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Smart Sensor-GSM Framework for Precise Pollution Localization in Drinking Water Distribution Networks

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Abstract: In recent years, Baghdad's drinking water quality has been declining, primarily due to untreated sewage, hospital waste, and agricultural runoff being indiscriminately dumped into the Tigris River. The contamination imposes significant health risks to the population. It requires an inexpensive and responsive system that can test water safety at the point of consumption. This research introduces a Smart Sensor-GSM-based framework to oversee water quality in Baghdad's residential distribution network. Utilizing an Arduino Uno microcontroller paired with a GSM module, the system gathers and transmits data from sensors installed on domestic water taps in several districts. These sensors record electrical conductivity (EC) and temperature, which are used to estimate total dissolved solids (TDS). When TDS levels surpass the recommended limit of 500 ppm, in line with WHO and EPA standards, an alert message is automatically dispatched to the monitoring center via SMS. The experiment's water samples collected from six different Baghdad locations recorded TDS values ranging from 200 ppm to 275 ppm, all within safety limits. Calibration tests also confirmed the accuracy of the sensor-based measurements. These findings demonstrate the viability and credibility of the system suggested as a local real-time water quality monitoring system with a viable alternative to traditional laboratory testing.

Keywords: Drinking Water Pollution, Electrical Conductivity, GSM_ GPRS SIM900A, Total Dissolved Solids, Water Quality Monitoring

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1. INTRODUCTION

One of the most essential critical natural resources for human health that should be monitored is drinking water. Due to the quick evolution of societies and various human activities, water pollution has increased and crumbled water sources. For this reason, monitoring water quality is indispensable to indicate any variations in the parameters of water features from time to time and ensure it is suitable for human consumption [1-3]. In Baghdad, Iraq, the drinking water sources are polluted in different locations, and this is attributed to t inefficient systems for the safe elimination of sewage, wastewater, medical residues, and agricultural waste, resulting in an environmental disaster by throwing them in rivers [4]. Consequently, it hurts people's health and the naturalistic environment. Therefore, a continuous real-time monitoring system for drinking water at a low cost is very necessary. TDS (Total Dissolved Solids) is one of the most paramount factors that determine the quality of water. It is a measure of the organic and inorganic materials that are dissolved in water. At the same time, the electrical conductivity (EC) is a measure to conduct electrical current. EC depends on the ions density, solution temperature, and the ions type. An increase in any of these factors leads to increasing EC [5-7]. ship between EC and TDS, which can be explained by the equation(1) . The correlation factor (ke) varies between 0.55 and 0.9 [8,9].

$$TDS\ (mg/L\ or\ ppm) = ke\ EC\ (\mu S/cm) \quad (1)$$

People often seek alternative water sources when the water's taste is unacceptable. Unfortunately, poor-tasting water may lead individuals to choose water that, while non-potable, has a better taste [10,11]. If the percentage of TDS in drinking water is higher than the acceptable range, the water becomes unpleasant, salty, and colored. Some people decided to install treatment devices that were installed in their homes to test water taste and quality [12,13]. Moreover, according to [14,15], there is a relationship between the density of total dissolved solids in drinking water and the death rate from cancer, heart, and blood vessel diseases. Though previous studies have explored different sensor-based and GSM/IoT-enabled methods for water quality analysis, the present paper presents a new synthesis developed specifically for Baghdad's contextual needs. The approach involves direct installation of sensor nodes on home water taps and is thus distinct from centralized or laboratory-based arrangements. The Smart Sensor-GSM system proposed offers real-time and on-site estimation of important water quality parameters—i.e., EC, temperature, and computed

TDS—and features automatic alerts via GSM on exceeding unsafe levels.

A remote and real-time monitoring system for TDS values in the Baghdad drinking water system is urgently needed. This paper aims to measure the electrical conductivity (EC) and the tap water and convert water temperature at people's homes' tap water to TDS. It should be noticed that the TDS value that is measured in this paper has a maximum allowed value 500 ppm. The United States Environmental Protection Agency (U.S.EPA), and World Health Organization (WHO) [7-8] state the maximum allowed level for TDS to 500 parts per million as shown in Table 1. At the same time, a low level of TDS also has a bad effect on drinking water quality, giving it unpleasant and strange taste characteristics [18,19]. In this work, a system was designed to obtain readings of EC sensors located in water tap at several sections of Baghdad. At each section, homes were chosen arbitrarily to locate these sensors. The system has an Arduino Uno (microcontroller) that processes the obtained data from these sensors. When the data value is higher than the threshold value (500 ppm), the microcontroller sends a warning message to a control room via the global system for mobile communication (GSM) technology.

