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WatAr: An Arduino-based Drinking Water Quality Monitoring System using Wireless Sensor Network and GSM Module

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Abstract— **This paper presents an Arduino-based monitoring system that measures four physicochemical parameters of water: pH, temperature, turbidity, and electrical conductivity to identify possible water contamination. The system is designed with two nodes: the sensor node and the sink node. The sensor node performs the collection, pre-processing of data, relay of sensed data wirelessly, data storage systems, data display in an LCD and ThingSpeak channel, and SMS notifications. While the sink node performs data reception from the sensor node, data display in an LCD, and alert systems utilizing a buzzer whenever water is determined to be unsafe for drinking.**

Keywords—Arduino, sensor node, physicochemical parameters, sink node, ThingSpeak

I. INTRODUCTION

Water is a fundamental need that people cannot live without which has no alternatives and is used in a variety of applications including the use of water for drinking. According to World Health Organization (WHO), billions of people around the world have no access to safely managed drinking water while according to the results from the 2017 Annual Poverty Indicators Survey (APIS) and Water Quality Testing Module, 1,461,240 families obtain their drinking water from an unimproved source. With these, water may either be a source of life and good health or a source of diseases and deaths to people depending on its quality. In the real-time process, drinking water utilities and water supply to the consumer end taps in urban areas face new challenges to safeguard water supplies from deliberate or inadvertent contamination. And according to the WHO, globally, 3.4M people die from water-related diseases and most of these are children. Therefore, there is a need for a water quality monitoring system to be deployed in the water distribution network and at consumer sites to monitor, record, and organize collected water quality parameters caused by physical, chemical, and biological contaminants which have a major consequence on physicochemical parameters of water such as pH, temperature, turbidity, and electrical conductivity.

This study aims to implement an Arduino-based drinking water quality monitoring system using Wireless Sensor Network and GSM module, to create a system capable of monitoring, gathering, and storing the four water quality parameters namely pH, temperature, turbidity, and electrical conductivity, to design and implement a drinking water quality monitoring system using an Arduino microcontroller and IoT, and to test the functionality and accuracy of the system in providing water contamination alert in real-time.

For the scope and limitations: the Arduino-based drinking water quality monitoring system will focus on four drinking water quality parameters namely pH, temperature, turbidity, and electrical conductivity, the prototype to be developed for water quality monitoring is designed specifically for Arduino only, the system's time is set manually using the pushbuttons and there is an instance that the time set is not exactly the same as the Network Time Protocol, the probe of the sensors must be entirely immersed in water to obtain reliable data readings and the time it is immersed in water must not be extremely prolonged since the sensors are laboratory grade, the system implements a time-based water quality measurement where the time interval is every 15 minutes if the water is safe for drinking and if not, the time-based water quality measurement will include a twelvefold reading with three-second interval to assure that the data gathered is not an anomalous reading, all the data collected are stored in an SD card for back-up data storage and presented in a ThingSpeak channel for either private or public viewing, and SMS notifications can only accommodate a limited number of characters per message and a limited number of recipients since it utilizes a large amount of program size.

II. RELATED LITERATURE

Various studies are implementing different approaches for water quality monitoring which can be found in the literature.

A. Sensor Node

N. A. Cloete et al. 2016 [4], proposed a monitoring system where the sensor node's design measures pH, temperature, conductivity, flow, and oxidation-reduction potential of water. The design of sensors was investigated to assure accurate measurements of the water quality parameters which are linked to a signal conditioning circuit for sensor signal processing and connected to a microcontroller.

A. Demetillo et al. 2019 [5], measures the temperature, pH, and dissolved oxygen of water and the sensors for measuring these parameters were chosen because it is affordable, readily available, and compatible for Arduino-based monitoring system.

K.A. Mamun et al. 2019 [6], measures water parameters for analysis such as pH, temperature, conductivity, and oxidation reduction potential of water using Remote Sensing

(RS) Technology which includes anomalous measurement to receive a stable set of results and the user will be notified with the aid of IoT technology.

In the study of M. Mancini et al. 2018 [7], algorithms for anomaly detection involve statistical methods where previous measurements are used to approximate a standard of correct behavior of specific sensors. Whenever new data readings or measurements are registered, it is compared to the standard and if results appear to be statistically incompatible, it is classified as an anomaly. This method is not only applied to single data readings, but also on windows of readings which help in reducing the number of false positive results.

