement is also planned in this configuration to determine usage, as well as for billing and consumption patterns. Leakage at any level will be recognized, and treated swiftly by stopping the pump and adding value to this project by minimizing the waste of this noble fluid.

Potential future enhancements encompass introducing prepaid billing and automated water treatment in response to contamination types. For automated billing, a water metering system will be employed, which will eliminate the problems of standard water metering systems. This innovative concept can be used in other areas, such as oil and natural gas monitoring systems.

AUTHORS CONTRIBUTIONS

K.V. contributed to conceptualization, methodology/study design, software, validation, formal analysis, investigation, resources, data curation, writing – original draft, writing – review and editing, and visualization. P.V.Y. contributed to conceptualization, software, validation, formal analysis, investigation, writing – review and editing, and visualization. R.E. contributed to validation, formal analysis, investigation, resources, writing – review and editing, visualization, and supervision.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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