

SMART WATER-QUALITY MONITORING SYSTEM BASED ON ENABLED REAL-TIME INTERNET OF THINGS

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Abstract

The degrading drinking-water quality in Najaf, Iraq, requires immediate attention. This paper present an electronic water-monitoring system capable of facilitating proactive response to curb unsafe water supply in Najaf. The proposed system is intended to replace the conventional method, which is time-consuming and fails at real-time data generation. The proposed system is affordable and based on a wireless sensor network (WSN) and internet of things (IoT) to perform real-time monitoring and issue timely warning SMSs and e-mails. In this study statistical analysis was performed on data collected from five different water stations within Najaf. To demonstrate implementation of the proposed system, a user-specific website that highlights the water-purification process has been developed. The system affords remote- and smart-monitoring capabilities to determine water pH level; temperature; nitrate, chloride, and dissolved oxygen concentration; turbidity; oxidation-reduction potential (ORP); conductivity or total dissolved solids (TDS) and sodium content. Findings of this study indicate that drinking-water quality in Najaf is poor, and that the current water-purification system is unable to maintain prescribed water-quality standards. Results from five stations demonstrate that measured levels of water-quality parameters are well below those prescribed by the World Health Organization. Use of the proposed water-quality monitoring system serves to enhance drinking-water quality significantly.

Keywords: Euphrates river, Internet of things, Water pollution, Water quality, Wireless sensor network.

1. Introduction

Water is a scarce but essential natural resource for humans, animals, and plants. Approximately 5-10 million deaths due to water-related diseases are reported annually [1]. However, of the available water on earth, approximately 97%, is saline, implying that freshwater only comprises 3%. Furthermore, 68.75% of freshwater is stored in the form of glaciers and icecaps, whereas 30.1% is groundwater and 0.3% is surface water [2]. As of 2013, only 2.6 billion people had access to improved water quality standard [3].

The quality of water determines whether it is a source of life and good health or death and diseases. It is affected by increasing environmental degradation due to various sources of pollution, including sewage discharge, effluents from industries, and runoff from agricultural and urban setups. Floods, drought, and lack of awareness are also significant contributors to water pollution [4]. Developing countries such as the Republic of Iraq suffer significantly from water pollution, as evidenced by the number of reported deaths and cases due to water-related diseases [5].

The alarming rates of pollution of water sources necessitate the use of advanced methods for monitoring the quality of water. In contrast to the conventional method, online water quality monitoring provides real-time analysis of collected data and suggests necessary interventions. The online monitoring method also assesses the microbial chemical and physical properties to identify abnormalities and provide early warning.

Obtaining access to safe drinking water is extremely challenging for people in Iraq because the conventional water quality monitoring method does not meet the expectations of the residents. There are two rivers flowing through Iraq, namely the Tigris and the Euphrates, and the country also has several lakes and marshes. The conventional method of water quality monitoring in Iraq is time-consuming and does not generate data in real time. To overcome this problem, an automated method that generates data instantaneously is necessary. This method should use wireless communication technology with many applications for control, automation, and data acquisition.

Wireless sensor networks (WSNs) use signal processing, connectivity, and electronic nodes for sensing. WSNs were developed concurrently with Internet of Things (IoT) technologies, which enable several things to be linked together in networks [6-8]. IoT has evolved and can be used in water technology. It allows objects to be sensed, monitored, and controlled across an active network infrastructure. It also creates opportunity for integrating the physical world into computer-based systems, which improves accuracy and reduces human intervention [9-12].

This paper proposes a system that reduces the complexity associated with the conventional water quality monitoring method. The proposed system collects data in real time and uploads them into a specially designed website. Furthermore, data can also be retrieved from the website from any location in the world. Ten water parameters are measured, namely pH, temperature, nitrate, chloride, fluoride, dissolved oxygen, total dissolved solids (TDS) or conductivity, oxidation-reduction potential (ORP), turbidity, and sodium. The ten parameters monitored in the proposed system are described in Section 3; other essential parameters are described in [13], while the criteria recommended by the World Health Organization (WHO) for drinking water are presented in Table 1 [14].

Table 1. WHO water quality standard.