B. Wireless Sensor Network

K. Kamaludin and W. Ismail 2017 [8], proposed a water quality monitoring system employing the Internet of Things (IoT) based system since the IoT system is widely used for reliable data acquisition and has several approaches for communication in a real-time monitoring process.

N.A. Cloete et al. 2016 [4], designed a system which is divided into four subsystems, these are the sensing node, the measurement node, the wireless node, and the notification node. For the wireless node, a wireless transmitter and receiver modules are used to relay the data to the notification node. The notification node receives the data from the wireless receiver module and then notifies the user of the real-time water quality.

K. Khaing 2019 [9], proposed a system that will monitor the real-time values of the temperature and humidity from any location via the internet. In the proposed system, temperature and humidity values of the environment were monitored, stored, and displayed on the web via the Internet and the stored old values can also be used for predictions. The implementation of IoT based monitoring system using Node MCU includes two sections which are the hardware implementation and software implementation. This system is used to forecast the parameters based on the historical data and to control the room temperature and humidity. The sensor is connected directly to the ESP8266 controller with Wi-Fi Module and sends data through the gateway via the internet to a web page called "ThingSpeak". The "ThingSpeak" can get the signal from the sensor as a variable along with the value. The data sent from homes were received by ThingSpeak server using MQTT protocol and visualized in one channel. The channel receives data at an interval of 30 seconds and was visualized as line graphs in the channel. After processing of data, the controller sends a cooling or heating signal to the system. A relay was used to control the air conditioning system in the room.

C. GSM Module

Mahmud et al. 2017 [10], proposed a system that is capable of transmitting messages to the user through a GSM modem. The WSN gathers the room condition information and sends information to the data storage system to analyze the causes of fire. After getting the signal from the microcontroller, the GSM modem sends SMS to the authorities so that they can be alerted and take necessary actions. The SMS sending process differs depending on the degree of the fire.

Suliman et al. 2011 [11], used Ozeki Message Server as an SMS gateway application that can send SMS from website to the mobile utilizing the GSM modem. The GSM modem used SIM card to send alert messages for the controller that resides in the computer when he is not present at the flood control center.

M.U. Tahir et al. 2018 [12], proposed a wireless system using SIM900D. GSM is connected to the Arduino to receive and transmit the data to the user. The study states that after reviewing the literature, it is found that GSM technology has not been used for the implementation of the system under consideration. Using GSM, the data can be collected from remote areas and keep the record effectively and efficiently.

III. Methodology

The WatAr is designed to monitor, gather, and store the four physicochemical parameters of drinking water regularly and identify if the quality is either safe or unsafe for drinking. These drinking water quality parameters are pH, temperature, turbidity, and electrical conductivity are monitored based on the standards and guidelines for drinking water determined by the World Health Organization (WHO). Table I depicts the parameters to be monitored by the DWQMS.

TABLE I. Drinking Water Quality Parameters

Parameter	Units	Quality Range
pH	pH	6.5 - 8.5
Temperature	°C	20°C - 40°C
Turbidity	NTU	0– 5
Electrical Conductivity	mS/cm	0 - 1

The hardware implementation part manipulates the whole water quality monitoring system wherein its design preference is established with the aid of pairwise comparison chart as shown in Table II where goals are ordered in relative importance with the objectives which are ranked depending on its value or importance.

TABLE II. Pairwise Comparison Chart

Goals	Accuracy	Complexity	Cost	Lifespan	Power Consumption	Score
Accuracy	***	1	1	1	1	4
Complexity	0	***	1	1	0	2
Cost	0	0	***	0	0	0
Lifespan	0	0	1	***	0	1
Power Consumption	0	1	1	1	***	3

With the results tabulated above, the parameter accuracy is given the highest importance since the data readings will be the basis of determining if the water is safe or unsafe for drinking. Second is the speed that ensures that the microcontroller, sensors, and modules function optimally. The third is the complexity that characterizes the system's implementation on which the components interact with each other in multiple ways. This study aims to build an approach considering the difficulties of the system's implementation. Lifespan is anticipated for aging can affect some sensors' accuracy and can cause sensors to slowly lose sensitivity over time. Cost is given the least importance thus, is significant regarding the implementation of any system.

IV. Technical Study

Sensors

The selection of the four sensors depends on the goals of this study. In this study, the SKU-SEN0161 pH sensor, SKU-SEN0189 turbidity sensor, SKU-DFR0300 electrical conductivity sensor, and DS18B20 temperature sensor are used as shown in Table IV with their specifications. Figure 1 shows the actual photos of the sensors used in the DWQMS.

