Studies on
IoT based Water Quality Monitoring System

By
SANTANU TUDU
Registration No. 136167 of 2016 - 2017
Exam Roll No. M4ETC22002

Under the Guidance of:
Prof. P. VENKATESWARAN

Thesis submitted in partial fulfillment of the requirements for the award of the Degree of Master of Engineering in Electronics and Telecommunication Engineering

Department of Electronics and Telecommunication Engineering
Jadavpur University
Kolkata-700032.

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Name of the Candidate**: Santanu Tudu**

Exam Roll No: **M4ETC22002**

Thesis Title: **Studies on IoT based Water Quality Monitoring System**

Signature of the Candidate: -------------------------------------

Date:

FACULTY OF ENGINEERING AND TECHNOLOGY

JADAVPUR UNIVERSITY

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I hereby recommend that this Thesis prepared by Santanu Tudu entitled "Studies on IoT based Water Quality Monitoring System" under my supervision be accepted for partial fulfillment of the requirements for the award of the Degree of Master of Engineering in Electronics and Telecommunication Engineering.

……………………………………..

Dr. P. Venkateswaran
Professor
Dept. of Electronics and Tele-Communication Engineering
Jadavpur University, Kolkata- 700032

……………………………………

Dr. Manotosh Biswas
Professor and Head
Department of Electronics and
Telecommunication Engineering
Jadavpur University, Kolkata- 700032

……………………………………

Prof. Chandan Mazumdar
Dean
Faculty of Engineering and Technology
Jadavpur University, Kolkata- 700032

FACULTY OF ENGINEERING AND TECHNOLOGY

JADAVPUR UNIVERSITY

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Committee on ....

Final examination for evaluation of the thesis of:

Santanu Tudu

Exam Roll No: M4ETC22002

....

Signature of Examiners

* Only in case the thesis is approved.

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Computer Networking Lab (T-3-16A)
ETCE Dept., Jadavpur University
Kolkata - 700 032. West Bengal.
August 2022

…………………………..

Santanu Tudu

ABSTRACT

Water is an absolute requirement for the survival and nutrition of all living things. The quality of water has deteriorated in recent years because of toxic waste and contaminants. This ever-increasing water contamination is a major source of concern because it is degrading water quality and leaving it unfit for any usage. Contaminated water supplies can have major consequences for humans as well as aquatic life. That's why water quality monitoring is important. The technology for water monitoring systems is improving day by day. Traditional approaches have played a significant role in the field of water monitoring systems, but traditional techniques for measuring water quality include manual examination in a laboratory, which is time-consuming, costly, and inefficient. The research presented in this Thesis examines the problem, and provides IoT based solution in comparison to the time-consuming conventional way of water monitoring. The research also includes measuring pH, total dissolved solids (TDS), and turbidity to monitor the water quality and derive a correlation between water parameters and UV absorption.

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Chapter 1

Introduction

1.1 Preamble

Water is the most fundamental and valuable resource in the world. Without water, life cannot be sustained [1]. It is used for direct and indirect uses. Direct use of water includes drinking, bathing, and cooking, while indirect use includes irrigation and industrial purposes. With the advancement of technology, industrialization, and population growth, the quality of water is degrading every day [2]. Water pollution is now a serious issue around the world. Water pollution is degrading our biodiversity. The farming sector is getting contaminated because of toxic waste mixing in the water [3]. Contaminated water increases the spread of diseases such as cholera, diarrhea, dysentery, hepatitis A, typhoid, and polio. Every year, around 8.29 lakh people die from diarrhea because of drinking contaminated water (WHO 2022). Biological, organic, and inorganic pollution have contaminated over 70% of India's surface water resources and a significant percentage of its groundwater supplies [3, 4]. Almost every river in India is now heavily polluted. The increasing demand for water for human usage, irrigation, and expanding industrial operations has highly impacted the water quality of rivers, i.e., decreasing flows in rivers and depleting water levels of subsurface resources [5]. In a study in 2015, the Central Pollution Control Board (CPCB) identified 302 polluted river stretches on 275 rivers in our country [6]. The pollution of these river stretches has been classified into five different priority classes. Among 302 river stretches, 34 fall under Priority Class (PC) – I. Similarly, 17 are in PC – II, 36 are in PC – III, 57 are in PC – IV, and 158 are in PC – V.

The description of priority classes (I-V) is summarized [6] in Table 1.1.

Table 1.1 Priority class of river stretches

Priority Class – I	Grossly Polluted (BOD greater than 30 mg/l).
Priority Class – II	very polluted (BOD between 20-30 mg/l)
Priority Class – III	moderately polluted (BOD between 10-20 mg/l)
Priority Class – IV	Slightly Polluted (BOD between 6-10 mg/l)
Priority Class – V	Good (BOD between 3-6 mg/l

Rapid urbanization, sewage disposal, fertilizer run-off, chemical waste disposal, and radioactive waste are all reasons for water pollution, but water can also be contaminated by natural pollution. Animal feces, volcanoes, dirt from storms and floods are all major sources of natural pollution. Fig 1.1 shows the dominance of water pollution against other pollutions in major Indian states [7].

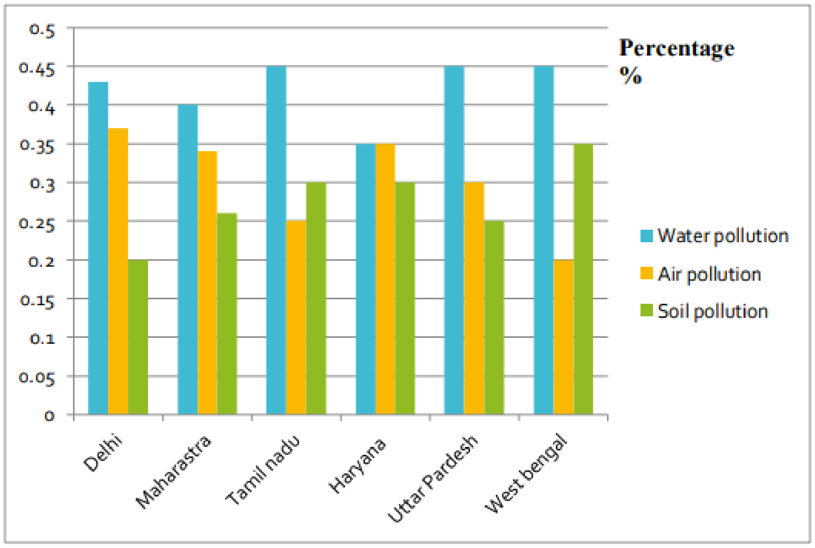

Fig 1.1 Water pollution dominance against soil and air pollution.

1.2 Problem Statement

Water obtained from various sources may not be pure and utilizable. To check the water is usable and harmless and to prevent the spread of any damage to consumers it is critical to continuously monitor water quality. Although there are many water monitoring and treatment policies available but most of them are lab-based, so these are effort-intensive, time-consuming, expensive, and do not provide real-time information. To accurately examine the water quality, samples should be collected on a regular basis over a long period of time as parameters may vary with different natural events. To observe the change in water parameters, systematic monitoring over a period of time is needed. An IoT system also needs to be designed to perform the monitoring remotely and efficiently.