The remaining sections of this paper are constructed as follows: in section two a brief literature survey about related works. Then, in section three, the proposed monitoring system and the methodology will be described in detail. In Section 4, the simulation results of the proposed system are presented. Finally, Section 5 concludes the paper.

2. LITERATURE SURVEY

Recent years, the new technology has widely used to solve the most of problems that related to water supplies. It has been used to measure the water's pressure, consumption, flow, and quality. Most water utilities are very curious to provide their consumers with good quality water. Using membrane technology helps desalinate water from contaminated sources, seawater, and brackish water [20,21]. The permanent obtaining of this service for many water utilities carries many challenges due to the change in both treatment and the water sources [22,23]. Examples of these treatments include aesthetics and taste, which are difficult to maintain within a limited range. The taste of water—such as bitter, salty, sweet, or sour—depends on the concentration of dissolved minerals [24,25]. When the difference between two water samples in TDS is less than or equal to 150, people and even specialists do not recognize the difference in the taste of water in the range of room temperature. Additionally, people probably easily distinguish increased TDS in low water from decreased TDS in high-value TDS water [26,27].

Traditionally, the taps water could be monitored by collecting samples from different locations and then analyzed and filtering these samples at laboratories with appropriate tools. This conventional, non-continuous monitoring approach results in less reliable water quality data. Therefore, to eliminate this traditional method and its disadvantages, many researchers have developed a continuous and real-time monitoring system that uses different approaches with various technologies.

Several techniques have been used to monitor water quality and send their data to a remote center. Some of them used wireless sensor networks (WSNs) technology for doing this purpose. Solar power harvesting with WSNs technology is used to measure nitrates in rivers [28]. In addition, in [29], WSNs were used to monitor water's temperature and salt concentration. In the research presented in [30], pH and TDS were measured using sensors, and a Raspberry Pi was employed to collect the data and transmit it to a GSM modem, which then sends the data to the users. Furthermore, [31,32] used WSNs and NodeMCU to monitor environmental conditions such as air humidity, soil temperature, and soil moisture.

In contrast, WSNs encounter numerous challenges in functioning optimally, such as the potential for loss of data from their sources, the limitation of modifying scripts and network algorithms, and challenges in fulfilling the paramount requirements of their target applications [33]. They developed new sensor nodes named WiSeN. According to [34], WiSeN is suitable for all sensors and it is the solutions for many problems that could be found in WSNs. In [35], NodeMCU-based setup was used to read data from a sensor and provide wireless transmission according to the Internet of Things (IoT) concept. The execution of IoT depends on the presence of internet connectivity where the system is installed. Furthermore, a General Packet Radio Service (GPRS)-based remote water quality monitoring framework was suggested. The framework has three primary elements: a monitoring station, a GPRS modem, and a central monitoring center [36].

While similar systems using WSNs, IoT platforms, and GSM-based frameworks have been explored in the literature, most existing studies are either laboratory-scale, cloud-dependent, or rely on centralized sensor arrays. The novelty of this study lies in its decentralized deployment directly on residential water taps, enabling real-time, localized monitoring at the point of consumption. Additionally, this system avoids reliance on internet connectivity by using GSM communication, which is more suitable for urban areas with infrastructure instability, such as Baghdad. To our knowledge, this is the first study to implement a standalone Smart Sensor-GSM system tailored for drinking water distribution in Baghdad with actual field deployment and practical validation at multiple household nodes.

3. METHODOLOGY

The proposed system comprises three main stages. The first stage, the temperature, and EC sensors read values from a water tap in homes in several sections of Baghdad, Iraq. In the next stage (the controlling stage), Arduino Uno periodically allows a relay to take samples from a water tap through a Solenoid valve. Then, Arduino Uno reads and processes data from these sensors. If the value of the TDS is greater than the threshold value (500 ppm), then Arduino Uno sends a warning message to a GSM-GPRS module. In the third stage (transmission stage), the GSM-GPRS module receives the warning message from Arduino Uno and sends it to a control center. The control center has a cell phone to receive data (text message) from the system

Table 2. U.S. EPA Rate of TDS

TDS Rate in PPM	0-50	51-169	170-200	200-299	300-499	500+
TDS Rate description	Idealistic water	Mountain Springs	Hard water	Slightly acceptable	Water with High TDS	Over acceptable value

to perform an appropriate procedure to eliminate the contamination water risk. Figure 1 shows the functional block diagram of the proposed system. A detailed explanation will show all of the hardware components, an experiment, and the software setup of the system.