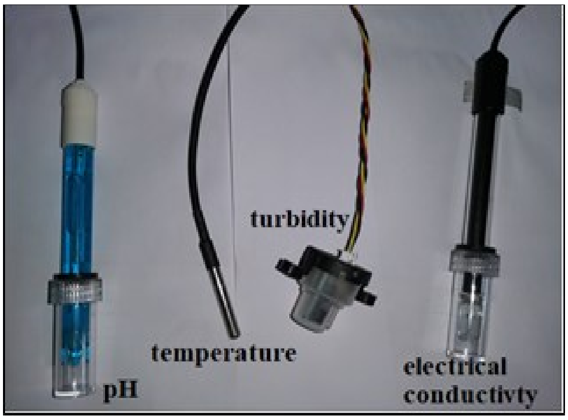

Fig. 1. Water Quality Parameter Sensors

The DWQMS utilizes an Arduino Nano microcontroller for the sensor node since it provide low energy consumption. For wireless sensor networks, NodeMCU V3 ESP8266 ESP-12E is used and is a wireless communication technology designed based on the ESP8266 ESP-12E variant. It also allows users to have an 80 to 160 MHz frequency band. It is a high integration wireless SOCs designed for space and power-constrained mobile platform designers and provides unsurpassed ability to embed Wi-Fi capabilities within other systems or to function as a standalone application, with the lowest cost, and minimal space requirement. For text notifications about levels of water quality parameters or whenever there is possible water contamination, a GSM module SIM900 is used.

Figure 2 and Figure 3 represent the hardware architecture and flowchart of the whole monitoring system respectively. The system is comprised of sensors, a microcontroller, SD card modules and storage, RTC module, LCDs, buzzer module, and a GSM module. As shown in Figure 2 is the block diagram of the drinking water quality monitoring system which is composed of two nodes: the sensor node and sink node. The sensor node includes water parameter sensors namely pH, temperature, turbidity, electrical conductivity, and sensors gather data readings from the water samples throughout the scheduled time and are communicated to the microcontroller for data processing. After data processing, the data is interfaced to the NodeMCU for two distinct data storage, a CSV file within an SD Card and ThingSpeak channel. The SIM900 GSM Module manages all SMS updates and alerts concerning water quality parameters to five sim number recipients that belong to two administrators of the water utilities, City Health Office, and two Community Heads. Real-time data readings of the sensors are displayed in an LCD and ThingSpeak channel. The sink node of the system collects, and pre-processes data gathered from the sensor node. It displays and provides data monitoring in places distant from the sensor node. The NodeMCU in the sink node serves as a microcontroller and Wi-Fi module that takes data from the ThingSpeak throughout the programmed time and displays it in an LCD. The buzzer is an alert every time the result of the water quality is unsafe.

Figure 3 shows the workflow of the proposed water quality monitoring system. On start-up of the water quality monitoring system, sensors will be powered up along with the connected modules of the whole system, and data within the SD card are loaded to the microcontroller. The system has a scheduled time that is assigned every quarter of an hour for data gathering from sensor readings. It will continue to read in real-time and wait until the scheduled time before gathering and processing the data from the sensors. It will evaluate the parameters of the reading of the sensors and will identify the quality of the sample water. If the water is safe, the data will be sent to the ThingSpeak channel and in a CSV file in the SD Card. The system has scheduled updates of water quality every 6AM, 12NN, and 6PM. The update SMS includes average data values from 12 previous readings of the water quality level and will notify the administrators and concerned individuals. However, if the water is unsafe, the system will detect if the data is an anomalous reading. It will collect data every three seconds for 12 times and will get the average value of these 12 readings. The three-second interval in between data gatherings is for the consideration of the response time of the sensor and for the sensor readings stabilization. If the average value falls to safe, then the previous reading is an anomalous reading and the system will store the average data. However, if the average value still falls under unsafe conditions, then the water is verified unsafe to drink. Alert message will be sent to the five numbers to notify them that the water is unsafe to drink. The data will be sent to the ThingSpeak channel and stored in the CSV file. The buzzer in the sink node will also alarm to alert the people in the water utility. The system will wait for the next scheduled time to gather data from the sensor. If the next present data is safe, then an update message will be sent to five numbers to notify them that the water is already safe to drink. However, if it is still unsafe, the system will perform another detection of anomalous reading to verify the quality of water. If the water is still unsafe then, an alert message will be sent to the administrators only to alert them that the water is still unsafe to drink. It will iterate the same process until the present data becomes safe.