1.3 Thesis Motivation

Water pollution is a big worldwide issue. According to studies, water contamination is the biggest cause of deaths and diseases worldwide. According to data, more than 14,000 people die every day around the world. Every day, 580 persons in India die as a result of water pollution-related illnesses. In many underdeveloped countries, unclean or contaminated water is consumed without any prior treatment. The main cause of this is public and administrative ignorance, as well as a lack of an efficient water quality monitoring system, which produces serious health hazards. Natural events can also alter the quality of water and cause contamination. Water is the most crucial aspect for all living species, and it is important to maintain water. As a result, monitoring water quality is essential in protecting water resources. The system proposed in this thesis will aid in monitoring water quality and determining various properties of water. The system can collect parameters such as temperature, pH, TDS, and turbidity from water using various sensors and help to make an appropriate decision.

1.5 Thesis Objectives

The Objectives of the thesis are:

- To design an Internet of Things (IoT) based Water Quality Monitoring (WQM) technology in comparison to the time-consuming conventional way of water quality monitoring.
- It also includes measuring pH, total dissolved solids (TDS), and turbidity to monitor the water quality and derive a correlation between water parameters and UV absorption.

1.5 Thesis Outline

This thesis provides the details about both the hardware and software components. The software is mostly used for coding, and for hardware simulation. The hardware is utilized to deploy the prototype in order to collect the real-time data. Further, the entire work is divided into three major Sections: Research & Data analysis, Prototype construction and Report writing. The thesis is divided into five Chapters. The first chapter is an introduction to Water Quality Monitoring (WQM), the necessity for the WQM system, the problem statement, the motivation behind the study, the Objectives of the study, and an Overview of the thesis. The second chapter focuses primarily on a brief discussion on water Quality parameters and other researchers' studies on WQM in order to provide a better decision on the sort of hardware to be used. The study area, methodology, and data analysis are discussed in Chapter 3. Chapter 4 provides the detail regarding the prototype, architecture, and the results acquired by the prototype after deployment. The fifth and final chapter summarizes the entire report, and proposes Conclusion and Future work.

Chapter 2

Literature Review

2.1 Water Quality Parameters

Water quality monitoring is defined as sampling and surveying water constituents and conditions, which can be done by analyzing the physical, chemical, and biological characteristics of water. Physical properties of water quality include temperature, color, odor, turbidity, and total dissolved solids (TDS). Chemical properties include pH, electrical conductivity (EC), alkalinity, hardness, dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). The biological properties of water include microbial contamination, total coliform, and fecal coliform.

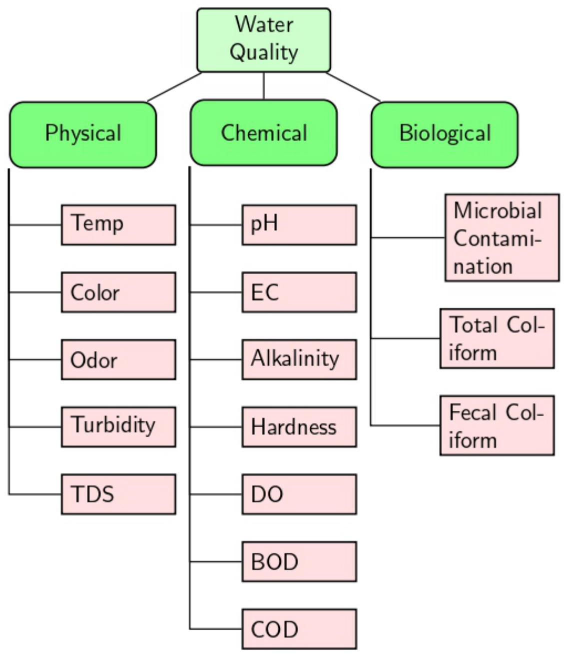

Fig. 2.1 Distribution of Water Quality Parameters

Temperature: One of the most essential parameters that have a significant impact on aquatic life is temperature. Viscosity, palatability, solubility, odors, and other chemical reactions are affected by temperature. As a result, temperature influences the sedimentation, chlorination, and BOD processes. It also affects the biosorption of dissolved heavy metals in water. It is usually expressed in degrees Celsius, and a thermistor or thermometer is used to measure it [8].

Color: Decayed materials from both organic and inorganic substances add color to the water. The color of the water gives a general idea of the level of water pollution in that waterbody. Its value is calculated by comparing it to standard color solutions or colored glass discs [9].

Odor: Organic and inorganic compounds, or dissolved gases, can alter the odor of water. Like color, the odor can also provide information about water contamination. The odor value is calculated by comparing it with a sample of odor-free distilled water [10].

Turbidity: Turbidity describes the cloudiness of the water. It quantifies the ability of light to travel through water. Turbidity in water is caused due to suspended particles such as clay, dirt, organic matter, plankton, and other granular materials. Turbidity in drinking water is undesirable because it causes the water to appear discolored [11].

TDS: Solids in water exist in two states: solution and suspension. These two types of solids can be distinguished by bypassing a water sample through a glass fiber filter. The suspended solids remain on the filter's surface while the dissolved solids pass through with the water.
When a filtered fraction of a water sample is evaporated in a tiny dish, the solids that remain as a residue are referred to as total dissolved solids or TDS [12], [10]. Total solids (TS) are calculated as the sum of total dissolved solids (TDS) and total suspended solids (TSS).

pH: The pH of water indicates how acidic or alkaline it is. Between 0 and 6, the acidic range is found, and between 8 and 14, the alkaline range is found. The form of some chemicals can change by the change of the pH in the water. Therefore, it may affect other water quality parameters. The pH range of 6.5 to 8.5 is the most suitable [13].

EC: The property of a solution to carry or conduct an electrical current is measured by its electrical conductivity (EC). The greater the concentration of dissolved charged chemicals in water, the greater the electrical current that can be carried. It is not directly beneficial to water quality. However, it is more beneficial in terms of water's ionic content, which determines hardness, alkalinity, and some of the dissolved solids. It is determined using the electrometric method [13].

Alkalinity*:* Alkalinity is a measure of the ability of water to neutralize acids. This is known as water's buffering capacity, or the ability of water to resist a change in pH when acid is added. The alkalinity of water is primarily caused by the presence of hydroxide ions (OH-), bicarbonate ions ($HCO_3 -$), carbonate ions ($CO3^{2-}$), or a combination of the two in water. High amounts of alkalinity in water may indicate industrial or chemical pollution. Alkalinity can also occur naturally. The acidity and alkalinity in natural waters provide a buffer action on acid wastes and protect fish and other water-living organisms from sudden changes in pH [13].

Hardness: Hardness in water is caused by multivalent metal ions, which are derived from dissolved minerals in the water. The capacity of these ions to react with soap to create a precipitate or soap scum determines their hardness. The majority of hardness in naturally produced water is caused by calcium and magnesium ions. They primarily enter water through contact with soil and rock, especially limestone deposits. These ions can be found as bicarbonates, sulfates, chlorides, and nitrates.