3.1 Hardware Design

The system contains hardware components such as Arduino Uno to control the system, a temperature sensor, EC sensors to read the variable data from the water, a solenoid valve to control water samples, a relay to enable the valve, and a GSM Module to send the data wirelessly.

The Arduino Uno board is a microcontroller based on the ATmega328P chipset. It was chosen for this study due to its low cost, open-source platform, low power requirements, and high compatibility with electrical conductivity (EC) and temperature sensors [37]. These features make it particularly well-suited for large-scale implementation in resource-constrained environments such as Baghdad. In this work, the Arduino Uno was utilized for system control, data conversion, and analysis of tap water samples. Arduino Uno board is powered with 7 to 12 V [38]. The Arduino Uno periodically sends an enable signal to the relay to enable the solenoid valve to work. When the valve works, the water sample is passed to both EC and temperature sensors to test water quality.

Although the individual components utilized in this study, such as the Arduino Uno, EC sensors, and GSM modules, are commercially available and widely documented, the contribution of this work lies in the context-specific integration of these elements for practical field deployment in Baghdad. In contrast to existing Internet of Things (IoT)-based water monitoring systems that typically depend on Wi-Fi connectivity, cloud infrastructure, or are limited to laboratory-scale validation, the proposed framework supports offline, low-cost, and localized real-time monitoring. The innovation of this system is demonstrated through its direct installation on household water taps, automated alert functionality using GSM communication, and validation through actual field calibration and deployment. The design prioritizes operational simplicity and cost-efficiency, making it well-suited for implementation in resource-constrained environments and regions with limited digital infrastructure.

In this research, the solenoid valves are mounted at the endpoint of the water distribution network in multiple places in Baghdad. The solenoid valve is electromagnetic equipment enabled by a relay signal and is normally closed. As you see in Figure 2, the solenoid valve is connected with the relay in series. When the relay receives the control signal from the microcontroller, it passes the power to the solenoid valve to work. After that, the solenoid valve pours water samples to the sensors. This experiment was done in different distributed nodes of the water network in Baghdad governorate sections.

The EC sensor is designed to be compatible with Arduino Uno. It is a built-in, simple, suitable, and practical connection. It is used for electrical connectivity measurement. The conductivity of water is a prime indicator for estimating water quality, which depends on the number of electrolytes present in the water. obtained. This work obtained the temperature since the temperature range affects the electrical conductivity. The electrical conductivity of the water relies upon its temperature; when the temperature rises, the electrical conductivity will increase too. Several electrical conductivity sensors are set to 25 °C automatically.

GSM_ GPRS SIM900A module is used to transmit data. GSM shield is associated with Arduino, which has low power and low cost. The processor processes the TDS reading, and if it is greater than the threshold, the e. The GSM module will send an alarm SMS (short message service). . The control water station will receive a warning SMS when the TDS measurements override the permitted range. The authorized operators in the maintenance station will record the TDS reading based on the GPS location in the transmitted part of the system. Then it is quite recommended to supervise a quality, type of selective barrier or filter, and change them when required.

3.2 Calibration Experiment

The system was needed to demonstrate its work in a laboratory to measure the solution's temperature and electrical conductivity. Two different solutions samples were used to read their known electrical conductivity and temperature by the system's sensors. The electrical conductivity of the first solution is 12.88 ms/cm while the second solution has a conductivity of 1413us/cm. The electrical conductivity sensor was calibrated before use to obtain accurate readings. Figure 3 shows the experiment setup.

Firstly, the output data of the Arduino Uno will be sent to a personal computer. The data will be shown on the screen of the personal computer instead of sending it wirelessly in this experiment. The Arduino Uno was programmed to receive data from the EC sensor (ms/cm), Analog value, voltage (mV), and temperature (°C) that appeared on the serial monitor of the IDE.