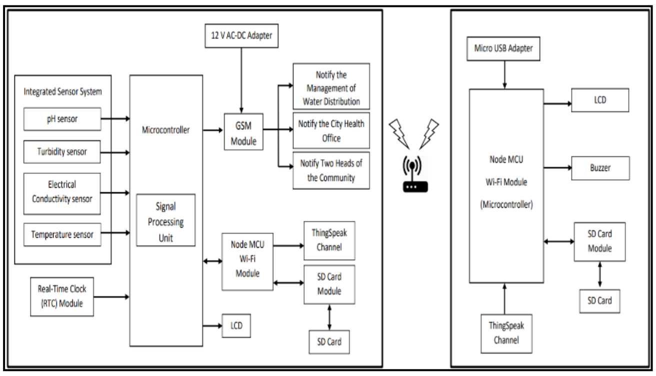

Fig. 2. Block Diagram of the Drinking Water Quality Monitoring System

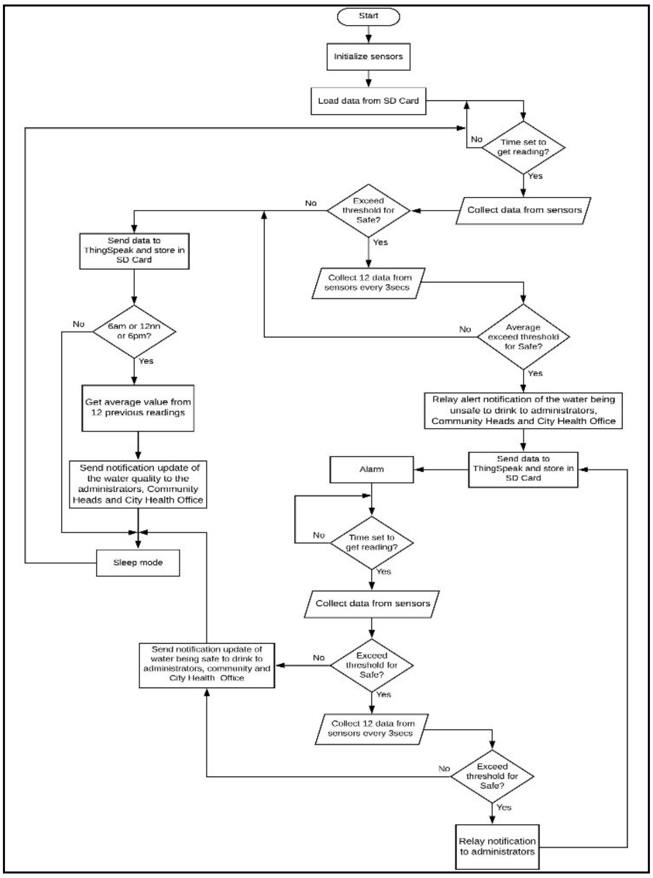

Fig. 3. Flowchart of the Proposed Water Quality Monitoring System

Verification Plan

Different procedures and methods of verification were conducted including sensor calibration, prototyping, and prototype testing to assure that the system meets the objectives of the study. Sensor calibration is performed specifically for the pH sensor and electrical conductivity sensor to eliminate structural errors in the sensor outputs for better performance and improve its overall accuracy. Prototyping is additionally performed to prove and test the functionality of the design and identify issues during the development stage. Further, prototype testing is performed that includes three types of tests: the 6-hour run test, 12-hour run test, and 24-hour run test.

For the 6-hour run test, researchers add a consistent amount of the same solutions to previous water samples every five minutes ahead of the scheduled time of data gathering to observe the sensitivity of the sensors. Variously, the 12-hour run test was conducted to observe the system's behavior under a controlled environment by modifying the quality of water to either safe or unsafe for drinking using different solutions. While the 24-hour run test is for observing the response of the system to tap water samples under normal conditions.

V. Results and Discussions

The researchers prefabricated a prototype design of the proposed drinking water quality monitoring system. Figures 4 and 5 show the prototypes of the system's sensor node and sink node.