Hardness is classified into two types: carbonate and noncarbonate hardness. Carbonate hardness refers to the hardness of calcium and magnesium bicarbonate. It is also known as "hardness" or "temporary hardness" since it can be eliminated or reduced by boiling. On the other hand, chlorides and sulfates are the primary causes of non-carbonate hardness. Non-carbonate hardness is also known as "permanent hardness" [14].

DO*:* Dissolved oxygen is one of the most important aspects of water quality in streams, rivers, and lakes (DO). It is a significant indicator of water contamination. The greater the concentration of dissolved oxygen, the better the water quality. The amount of dissolved oxygen in the water fluctuates depending on pressure, temperature, and salinity. Although dissolved oxygen has a little direct impact on public health, some people find drinking water with very little or no oxygen unpleasant. The colorimetric approach, which is a quick and economical method, the Winkler titration method, which is the conventional method, and the electrometric method are the three primary methods for determining dissolved oxygen concentrations [13].

BOD*:* Organic substances are used as food by bacteria and other microbes. They utilize oxygen while metabolizing organic material. Microbes use the energy released from the breakdown of organics into simpler chemicals like CO2 and H2O for growth and reproduction. The oxygen utilized in this process in water is the DO in the water. If oxygen is not continuously provided in the water, either naturally or artificially, the DO content will decrease as the microorganisms break down the organic molecules. The biochemical oxygen demand (BOD) refers to the need for oxygen. The higher the BOD consumed by the bacteria; the more organic material is present in the water. The BOD is a metric for determining the strength of a substance. BOD is a metric for sewage strength; strong sewage has a high BOD, whereas weak sewage has a low BOD [10].

COD: The chemical oxygen demand (COD) is a metric for measuring all organics, including biodegradable and non-biodegradable. Like BOD, it is also an important parameter for representing the status of water quality. It is determined in milligrams per liter by micro digestion, colorimetry, and reflux distillation with acid potassium dichromate, followed by titrimetric. For the same sample, COD readings are always greater than BOD values [10].

Microbial Contamination: Microorganisms can be found all around the planet. Human bodies maintain a typical population of microorganisms in the digestive system, with coliform bacteria accounting for a substantial portion. Despite the fact that wastewater includes millions of bacteria per milliliter, the vast majority of them are harmless. The presence of hazardous bacteria in wastewater is only damaging when the wastewater contains waste from sick persons [15].

Total Coliform: Total coliforms are made up of fecal coliforms and other non-fecal bacteria that are mostly found in soil. Total coliforms are associated with fecal coliforms and indicate the presence of harmful microorganisms. They are counted using the membrane filtration method [15].

Fecal Coliform: Fecal coliforms are bacteria found in human and animal faeces that originate mostly in the intestines of warm-blooded species. They highlight the possibility of fecal contamination of water. Membrane filtration is a preferred method for analyzing fecal coliforms in water [15].

2.2 Water Quality Index

The quality of water cannot be defined by any single parameter. To effectively maintain the quality of the water, it is essential to continuously monitor a wide number of water quality parameters. By combining multiple water quality parameters [16, 17], the Water Quality Index

(WQI) is a useful tool that provides a single value that indicates overall water quality at a certain location and time. WQI converts the complex water quality data into an easy-to- understandable format [18]. WQI was first discovered by Horton [19]] in 1965 and it proposed a mathematical approach for calculating a single number from several water quality parameters (BOD, temperature, turbidity, conductivity, pH, turbidity, etc.) to represent water quality. Different countries and organizations have their WQI index system. Some of them are, National Sanitation Foundation Water Quality Index (NSFWQI) by U.S [20, 21], Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) [22, 23], British Columbia Water Quality Index (BCWQI) [24], Overall Index of Pollution (OIP) [25], Oregon Water Quality Index (OWQI) [26] etc.

In general, the WQI method consists of the following four steps [16, 27]:

i) ***Parameter selection***: Identifying and selecting the most important factors that can be used to provide a functional sense to the water quality index. This step necessitates proficiency in order to supply the correct number of parameters. This method is typically carried out with the assistance of an expert opinion (individually or in groups) or statistical tools.

ii) ***Obtaining sub-index values***: As there are multiple scientific units for different water quality measures, it is necessary to convert them into a single common scale, which is accomplished by creating sub-indices.

iii) ***Parameter weight values assignment:*** Each variable is weighted based on its relevance, which is determined by assessing the potential impact of each parameter when its concentration levels exceed the allowable limits. Despite the fact that it is a time-consuming procedure, the strategy will reduce subjectivity in weighting and improve the index's reliability.

iv) ***Aggregation of sub-indices***: This is the final step in calculating a final cumulative index value. Mathematical models are used to integrate all of the sub-indices into a single index number to understand the allocated weights. There are several aggregation methods available, but three main models are typically utilized. These are additive, multiplicative, and logical functions. The general structure of the WQI model is given in Fig.2.1.

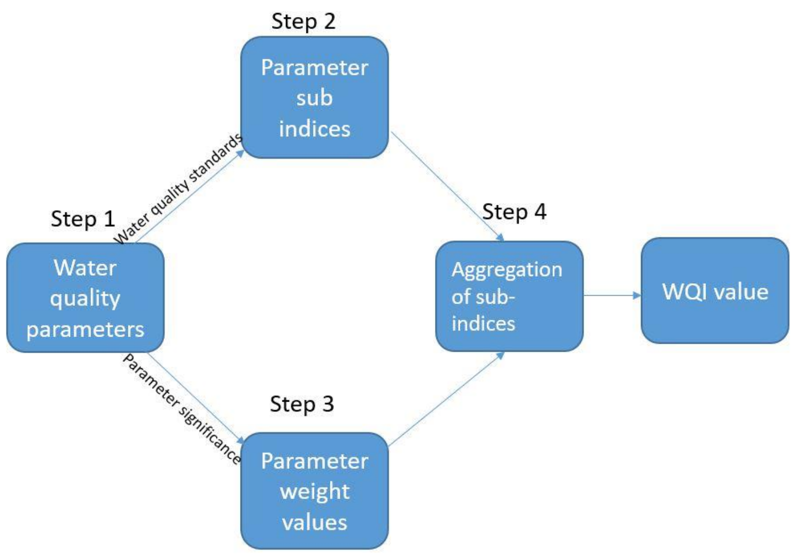

Fig.2.2 General Structure of WQI model

WQI method is very effective for water monitoring and has several advantages like

i) Fewer parameters needed to compare water quality for a specific application.

ii) Provides a single value that measures total water quality at a certain location and time.

iii) Transforms a complicated dataset into an easy and understandable information

but most of the WQI methods are computationally expensive and different WQI methods assign different weight values for different water quality parameters, so it is not an absolute assessment of pollution or water quality.