The temperature sensor and conductivity electrode were put into the two calibration solutions as shown in Figure 3. The solution was vibrated for a short time. The sensors took the measurement, and it should be close to the real values (12.88 ms/cm, 1413us/cm). The calibration results showed that sensor readings closely matched the known conductivity values of the standard solutions (12.88 ms/cm and 1413 µS/cm), with minor deviations observed. Multiple measurements were taken for each solution to

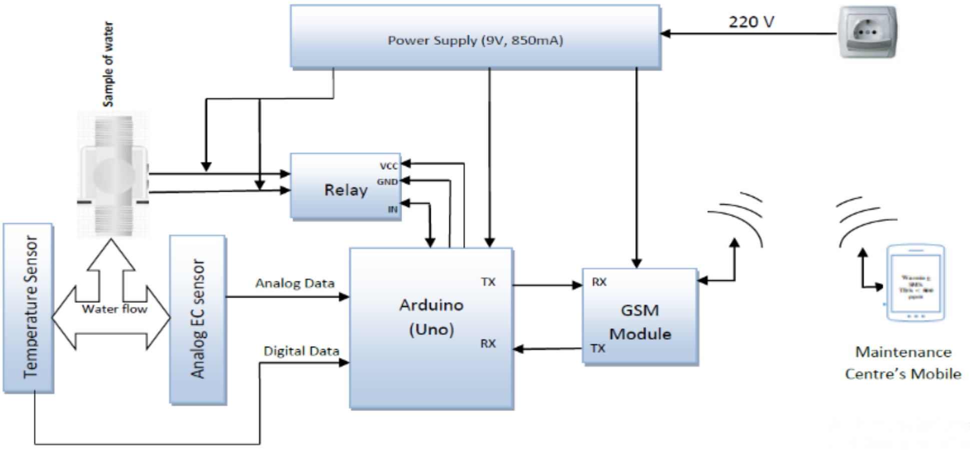

Figure 1. The main components and the data path of the monitoring system

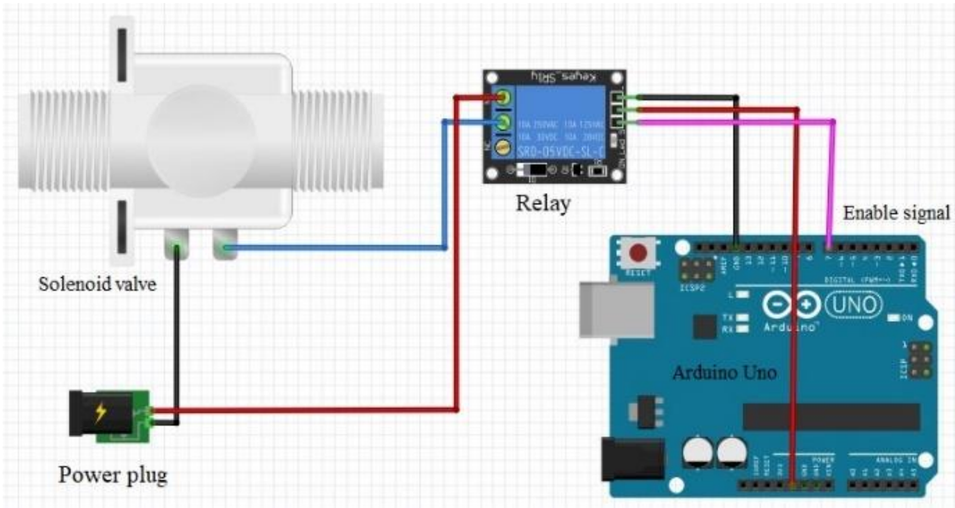

Figure 2. Connection of the solenoid valve in the system

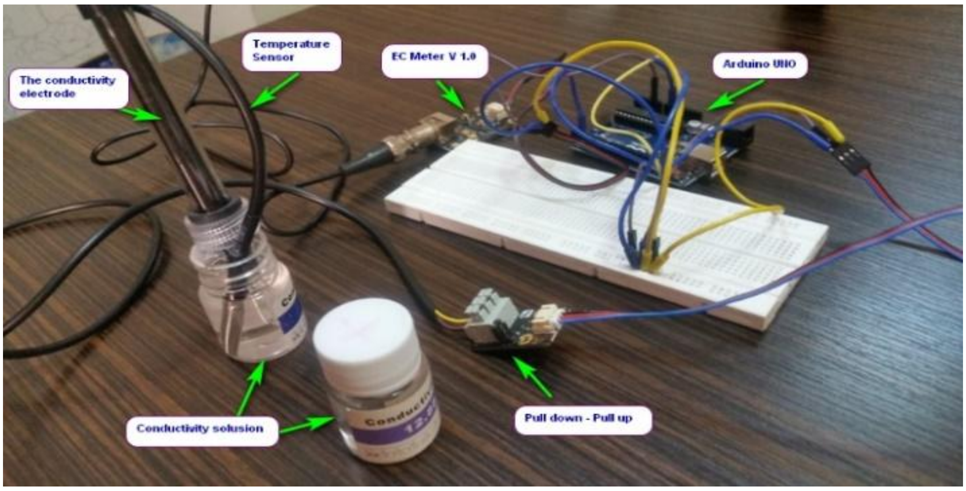

Figure 3. Calibration experiment set up

confirm consistency. Furthermore, temperature compensation was applied to normalize the EC readings to 25°C, as international water quality guidelines recommended.

3.3 Software Design

The software of the proposed system was processed using The Arduino Software (IDE to write the code and uploaded to the Arduino Uno to communicate with external ports like GSM module and sensors. The following steps illustrate the specification of the method:

- The number of measurements that were taken from the temperature sensor was set to (20) samples.

- Temperature sensor tr (time rise) = (750) ms
- In order to enhance the accuracy of next reading, *tr* was increased by 100 ms, subsequently, the overall tr will be (850) ms, and equals to interval temperature.