No.	Parameter	Maximum Allowable Concentration
1	Potential of Hydrogen (pH)	6.5-8.5 moles/l
2	Temperature	10-22 °C
3	Nitrate	10 mg/l
4	Chlorides	250 mg/l
5	Fluoride	1.5 mg/l
6	Dissolved Oxygen	4-6 mg/l
7	TDS (Conductivity)	1000 mg/l
8	Oxidation Reduction Potential (ORP)	At least -50 mV
9	Turbidity	5.0 NTU
10	Sodium	200 mg/l

In this study, ten parameters were monitored in water collected from five stations in the Province of Najaf, Iraq (coordinates 32°01'44N 20°23'E), which draws its water from the Euphrates river. The five water stations in Najaf city include Najaf district, in the center of the city; Haidariya, in the north; Hurriya, in the south; Kufa district, in the east; and Shibcha, in the west.

The remainder of this paper is organized as follows. A literature review is presented in Section 2. Section 3 describes the proposed system. The research methodology is presented in Section 4. The results and discussions are presented in Section 5. Finally, the conclusions drawn from the findings of this study are presented in Section 6.

2. Literature Review

Various studies involving the implementation of water quality monitoring systems using Wireless Sensor Networks (WSNs) and Internet of Things (IoT) technologies can be found in the literature. We investigated related works in the subject to identify the most important points in the field and the niches of opportunity that comprise the state-of-the-art methods of these types of systems.

Based on extant research published over the past two decades, Zhang [15] analysed available data using CiteSpace 5.0. Results of this analysis revealed the direction, frontiers, and hotspots pertaining to the water quality index. With respect to institutional research, research keywords, word frequency, cited literature, and subjects, results obtained demonstrate that India, China, the United States, Brazil, and Iran are major countries. Keywords, such as water-quality management and drinking-water quality, indicate major research hotspots and frontiers of social networks pertaining to water contamination and problems associated with water quality in China and India.

Demetillo et al. [16] presented a low cost, real-time water quality monitoring system that can be applied in remote rivers, lakes, coastal areas, and other water bodies. The hardware of the system primarily consists of off-the-shelf electrochemical sensors, a microcontroller, a wireless communication system, and a customized buoy.

Khatri et al. [17] presented a low-cost, wireless water-quality monitoring system based on the Arduino and Zigbee module. In their study, water-quality parameters to be monitored are decided by the Central Pollution and Control Board,

New Delhi, India. Water-quality sensors were interfaced with the Arduino board via a signal-conditioning circuit. Acquired data was transferred to a server over a wireless network via the Zigbee module. At the server, Raspberry Pi was used to receive the transferred data, and results are shown on a graphical display. The water-monitoring system used by Jiang et al. [18] comprised an alarm that notifies personnel in-charge in case water contamination is detected. The system measures four parameters-pH level, conductivity, temperature, and dissolved oxygen concentration-using off-the-shelf sensors, and recorded data are sent to a station via General Packet Radio Service (GPRS).

Wang et al. [19] employed ZigBee-based WSN for remote probing and instant monitoring of water parameters as well as for determining the previous and current status of water quality. Kotamäki et al. [20] used soil weather, a river based WSN, for agricultural and water monitoring. They used GSM and GPRS technology for data transmission, similar to the approach in Jiang et al. [18]. O'Flynn et al. [21] deployed an autonomous network of sensors over a wide area to measure parameters such as pH, temperature, depth, and dissolved oxygen. The system is known as the DEPLOY project and can be used to monitor various indicators other than water parameters, such as the spatial and temporal distribution of water quality in a river catchment area.

Chung et al. [22] proposed a micro-controller based WSN to measure the pH, temperature, and chlorine concentration in pool water. In this system, data are transmitted using GSM. The WSN used by Nasirudin et al. [23] measures the quality of freshwater, and data are collected from the sleep node and transmitted via the subbase node to the GSM network at the monitoring station. Maqbool and Chandra [24] demonstrated the importance of using a wireless system to monitor the level of water in different sources such as a tank, groundwater, and boreholes. The system can also detect floods and send information to other locations wirelessly.

A low-cost real-time in-pipe sensor node with a sensor array has been proposed by Lambrou et al. [25] for measuring the flow, pH, conductivity, ORP, and turbidity using algorithms to make decisions and trigger alarms when contaminants are detected. Adamo et al. [26] employed a WSN with the standard ISO/IEC/IEEE 21451 for measuring surface water bodies to capture severe events and collect data for extended periods.