2.3 Water Quality Standards

There are various water quality standards that can be followed. One of the most widely used standards is that established by the World Health Organization (WHO). The WHO has set guidelines for the lower and upper limits of certain water parameters for drinking water. Table (2.1) explains the maximum admissible limits for drinking water as specified by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS).

Table 2.1 Water quality standards for Drinking

Parameter	Bureau of Indian Standards (BIS 2009)	WHO standard 2011
pH	6.5–8.5	7.0–8.5.
TDS (mg/L)	500	600
Alkalinity (mg/L)	200	300
DO (mg/L)	5	NA
EC (µs/cm)	750	750
Salinity (ppt)	100	100
Turbidity (NTU)	1	1

According to CPCB, the designated Best Use Water Quality Criteria for surface water is given in the Table 2.2.

Table 2.2 CPCB Water Quality Criteria for Designated Best Use

Designated-Best-Use	Criteria
Drinking Water Source without conventional treatment but after disinfection	• Total Coliforms Organism MPN/100ml shall be 50 or less • pH between 6.5 and 8.5 • Dissolved Oxygen 6mg/l or more • Biochemical Oxygen Demand 5 days 20C 2mg/l or less
Outdoor bathing (Organised)	• Total Coliforms Organism MPN/100ml shall be 500 or less • pH between 6.5 and 8.5 • Dissolved Oxygen 5mg/l or more • Biochemical Oxygen Demand 5 days 20C 3mg/l or less
Drinking water source after conventional treatment and disinfection	• Total Coliforms Organism MPN/100ml shall be 5000 or less • pH between 6 to 9 • Dissolved Oxygen 4mg/l or more • Biochemical Oxygen Demand 5 days 20C 3mg/l or less
Propagation of Wild life and Fisheries	• pH between 6.5 to 8.5 Dissolved Oxygen 4mg/l or more • Free Ammonia (as N) 1.2 mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	• pH betwwn 6.0 to 8.5 • Electrical Conductivity at 25C micro mhos/cm Max.2250 • Sodium absorption Ratio Max. 26 • Boron Max. 2mg/1

2.4 Related works on Water Quality Monitoring (WQM)

The related works on WQM have been divided into three subsections. The first subsection deals with research related to parameter analysis. In the second subsection, research related to UV absorbance is discussed, and in the last part research related to IoT is explored.

2.4.1 Research related to Parameter Analysis

In [28], Alam et al. surveyed the physical, chemical, and microbiological qualities of Surma River, Bangladesh, to find the river water quality. The study was conducted at different points of the river, and the duration of the Study were the two seasons: dry and monsoon. During the Study, it is found that the water becomes highly turbid in the monsoon season. However, BOD and fecal coliform concentrations were high in the dry season.

In the study [29], Tripathi et al. studied the Physico chemical characterization of the river Ganga at Varanasi, similar study was done by Matta et al. [30] in Uttarakhand, Chaturvedi and Pandey [31] at Vindhyachal Ghat, Mishra et al. [32] at Varanasi, and Chandra el al. [33] at Bareilly. All the studies have concluded that the Physico-chemical qualities of Ganga water have deteriorated through time, and it is continuing to do so.

The assessment of the Jakara River was done by Mustapha et al. [34]. The study was conducted to determine the primary determinants responsible for water quality fluctuations in the basin. A total of 27 sampling points were chosen from the river network of the Upper Jakara River Basin. Water samples were collected in triplicate, and the Physico-chemical characteristics were determined. In the study, the authors established a relationship between salinity, conductivity, dissolved solids, BOD, and COD, using Pearson product-moment correlation analysis.

In work [35], Memon et al. measured all three characteristics (physical, chemical, and biological) of Thatta, Badin, and Thar, to assess the drinking water quality of canals, shallow pumps, dug wells, and water supply systems in the administrative districts. According to the observations, all four water bodies were significantly turbid in open water and contaminated with coliform and soluble salts. TDS, alkalinity, hardness, and Na were all high in the underground water, and sodium was a major problem in the district's dug wells and shallow pumps.

In [36], Mishra et al. investigated the water quality of Rani Lake of Rewa (Madhya Pradesh), India. The purpose of the study was to find the effects of anthropogenic activities. Water samples were collected monthly from the six sampling sites of the lake to analyze various physicochemical parameters. Results of the study revealed that water has high values of EC, turbidity, TDS, total hardness, alkalinity, chlorides, BOD, COD, phosphate, and nitrate. Researchers also found that the water had a lower dissolved oxygen concentration than recommended, and it was alkaline and hard. Water quality observations indicated seasonal variations of parameters. The findings showed that the lake was contaminated and eutrophic because of wastewater disposal and other anthropogenic activities. A comparison study on physicochemical parameters of surface water was conducted in [37, 38], and it was found that EC has a significant correlation with Temp, pH, Turbidity, TDS, DO, BOD, and COD.

2.4.2 Research related to UV Analysis

Since the dawn of civilization UV absorbance technology has been used to measure organic contamination in water. In 1978, Japan first introduced 254 nm UV technology for measuring water quality. The UV absorption technology was then deployed in Europe. The absorption technique was used to remove organic materials from water. Some organic parameters naturally absorb UV rays with wavelengths ranging from 200 to 400 nm, and the absorbance of UV is affected by the concentration of BOD or COD. The presence of suspended particles affects the linear relationships of BOD and COD values with UV absorbance. Research regarding UV analysis are discussed below.

A 9-month field and lab research [39] of ultraviolet (UV) exposure was carried out at Hyrum Municipal Wastewater Treatment Plant. The study examined the effect of photo-reactivation on disinfection and established a link between generally measured water quality parameters and disinfection efficiency.

A UV and fluorescence-based research were done in [40] to development of software sensors for calculating the BOD of waste and river water. Samples of river and wastewater treatment plants were acquired at 1-hour intervals to test the feasibility of software sensors. The software sensors were developed utilizing a multiple regression analysis of dissolved organic carbon (DOC) concentrations, UV light absorbance at 254 nm, and synchronous fluorescence spectra.

A system for real-time wastewater analysis is demonstrated in [41]. The system correlates the amount of light absorbed in the chemical composition of wastewater using the ultraviolet and visible light spectrum, which is used to measure the amount of chemical oxygen demand in wastewater. The technique performs statistical analysis on obtained spectra using a spectrometer, and automatically determines the most sensitive spectral area and wavelength for chemical oxygen requirement.

In the work [42] Vaillant et al. proposed three basic approaches for the exploitation of UV spectra: direct comparison (plotting the absorbance values of one spectrum against the absorbance values of the other), spectrum differences (Subtracting spectrum of raw sample from the settled sample), and normalization. In the paper, the authors found that Simple spectrum comparisons can assist in understanding the UV physical reaction of total suspended particles and can be used to check for wastewater quality monitoring.