Primarily, all parameters of EC sensor was reset to zero before use it. To start serial communication with a PC, the baud rate was set to 115200 bps. The TDS values are calculated according to the equation (1), which is coded in the microcontroller software. The analog value was read from the EC sensor pin then the analog average value was calculated from this equation:

$$\textit{Average analog value} = \textit{overall analog value / no. of readings} \quad (2)$$

The analog to digital converter (ADC) of Arduino has a resolution of 10 bits, so ADC supposing 5V equals 1023 as it is clarified in the following proportionality:

$$\frac{ADC's\ resolution}{Sensor's\ voltage} = \frac{ADC\ reading}{Analog\ voltage\ measured} \quad (3)$$

$$Analog\ voltage\ (V) = (ADC\ reading \times 5)\ /\ 1023 \quad (4)$$

When the temperature of the drinking water increased, it influenced the conductivity at an average of (0.0192) ms/cm per one °C and the enrollment temperature of the sample (±0.01) °C in 25°C.

4. RESULTS

4.1 System implementation

Figure 5 provides an overview of the proposed water quality monitoring system, showing the assembled components used in the laboratory setup, including the sensors, Arduino Uno microcontroller, and GSM module. It was implanted on water taps are located in houses, to read temperature and EC of water to determine TDS value in different locations in Baghdad city, as seen in Figure 6. Figure 7 illustrates the distribution of six system locations throughout the city along with their respective readings at a single point in time. These locations were chosen arbitrarily to demonstrate the system's work, and it could be increased to more than six locations. Table 2 lists the same TDS water readings that are shown in the map with mention temperatures for each section of the city.