Perumal et al. [27] proposed the use of an architecture that implements the event condition action (ECA) method for the management of IoT in smart homes. The proposed architecture provides a long-term solution to interoperability in smart homes as it has a core repository for data storage using IoT protocols. Perumal et al. [28] also employed an IoT water monitoring system that measures water levels to detect the occurrence of floods. The system sends information on impending danger to social networks such as Twitter. The system employed by Vijayakumar and Ramya [29] has several sensors for monitoring both the physical and chemical properties of water. In this study, low-cost devices, such as a Raspberry Pi B+ core controller and an IoT module (USR WIFI 232), were used for real-time monitoring of water quality, resulting in a low-cost system.

Cloete et al. [30] proposed real-time water-monitoring system comprising a node equipped with several sensors, PIC32MX220F032B microcontroller, and ZigBee module to transmit data to the monitoring center. Geetha and Gouthami [5] proposed an IoT-based system for measuring water parameters. The said system employed

sensors for measuring parameter values, and recorded data were sent to a controller. Subsequently, measured parameter values can be displayed on a liquid crystal display (LCD) prior to being transmitted to the cloud via a Wi-Fi module.

Shahzad et al. [31] assessed the quality of water based on its turbidity, pH level, and E-coli tests performed on samples collected at three points-beginning, intermediate, and end-within the distribution system located in urban Mardan, Pakistan. The quantity of water supplied was measured by calculating discharges from water taps at the said three locations in the distribution system. Results obtained were presented in the form of an interactive Google Earth map and VBA-based dynamic database.

Hussain and Abed [32] used the Groundwater Modeling System (GMS) software for building a three-dimensional conceptual model to manage groundwater usage in the alluvial fan of the Mandali aquifer after determining the hydraulic conductivity, storage coefficient, and specific yield. Three scenarios with different daily operation times (6, 12, and 18) were tested for feasible well distribution based on minimum drawdown. The wells are hypothetically increased to 103 over the study area with spacing of 1500 m.

Above-described extant studies demonstrate that most water-quality monitoring systems comprise sensing nodes that establish wireless communication and process data. However, systems proposed in these studies face several limitations in that most systems monitor values of five parameters at not more than two locations. Additionally, these systems do not employ solar panels to reduce conventional-energy consumption.

The proposed study demonstrates development of a low-cost system that can be used for water-quality monitoring at minimum five water stations. The proposed system can be operated for long periods owing to its low power consumption and use of solar panels. The system accurately monitors water-quality parameters using ten sensors, and values of said parameters are displayed on a webpage specifically designed for this purpose, thereby providing real-time information regarding water-quality levels in monitored areas. Additionally, the proposed system can issue real-time warnings to appropriate personnel over SMS and e-mails. Furthermore, measured data are stored for statistical analysis. Sensors used in the proposed system were tested in a laboratory setup, wherein they demonstrated excellent performance.

3. Overall System Description

The parameters monitored in the proposed system are described below.

- **Potential of Hydrogen (pH):** pH is a measure of the acidity or alkalinity of a solution, which is usually determined by the concentration of hydrogen ions (H^+). Drinking alkaline water poses no health risks but can cause discomfort such as alkaline taste in the mouth, which makes coffee taste bitter and results in limescale that lowers the efficiency of electric water heaters.
- **Temperature:** Temperature regulates the metabolism of an aquatic system. Death of aquatic life occurs due to high temperatures as water cannot hold dissolved gases such as oxygen at such temperatures.
- **Nitrates and Nitrites:** Nitrates and nitrites occur in the environment because of the nitrogen cycle. Excessive use of pesticides, fertilizers, and poor

disposal of sewage waste lead to a high concentration of nitrates and nitrites in drinking water. High amounts of nitrites lead to the production of methemoglobin in warm-blooded animals, resulting in methemoglobinemia. High concentrations of nitrate may lead to lung and heart diseases.