2.4.3 Research related to IoT

2.4.3.1 An overview of IoT

The Internet of Things (IoT) is defined as a network of physical objects/things, such as devices, vehicles, and buildings, that are integrated with sensors, microcontrollers, and network connectivity, allowing these objects to collect and share data. IoT is a vast network of embedded devices with built-in wireless technologies that can be monitored, managed, and linked within the current Internet infrastructure. Each gadget has a unique ID and must be capable of capturing real-time data autonomously. Sensors, processors, gateways, and applications are the basic building blocks of the IoT. Wireless technologies such as Wi-Fi, Bluetooth, ZigBee, RFID, and 6LoWPAN enable devices to communicate with one another and with the Internet. The cloud services collect, store, and analyze the data collected by the sensors, allowing users to make further decisions. The general structure of IoT is shown in figure 2.2.

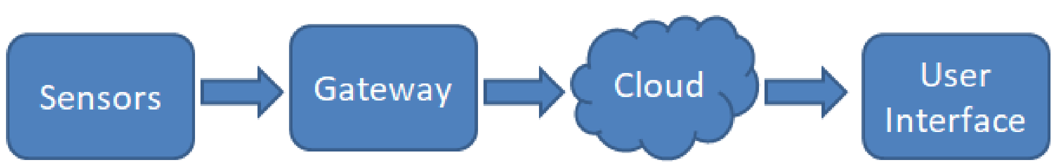

Fig.2.3 General Structure of IoT

In [43] the authors have proposed a design of a real-time WQM system. The system can measure flow, temperature, pH, conductivity, and oxidation-reduction potential, among other physicochemical characteristics of water. A microcontroller (PIC32MX220F032B) unit has been used to process and analyze the data, and a ZigBee receiver and transmitter modules have been used for communication. The proposed systems can display the readings and send an audio alert when water quality parameters reach unsafe levels.

In [44], an IoT-based water monitoring system has been proposed. The system can measure four parameters: turbidity, conductivity, water level, and pH. For connectivity, a single-chip microcontroller with a built-in Wi-Fi module TI CC3200 has been used. The system can collect and store the data in the cloud using a Wi-Fi medium. A similar study was done by [45], but instead of TI CC3200, Raspberry pi 3 is used in this model.

In [46], a system has been proposed to assess the amount of contamination caused by water leakage in pipelines. Arduino Atmega 368 is used in the proposed system, and Global System for Mobile Communication (GSM) module is used for communication. The system is used by the Tirunelveli Corporation (a metropolitan city in Tamilnadu, India) to capture sensor data like pressure, pH, level, and energy sensors automatically.

A real-time monitoring system for aquaculture has been proposed in the paper [47]. The system allows aqua farmers to be notified if the water source is contaminated. It consists of four modules i) power module, ii) sensor module, iii) micro-controller module, and iv) output module. The power module consists of a solar panel, charge controller, battery, and DC-DC converter. In the sensor module, several sensors are included like dissolved oxygen, ammonia, pH, temperature, salt, nitrate, and carbonates measure sensors. In the microcontroller module, Raspberry pi 3 is used, and an app-based interface has been used for the output module.

In [48], an IoT-based water monitoring system has been proposed that monitors pH, temperature, and EC 9 by different sensors. Then the collected data is processed through the LPC2148 micro-controller module and transferred via the ESP8266 Wi-Fi data communication module to the central server.

A PIC32 MCU-based system was designed in [49], that gathers data on water parameters (Turbidity, ORP, pH, EC and Temperature, pH, DO, nitrates) via sensors performs the water quality assessment and sends data via ZigBee module.

An IoT and ML-based water monitoring system is designed in [50]; the system consists of three parts. In the first part, an Arduino MCU is used to collect the data of pH and TDS sensor. Then in the second part, the collected data is sent to raspberry pi3 using Serial communication. In the last part, the processed data is uploaded to the cloud server. In Pi3, a machine learning approach called K-Means Clustering was used to predict water quality based on PH and TDS.

A WQM system for crab farming based on IoT was built in the article [51]. The device tries to help farmers grow soft-shell crabs by constantly monitoring water quality. The system consists of a low-cost small embedded system, sensors, and a Long-Range Radio (LoRa) wireless interface. It measures the water temperature, salinity, and pH level of water in the crab pond. The authors also developed a setup of a web-based monitoring application using a node-red dashboard for displaying water quality parameters in the graphical user interface. The experiments evaluated the adequate number of subscribers the single Raspberry pi broker can handle. The result showed that the single Raspberry pi MQTT broker could take at most 25 subscribers.

The paper [52] offers a real-time water quality monitoring system based on a broker-less publisher-subscriber (pub/sub) architecture framework. Sensors in the system detect water measurement metrics such as temperature, pH, and dissolved oxygen content. All acquired data were kept in a database and stochastically computed for subsequent water quality investigation. A complementary experiment contrasts the pub/sub architecture and MQTT. To conclude the experiment, the link between temperature, pH, and DO is examined, and the experiment concludes that water temperature is inversely proportional to pH and dissolved oxygen value.

In the paper, [53], a low-cost and long-term IoT-based water quality measuring system was presented to reduce water-related illnesses and avoid water contamination. The system incorporates various types of sensors for measuring the quality of drinking water (pH, Temperature, Turbidity, water flow, Water level). These sensors are linked to Arduino to monitor water quality factors. Serial communication between Arduino and NodeMCU was used to communicate the values, which would display the data on an online system using a web interface.

The paper [54] proposes an IoT-based system for monitoring water quality by combining the Radio Frequency Identification (RFID) technology, Wireless Sensor Network (WSN) platform, and Internet Protocol (IP)-based communication into a single platform. An analog pH sensor was used to measure the pH level. The Atmega328p microcontroller acted as both the sensor node and the network gateway, and WSN connection was accomplished via the Xbee Protocol.

A low-cost online WQM system based on wireless sensor networks (WSN) was presented in the study [55]. The system is made up of two modules, a wireless node and a base monitoring station. The wireless node is powered by a 9V battery and comprises a sensor unit and a CPU. The authors have used the ZMN2405HP ZigBee module, which includes a CC2430 transceiver IC. pH, temperature, and turbidity sensors were used in the system. The readings from these sensors were signal-conditioned to ensure their accuracy. Once conditioned, the wireless sensor node transfers the readings to the base monitoring station through the transceiver. The other ZigBee module, the transceiver at the base monitoring station, receives the readings and transmits them to the computer using the RS 232 protocol. The acquired data is then visualized on a custom C++ GUI.

A WSN and IoT-based WQM system is developed and implemented in the paper [56]. The device measures the pH, turbidity, temperature, and DO of the water sample. The measured data values of water quality are sent from sensor nodes to the ATmega328 microcontroller and, then to the 10 LoRa transmitter module, which is connected to the ATmega328 via serial peripheral interface. It transfers sensor data to a LoRa receiver wirelessly . The LoRa receiver displays the RSSI value of sensor data packet reception and sends the data value to the ESP32 Wi-Fi gateway module. The data is subsequently sent to the ThingSpeak server through the IP protocol by the gateway.

Chapter 3

Study Area

3.1 Introduction

In this study, the water quality of the Ganga River has been studied by analyzing different water parameters such as pH, TDS, and turbidity. The duration of the study was 6 months. During this duration, different meters were used to measure the value of the parameters, and the day wise variation of the parameters and their correlation with UV absorbance has been analyzed.