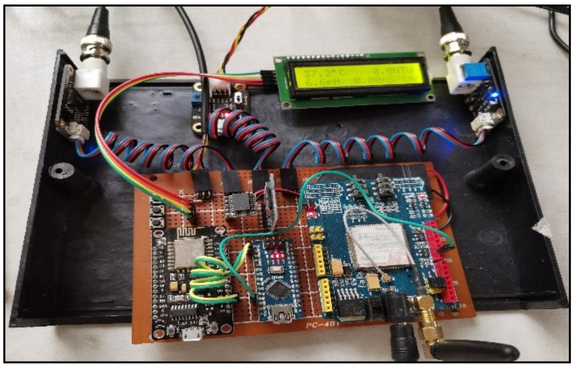

Fig. 4. Sensor Node's Prefabricated Prototype

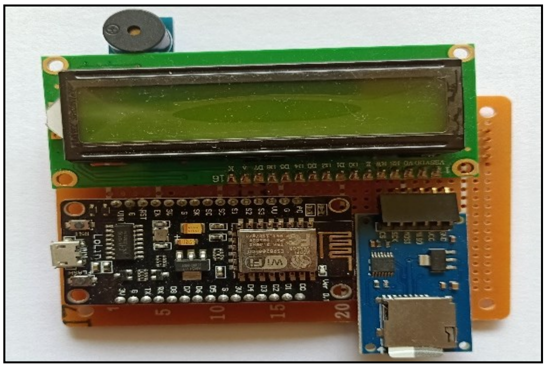

Fig. 5. Sink Node's Prefabricated Prototype

Two kinds water samples from tap water sources were used to test the functionality of the system. Data readings were taken at a 15-minute interval for a total period of 30 hours. Water samples were collected and tested in a safe controlled environment. However, for the tap water sample test, it was changed every quarter of an hour to see the consistency of tap readings.

A. 6-hour test

To test if the sensors can detect the effect of impurities being added gradually, the researchers added constant volume of different solutions to the water sample gradually every five minutes before the scheduled time of data gathering. The timeline for the adding of solution is shown in Table III and the results of the test are shown in Figure 6.

TABLE III. Timeline of the 6-hour Test

Point	Description
A	Start of test
B	Start of gradually adding 50mL vinegar to the water sample
C	End of adding vinegar to the water solution
D	Start of gradually adding 35g of laundry detergent to the water sample
E	End of adding laundry detergent powder to the water solution
F	Start of gradually adding 30mL of mud to the water sample
G	End of adding mud to the water solution
H	Start of gradually adding 30g of salt to the water sample
I	End of adding salt to the water solution
J	Start of gradually adding 200mL of hot water to the water sample
K	End of adding hot water to the water sample
L	New water sample without solution added
M	End of test

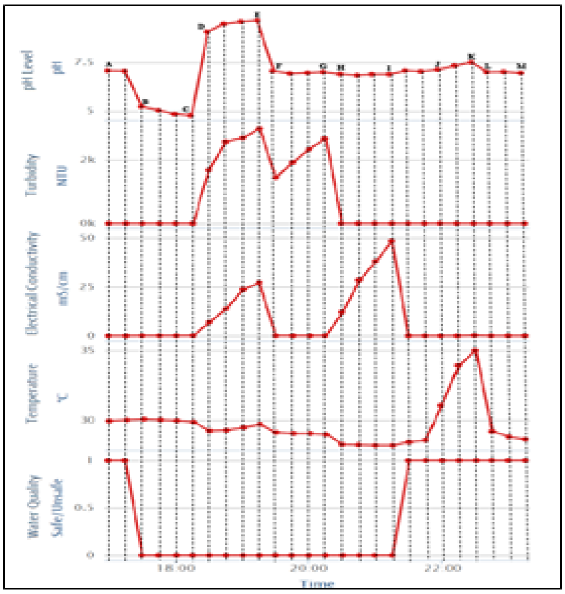

Fig. 6. 6-hour Run Test Sensor Readings of Modified Tap Water

The graph shows that different impurities, such as vinegar, detergent powder, mud, salt and hot water, added to the water were detected by the system and have effects on some of the sensors. Shown at points B to C, vinegar lowers the value of pH while at points D to E, detergent powder increases the value of pH, turbidity, and electrical conductivity. On the other hand, at points F to G, mud only have effects on the value of turbidity. At points H to I, salt increases the value of electrical conductivity of the water. lastly, at points J to K, hot water only affected the value of emperature. Besides detection of the impurities, the graph also shows that the sensors were able to detect gradual increase of the impurities added in the water sample.

B. 24-hour test

Figure 7 shows the trends of the acquired data and are consistent with the globally accepted values for pH, turbidity, electrical conductivity, and temperature.