- **Chlorides:** Chlorides are formed from the combination of chlorine gas and inorganic compounds. Chloride is a highly toxic inorganic compound, which flows into water sources from agricultural runoffs and effluent from industries. It affects the health of aquatic organisms and even the taste of food products.
- **Fluoride:** A high amount of fluoride in water reduces iron absorption leading to anemia. Dental and skeletal fluorosis results from high concentration of fluorides in drinking water.
- **Dissolved Oxygen:** Dissolved oxygen is an essential water parameter to assess as it affects the quality of aquatic life. The amount of dissolved oxygen depends on the temperature, salinity, and pressure. Large amounts of dissolved oxygen in water can lead to fish bubble disease, which increases the fish mortality rate.
- **Conductivity:** Conductivity is related to the TDS in water. It also indicates the amount of impurities in water; the cleaner the water the less conductive it is.
- **Oxidation-Reduction Potential:** The ORP indicates the ability of a solution to gain or lose electrons. An increase in ORP indicates that the water is an oxidizing agent, whereas a decrease in ORP indicates that it is an antioxidant.
- **Turbidity:** Turbidity indicates the extent to which water loses its transparency due to the presence of suspended particles. The higher the concentration of particles, the higher the turbidity.
- **Sodium:** The presence of sodium in water is not a concern for many people, except those taking a sodium-restricted diet. The human body needs sodium to maintain blood pressure levels, as well as healthy nerve and muscle functions. However, it raises concern about the safety of infants who take baby formula, or any other food produced using tap water containing high levels of sodium.

As mentioned earlier, the system proposed in this study monitored groups of water quality parameters. The remote real time monitoring process is based on WSN and IoT technology. The implemented WSN collects sensed data from five water stations in the city of Najaf, Iraq; the stations are distributed in five locations in the city (center, north, south, east, and west). The collected data were uploaded to a specially designed website to monitor and analyse the water quality, as well as to store the data. The system affords following features.

- High usability
- Remote monitoring of water stations
- Real-time operation
- Ability to send warning SMS and e-mails
- Data storage for statistical studies
- Generating reports on water quality over different durations.

The proposed monitoring system consists of three main parts-namely, sensing node (SN), data router (DR), and website (WS)-which are integrated as shown in Fig. 1.

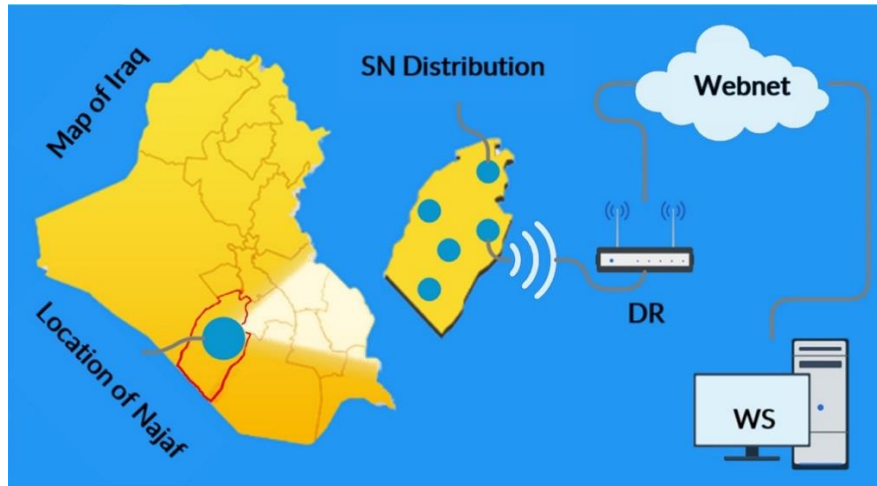


Fig. 1. Architecture of the proposed system.

The SN represents each water station, and each node has four parts, namely, controller unit, sensors, transceiver, and power supply unit. CONTROLLINO MEGA programmable logic controller (PLC) was used in the designed system as the control unit. The PLC is a small computer with peripherals based on the ‘open-source Arduino Atmel ATmega2560 platform’; the features and characteristics are CONTROLLINO MEGA [33]. In the implemented system, ten sensors were used to monitor the water quality; the main characteristics of the sensors are listed in Table 2.

It should be noted that some sensors were designed to be compatible with the selected controller, whereas others were adapted to ensure compatibility with the controller. The sensors were installed in the main water pipe.