3.2. Sample collection

Water samples of Ganga water were collected regularly from B. Garden ferry ghat, Shibpur, Howrah, India, 711103. The latitude and longitude of the Ganga ghat are 22.5529° N and 88.3007° E. Figs. 3.1, 3.2, and 3.3 depict the location of the Ganga water sample collection site.

Fig.3.1 Location of water collection

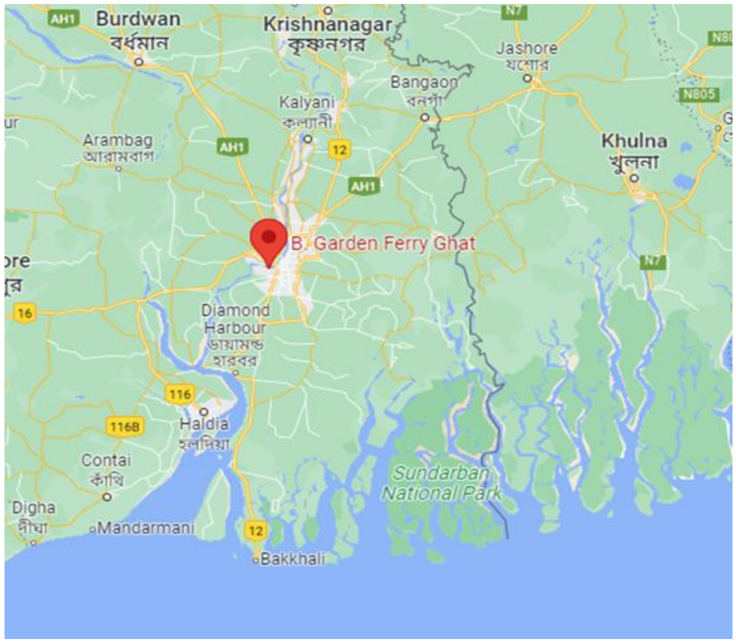

Fig.3.2: B. Garden ferry ghat

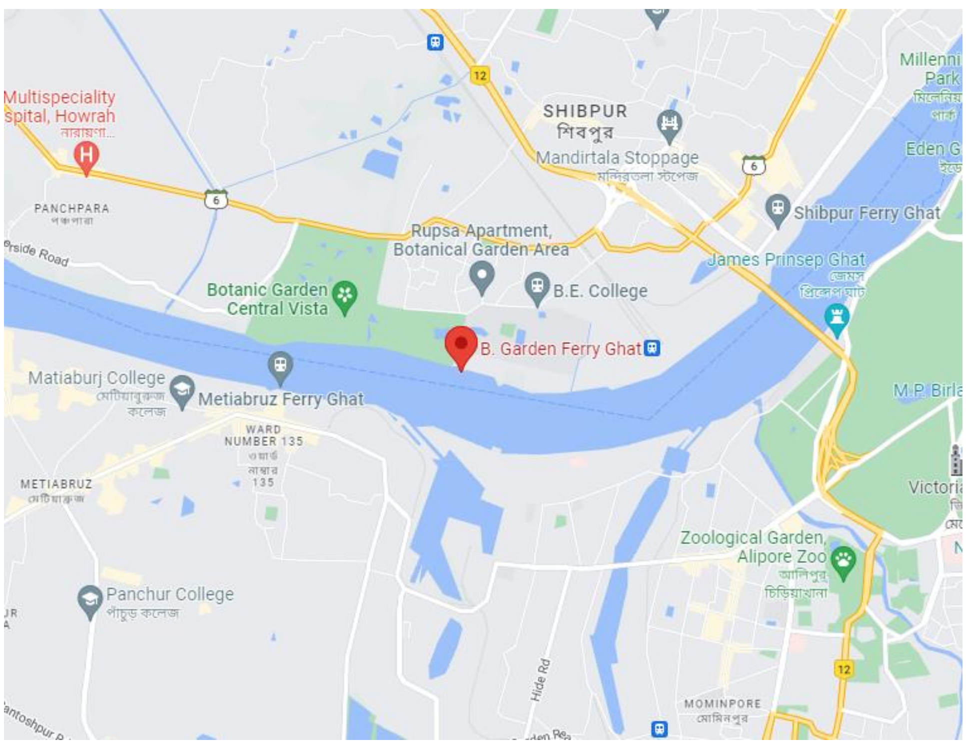

Fig.3.3 Ganga water collection point

3.3. Experimentation Methods and Equipment

The samples were collected from November to April 2022 during the spring and winter season. Various physical and chemical parameters like temperature, pH, turbidity, and total dissolved solids (TDS) were monitored in the study. Plastic bottles of 1 liter and 500 ml capacity were used for collecting samples. The name and date of the sample were noted on each container. Temperature, pH, TDS, and turbidity were measured using LabQuest 2 and other meters, and BOD and COD were measured using traditional methods.

LabQuest 2

Vernier LabQuest 2 is a stand-alone interface that collects sensor data and analyses it using its built-in graphing and analysis software. The device consists of three analog sensor ports and two digital sensor ports for data collection, and after the collection of data, statistical analysis of data is done on the graph screen. The device also consists of a built-in network module to save and import the data on PCs.

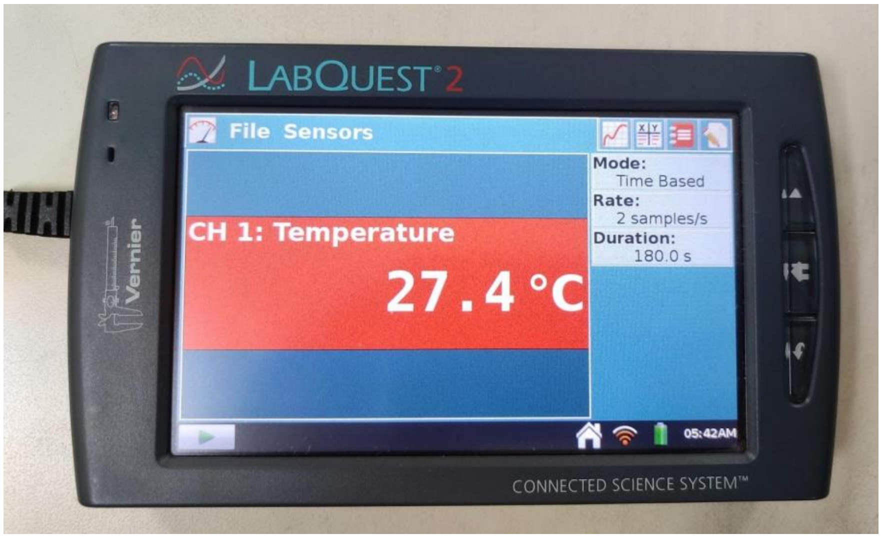

Fig.3.4 Vernier LabQuest

TDS, pH, and Turbidity meters

TDS and pH meter from Konvio Neer and Turbidity meter from vernier have been used for measuring the respective measurements. The image of the meters is given following.