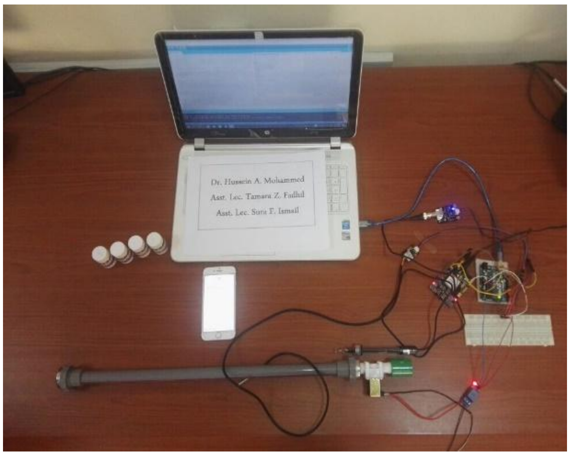

Figure 5. Overview of the proposed system components in the laboratory

Figure 6. Solenoid valve associated with tap water in a home

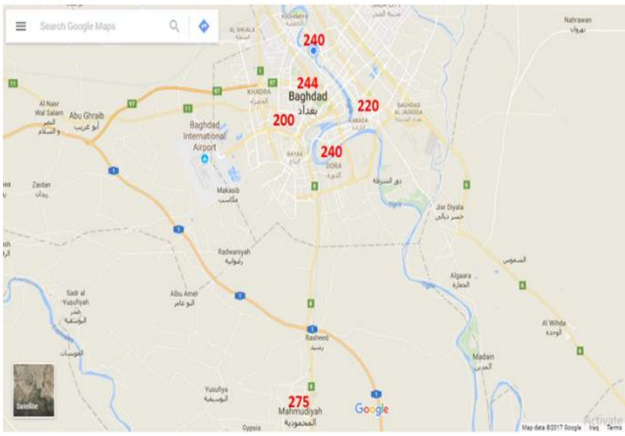

Figure 7. TDS measurements in different locations of Baghdad's Map

Table 2. TDS obtained from water samples in several locations in Baghdad

Baghdad's sections	TDS (ppm)	Temperature (°C)
Section 1	200	30.06
Section 2	244	30.12
Section 3	275	30.37
Section 4	220	30.04
Section 5	240	30.08
Section 6	240	30.31

When TDS levels exceed 500 ppm (the EPA's recommended limit for potable water), the system automatically sends an alarm SMS to an authorized person at the water control station, as shown in Figure 8. Then, it is highly recommended to observe quality, type of selective barrier or filter, and change them when required.

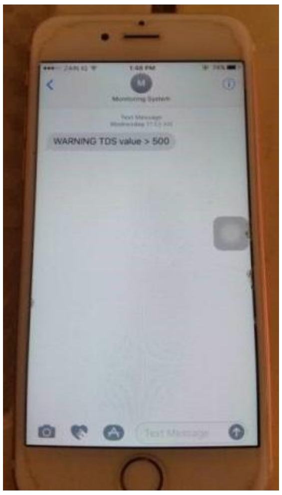

Figure 8. Warning SMS on a cellphone

4.2 Experimental Results

The calibration result indicated that when the voltage scale is lower than 50mv, the serial monitors show the statement "No conductivity solution" as shown in Figure 9, and if the read voltage is greater than 3300mv, the statement will be "out of sensor range".

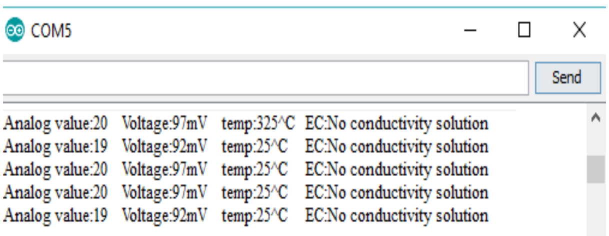

Figure 9. The data from the experiment in the personal computer screen.

Table 3 shows the conductivity, voltage, and analog measurements at different temperature values between (25 and 30.37°C, which show the result relative to the conductivity of the solution. Then, the calibration of the system was accurate.

Table 3. Electrical Conductivity Reading

Conductivity solution (ms/cm)	Temperature (°C)	Analog value	EC (ms/cm)	Voltage (mV)
12.88	25.00	314	10.40	1533
	25.03	316	10.44	1542
	25.06	317	10.48	1547
	25.06	320	10.55	1562
	25.12	318	10.48	1552
	25.12	296	9.94	1445
	25.19	307	10.20	1499
	25.25	324	10.63	1582
1.413	24.60	39	1.24	190
	24.62	40	1.28	195
	25.06	41	1.30	200
	25.12	39	1.23	190
	25.12	40	1.27	195
12.88	30.00	343	10.40	1674
	30.00	349	10.54	1704
	30.00	350	10.56	1708
	30.06	356	10.70	1738
	30.12	358	10.74	1748
	30.06	365	10.91	1782
	30.12	367	10.95	1791
	30.12	345	10.43	1684
1.413	30.31	44	1.27	214
	30.37	45	1.30	219
	30.37	44	1.27	214
	30.37	42	1.21	205

The charts in Figures 10 and 11 illustrate the relation of EC with voltage measurements (from Table 3) at two temperature degrees (25 and 30 °C). Their relation is linear where EC is raised by raising the voltage value. The effect of increasing temperature increases the values of both parameters (EC, V). Also, rising temperature will promote the generation of microorganisms and might increase problems concerning taste, odor, color, and oxidation.