The proposed system uses Wi-Fi for node to server communication. Each node has an ESP8266 Wi-Fi module for communication with the central server. The ESP8266 is a system on a chip (SoC) designed by Espressif System based on a 32-bit RISC CPU using the Tensilica Xtensa LX106 processor [34]. Connection for the IoT is through the SoC, which allows communication through the general-purpose input/output (GPIO) by connecting to the internet and transmitting data over it. The ESP8266 connects to the access point of the wireless network (DR) using the SSID and the password of the network. When it successfully connects to the access point, it obtains an IP identification.

The sensing node is powered by a rechargeable lithium battery with 5000-mAh capacity. It is suitable for use in lightweight applications and delivers high voltage over a long period. A crystal solar panel provides charging support to the battery. The panel provides nominal values of 5.5 V, 170 mA, and 1 W in terms of power supply; 8.2 V open-circuit voltage; and 6.4 V maximum load voltage. A LiPo Rider Pro board provides an output voltage of 5 V to charge the battery through the solar panel. Figure 2 depicts the flowchart describing various aspects of the implemented system code.

Table 2. Main characteristics of the sensors.

Sensors	Main Characteristics	Data Sheet URL Link
pH	Probe connector: BNC, measurement accuracy: ± 0.1 @25 °C, detection range: 0-14	<u>1</u>
Temperature	± 0.5 °C Accuracy from -10 °C to +85 °C, usable temperature range: -55 °C to 125 °C (-67 F to +257 F)	<u>2</u>
Nitrate	Ion: nitrate ion (NO_3^-), sensitivity: -54 ± 5 , Temp. (°C): 5-50, lineal range: 0,6 - 31000 mg/L	<u>3</u>
Chlorides	Ion: chloride ion (Cl^-), sensitivity: -54 ± 5 , Temp. (°C): 5-50, lineal range: 1,5 - 35000 mg/L	<u>4</u>
Fluoride	Ion: fluoride ion (F^-), sensitivity: - 54 ± 5 , Temp. (°C): 5-50, lineal range: 0,1 - 1900 mg/L	<u>5</u>
Dissolved Oxygen	Type: galvanic probe, detection range: 0-20 mg/L, temperature range: 0-40 °C, cable connector: BNC	<u>6</u>
TDS (Conductivity)	Probe connector: BNC, measurement accuracy: $\pm 5\%$ F.S., temperature range: 0-40 °C	<u>7</u>
ORP	Measurement range: -2000-2000 mV, suitable temperature: 5-70 °C, accuracy: ± 10 mV (25 °C), probe connector: BNC	<u>8</u>
Turbidity	Response time: < 500 ms, operating temperature: 5-90 °C	<u>9</u>
Sodium	Ion: sodium ion (Na^+), sensitivity: -27 ± 5 , Temp. (°C): 5-50, lineal range: 0,1 - 3200 mg/L	<u>10</u>

The sensing nodes send data through a link bridge, which is a Wi-Fi router in the cloud, where the database is located. Pre-processed data are transmitted by the WSN sensor nodes and sent to the cloud via a web application programming interface (API) where the quality of water is analysed. The WSN sensor nodes perform minimal analytics, whereas the rest of the analysis is performed in the cloud, thus lowering power consumption.

The website (WS) is friendly to mobile networks, which ensures ease of data monitoring for any period (yearly, monthly, weekly, daily, hourly, and in real-time). Data transferred from the cloud can be used for complex analysis to identify any contaminant in water. The code from the Arduino IDE was uploaded to the sensor nodes to access the wireless network as well as send measured data to the API web, which was developed in hypertext pre-processor (PHP) language used on desktops and mobile browsers.