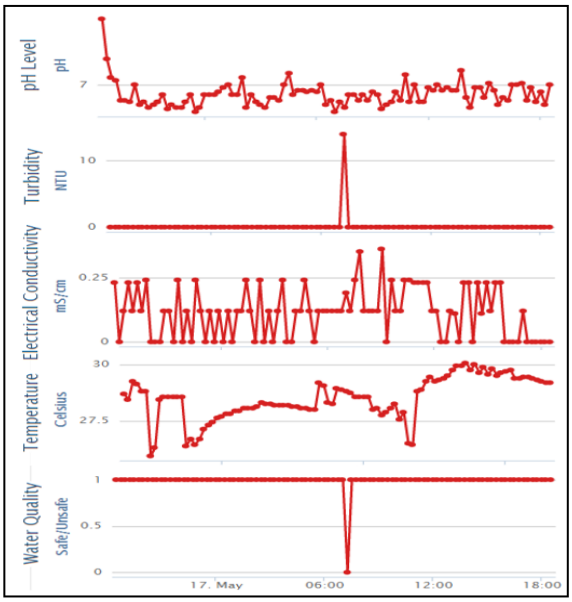

Fig. 7. 24-hour Run Test Sensor Readings of Tap Water

C. SMS Notifications

For the SMS notification system, Figure 8 shows a sample update message scheduled at 6AM, 12NN and 6PM received by administrators of the water utilities, and concerned individuals, Figure 9 shows sample alert message of the received by the administrators only and Figure 10 shows the alert messages received by the concerned individuals. Administrators received all alert messages of unsafe water quality while the concerned individuals received only the first alert message. However, all five numbers received the update of safe water quality from an unsafe state.

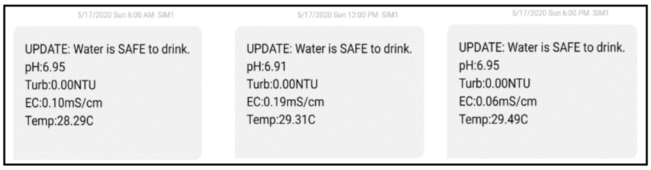

Fig. 8. Scheduled SMS Updates received by all Sim Number Recipients

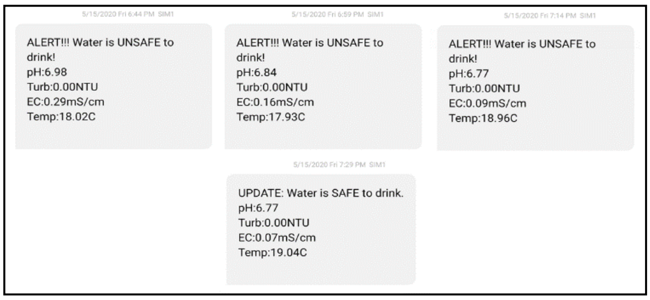

Fig. 9. Alerts and Updates of Water Quality received by the Administrators

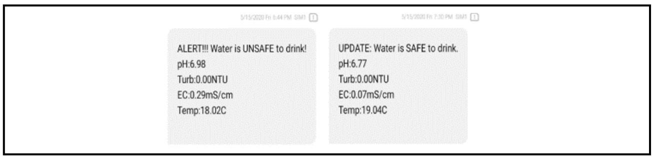

Fig. 10. Alerts and Updates of Water Quality received by Concerned Individuals

VI. Conclusions and Recommendations

This research demonstrates a drinking water quality monitoring system using WSN and GSM module. The researchers were able to create a system capable of monitoring and gathering data of the four water quality parameters namely pH, temperature, turbidity, and electrical conductivity and storing it in an SD card in CSV file format and in a ThingSpeak channel. The designed drinking water quality monitoring system was implemented using an Arduino Nano microcontroller and utilizes the IoT platform called ThingSpeak for its WSN application. Also, the system was able to provide real-time alerts and updates of water quality parameters to five mobile numbers including two administrators of a water utility, one for City Health office and two Community Heads.

Also, it is recommended to acquire more water parameters to measure by adding multiple sensors because more water quality parameters to measure will lead to higher reliable detection of drinking water quality levels, conduct standard laboratory tests of tap water samples to verify the reliability sensor data readings, use an industrial-grade probe instead of laboratory-grade probes for the sensors since industrial-grade probes have a longer lifespan and will establish a better water quality monitoring system, use the solar panel and rechargeable batteries as a backup power source to avoid loss of data, and provide design for system installation in pipes or tanks for easy and earlier detection of water quality levels.

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