Fig.3.5 TDS (in left), pH (in right) and Turbidity (In center) Meters.

3.4 Data Analysis

3.4.1 TDS

It is found that the TDS of Ganga water remains in the range between 188 and 240 (ppm).

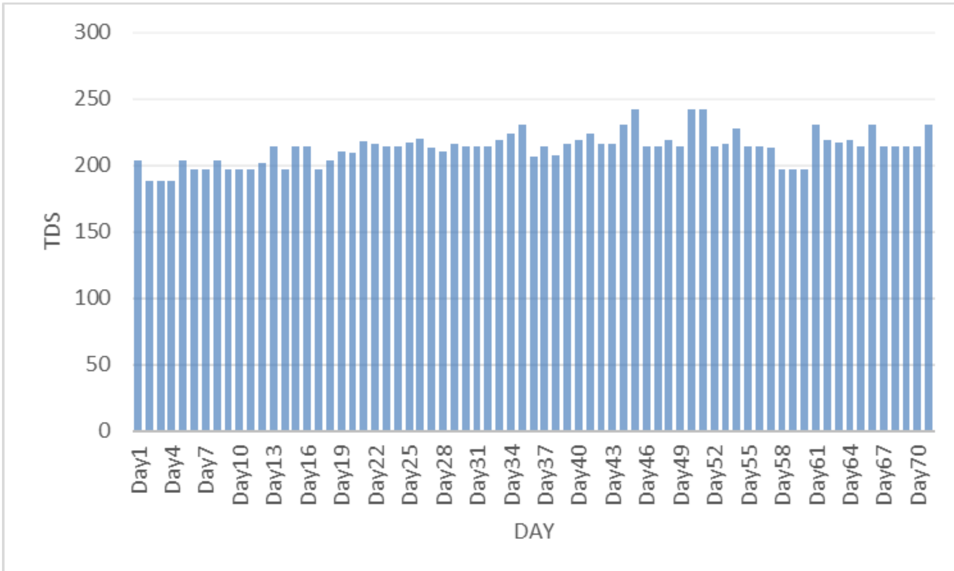

Fig.3.6 Day wise variation of TDS

3.4.2 Turbidity

The turbidity value of the water samples ranges from 33 to 182 NTU.

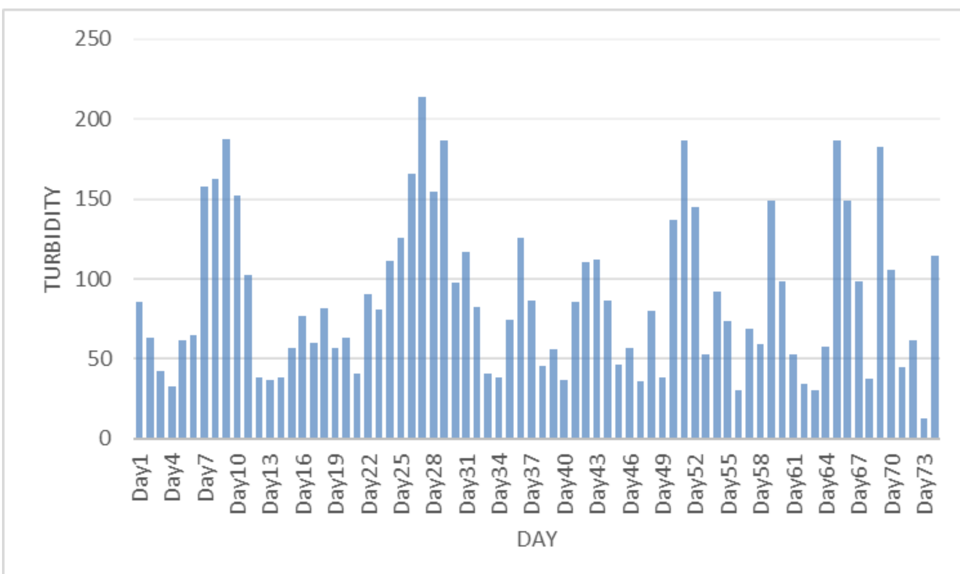

Fig.3.7 Day wise variation of Turbidity

3.4.3 pH

The pH value of the water samples ranges from 6.1 to 6.8.

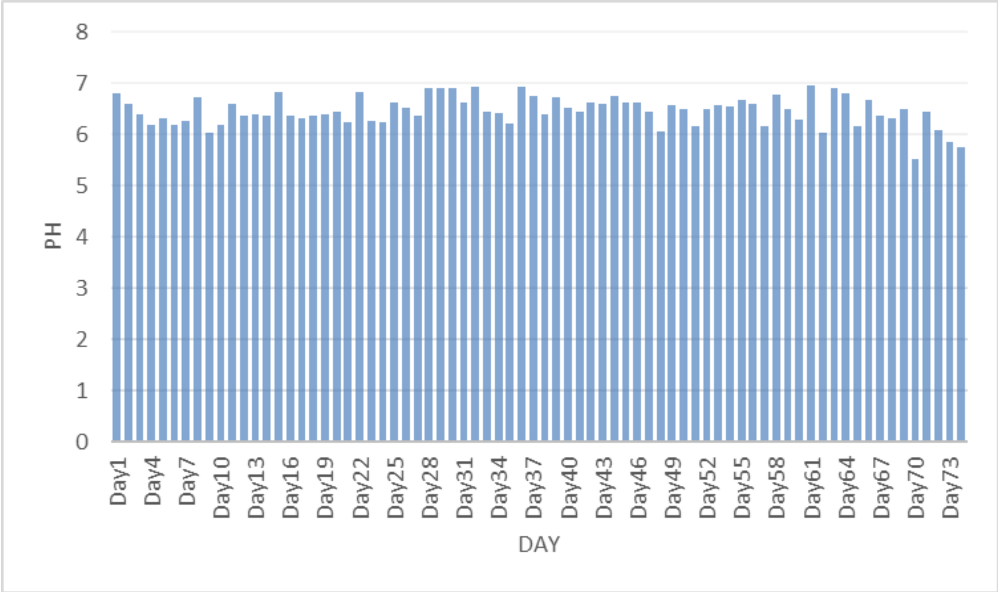

Fig.3.8 Day wise variation of pH

3.5 Correlation between abs and different parameters

A correlation study was also done to find the relation between UV absorbance (254 nm) and different water parameters and the findings are given below.

3.5.1 Turbidity vs Absorbance (UV254)

A linear relation between turbidity and Absorbance (UV254) has been found with R^2 value of 0.97.