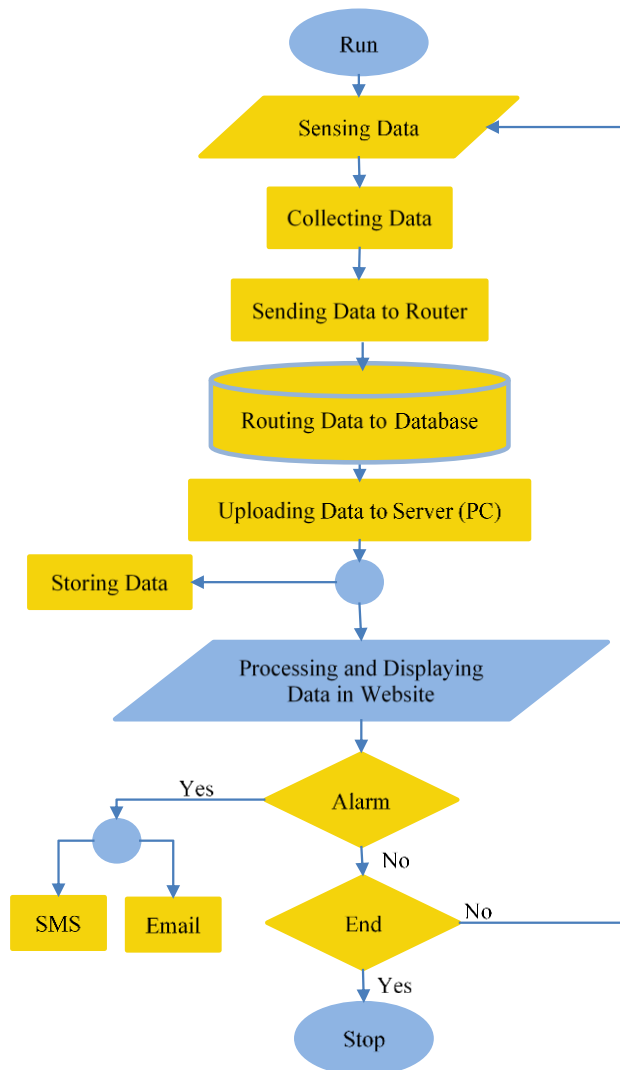


Fig. 2. Basic flowchart describing proposed system operation.

The database for the website was created using Michael Widenius Structured Query Language (MySQL) and contains features such as a ‘users table’ and a ‘configuration table’. The users table contains the users who can access the registered website, whereas the configuration table contains the sensors setting and the maximum and minimum range of each sensor.

Users can access data stored in the databases. There are two types of users: system administrators who are capable of writing and reading on the website and monitoring users who can only monitor uploaded data from various locations. Monitoring users log in from different stations and can access data. If an undesirable situation occurs, such as an increase in the turbidity, the website notifies the users in real-time via SMS notification to the user’s phone and an email to the Directorate of Water in Najaf.

4. Research Methodology

In this study, results of laboratory tests performed at five stations in Najaf, Republic of Iraq, were collected and qualitatively analysed. Introduction of the proposed electronic water-quality monitoring system was intended to facilitate issuance of a proactive response to supply of unsafe water when compared against the conventional method that is time-consuming and fails to generate real-time data.

5. Results and Discussion

The system was tested by the Ministry of Water Resources in Iraq/the Directorate of Water in Najaf after designing the sensor nodes and developing the website. The results obtained from this system showed good agreement with laboratory results (shown in Table 3). This is an indicator that the operation can provide the function accurately.

The five water stations were monitored 24 h for 10 days. During this period, test data were stored in the database every 10 min. Data collected from the five water stations are shown in Fig. 3 with the range of the water parameters.

The collected data were used to analyse the physical properties of the water quality monitoring system and the reliability of the network. The data obtained indicate real-time results that can predict the properties of water in the five regions of Iraq. The difference in the pH levels, temperature, and other water minerals is a clear indicator that the system is efficient. This is because the properties of water are expected to differ owing to the difference in the chemical properties and climatic conditions of the various places under analysis. The fact that the system can capture the difference is an indicator that the system is functioning correctly.

Before fabricating the system, the sensors were tested and verified using calibrated instruments. A functionality test was conducted on the system and the sensing operation was verified; the entire process was successful. The warning SMSs and emails were promptly sent. The process of logging in to the website was successful and data were correctly uploaded.

Table 3. Laboratory results.

Parameter	Stations				
	Najaf	Haidariya	Hurriya	Kufa	Shibcha
pH (moles/l)	5.9	5.4	5.1	5.7	5.0
Temperature (°C)	30.2	30.8	30.6	30.3	31.0
Nitrate (mg/l)	10.5	11.0	11.1	11.0	11.7
Chlorides (mg/l)	258.2	261.8	261.6	259.8	262.2
Fluoride (mg/l)	1.7	2.5	2.4	2.0	2.6
Dissolved Oxygen (mg/l)	3.9	3.6	3.5	3.6	3.2
TDS (Conductivity) (mg/l)	1259.3	1489.5	1507.7	1344.8	1671.2
ORP (mV)	+401.8	+470.2	+486.5	+412.1	+494.3
Turbidity (NTU)	5.0	5.7	6.2	5.3	6.6
Sodium (mg/l)	208.1	218.7	224.2	214.0	229.8