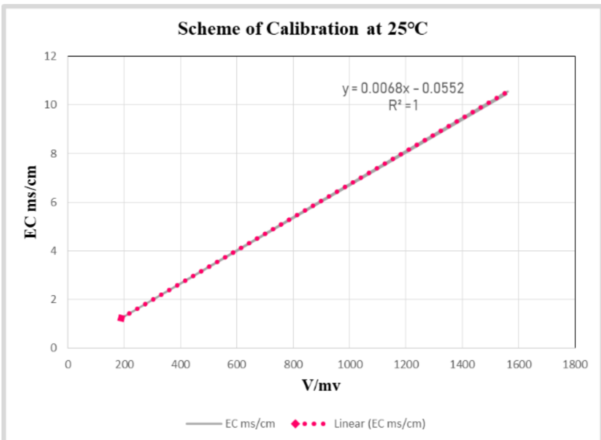

Figure 10. The relation between analog measurements, temperature and EC at 25 °C

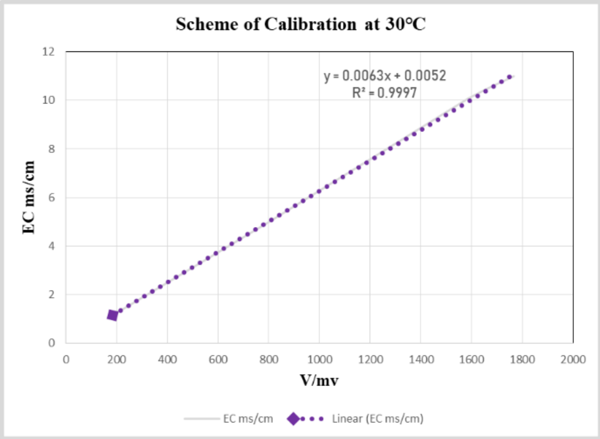

Figure 11. The relation between analog measurements, temperature and EC at 30 °C

The system offers significant advantages in enabling real-time monitoring, rapid contamination detection, and cost-effective deployment across diverse water distribution networks. Its reliance on existing GSM infrastructure enhances scalability and accessibility, particularly in underserved areas. However, the framework may face challenges related to sensor accuracy, communication reliability, and maintenance requirements. Acknowledging these limitations provides a balanced perspective and strengthens the practical relevance and applicability of the proposed solution.

Figure 12 shows the effect of rising temperature from 24 to 30 °C on TDS value. Clearly, the increasing temperature causes the values of the TDS in the water to grow.

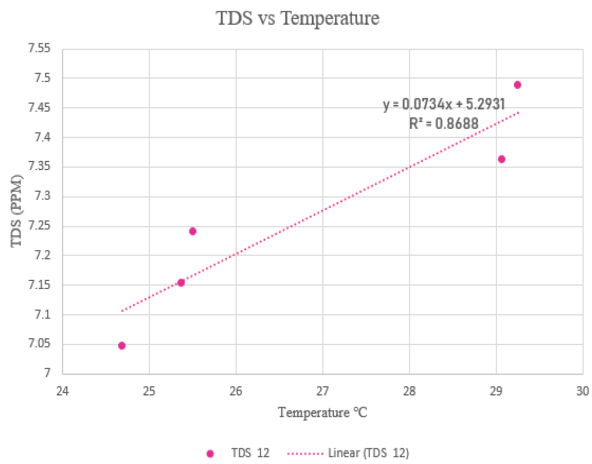

Figure 12. The relation between the TDS measurements and the temperature

5. CONCLUSION

A system was built to test the quality of drinking water to protect human health from several risks of contaminated water. It measures the electrical conductivity, temperature, and TDS of drink water. It wirelessly sends an alert text message, when not recommended TDS value occurred, to a control room which competent to monitor water quality. The system utilizes an Arduino Uno microcontroller to manage operations and a GSM module to transmit data wirelessly. It was distributed in different locations of Baghdad, Iraq to demonstrate its work. An experiment was done to prove the system's efficiency. Two different solutions with different electrical conductivity were used in the experiment. It concluded that when temperature rises, it affects EC and TDS value and subsequently water features such as taste, odor, and color. The advantages of this system are very low power consumption, low cost, high efficiency, and lightweight. Also, it is easy to set up, and it solves the problem that happens through the convey pipes water that feed homes with water.

While the system demonstrates robust performance in field conditions, future versions may include adaptive sensing, cloud integration, and data-driven analytics to enhance predictive capability. The current version prioritizes cost-efficiency and deployment feasibility but is a scalable foundation for more advanced architectures. Future work will also explore the integration of additional sensors such as pH and turbidity probes, and the wider deployment of this framework in rural and underserved communities.

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