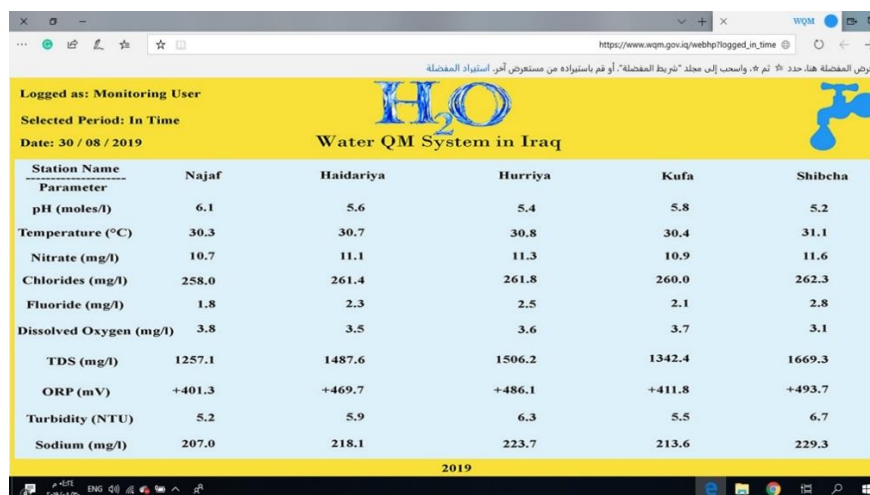


Fig. 3. Monitoring website (screenshot).

The results obtained demonstrated the poor quality of drinking water in the Province of Najaf, Iraq and the inefficiency of the water purification systems. The measured levels of nitrate, chloride, fluoride, sodium, temperature, dissolved oxygen, and turbidity are out of range of the WHO water quality standard presented in Table 1. The water showed high levels of pH, conductivity, and ORP, and is considered highly acidic, salty, and an oxidizing agent.

Such water quality may not be appropriate for general human usage. However, the availability of a system that can analyse and provide real-time data is crucial for developing a proper solution to deteriorating water quality.

6. Conclusions

This paper presents a smart electronic system to monitor the quality of water supplied to people in Najaf, Republic of Iraq. Characteristics of the proposed system include remote monitoring capabilities supported by WSN and IoT along with a more efficient system architecture compared to similar systems owing to its use of ten sensors to monitor water quality at five stations. The proposed system measures values of ten parameters pertaining to water quality and can issue timely warnings in the form of SMS and e-mails to responsible authorities to ensure appropriate action.

Test results obtained at the five stations based in Najaf revealed poor quality of drinking water coupled with use of inefficient water-purification systems. For instance, the measured levels of nitrate, chloride, fluoride, sodium, temperature, dissolved oxygen, and turbidity were observed to be well below corresponding standards prescribed by the World Health Organization (WHO). Additionally, water samples demonstrated high pH levels, conductivity, and ORP, thereby leading to it being considered highly acidic, salty, and an oxidizing agent. Overall, results of this study reveal that the quality of drinking water supplied from the Euphrates River, which passes through Najaf, is poor, and that water-purification systems installed at purification sites are inefficient. Consequently, it is recommended that responsible authorities use modern and reliable water-purification systems. The proposed smart

water-quality monitoring system is cost-effective, power-effective (owing to use of solar panels), provides real-time information, and offers a viable solution to ensure supply of high-quality drinking water.

However, there exist limitations and challenges associated with implementation of the proposed system. First, components required for fabrication of the proposed system prototype are not easily available given current political and economic scenarios in Iraq. Secondly, the cost of the entire system increases owing to limited access to electronic components owing to tight regulations imposed in Iraq in view of the suspicion of terrorist activities, thereby impacting the proposed system's affordability. In the future, additional sensors should be included in the system to increase its capability and collect data from all water stations.

Abbreviations

GSM	Global System for Mobile Communications
IoT	Internet of Things
ORP	Oxidation-Reduction Potential
PC	Personal Computer
PLC	Programmable Logic Controller
TDS	Total Dissolved Solids
WHO	World Health Organization
WSN	Wireless Sensor Network

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