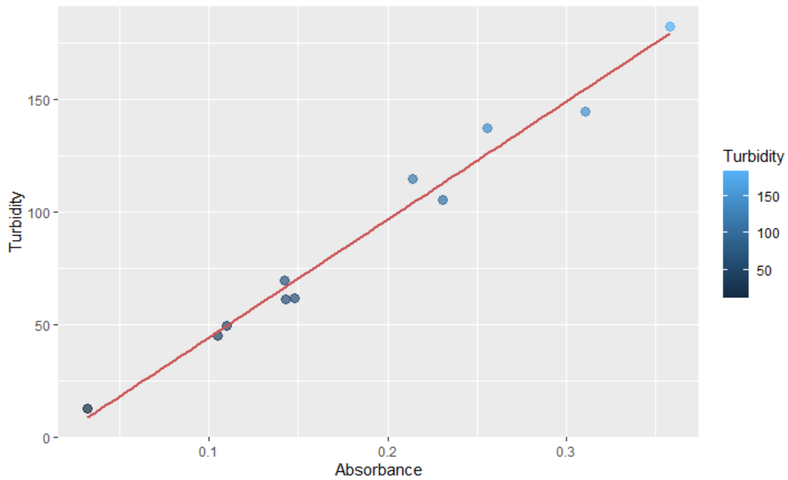

Fig.3.9 Relation between turbidity and Absorbance (UV254)

3.5.2 pH vs Absorbance (UV254)

A 6th order polynomial relationship has been found between pH and Absorbance (UV254) with the R^2 value of 0.84.

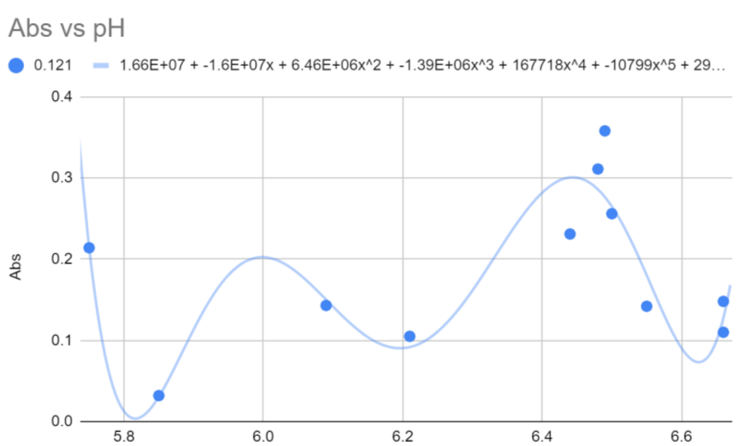

Fig.3.10 Relation between pH and Absorbance (UV254)

3.6 MATLAB Algorithm

A MATLAB algorithm was developed to find the overall water quality from the collected data. The algorithm can classify whether the water quality is good, bad, or moderate. If the sensed parameters are in the desirable range, then the water quality is classified as good; similarly parameters are within or slightly above the permissible range, then the water quality is classified as moderate, and if the parameters far exceed the permissible limit, then the water quality is classified as bad. From the simulation, it was found that the overall water quality of Ganga water is moderate.

3.6.1 Flowchart

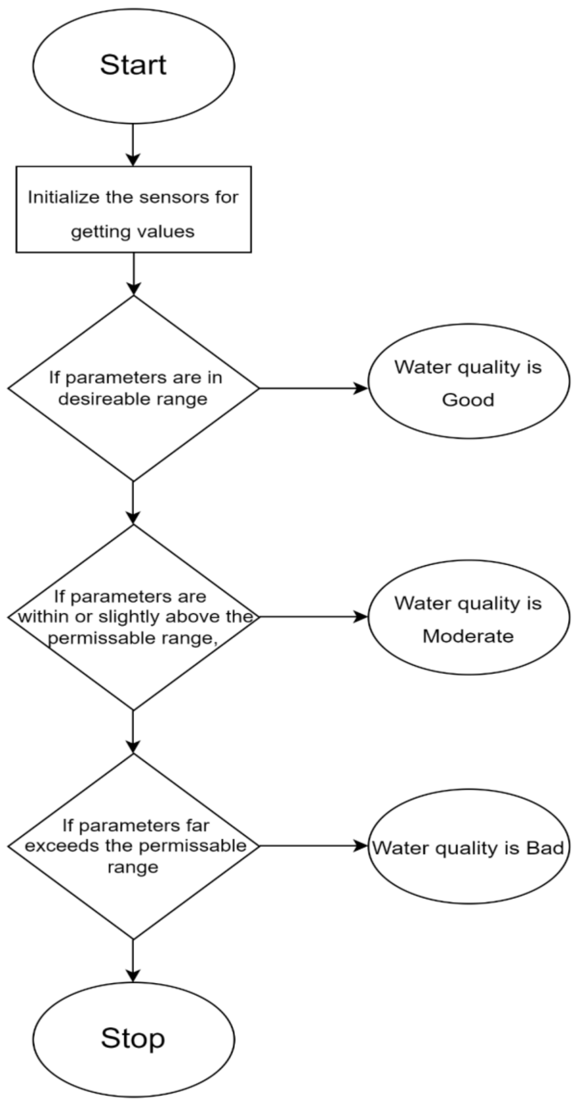

Fig.3.11 Flowchart of the algorithm.

3.6.2 Simulation Result

Fig.3.12 Line graph of overall water quality

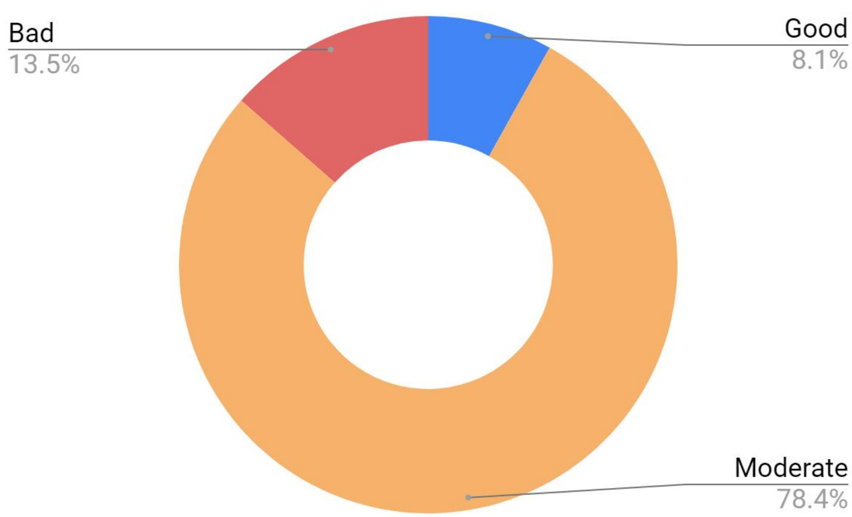

Fig.3.13 Donut graph of overall water quality

Chapter 4

Real Time Water Monitoring System

4.1 Proposed System

In this Thesis, four different types of sensors were used to assess the water quality parameters precisely. The proposed system includes four sensors: pH, turbidity, TDS, and DHT-11, as well as a microcontroller unit (Arduino Uno) and an ESP32 Wi-Fi module for the primary processing unit and one data transmission module. The microcontroller unit is the most important component of our water quality measurement system construction. The Arduino Uno has been utilized for a microcontroller unit that consumes less power and is compact in size, making it suitable for selling technological criteria as well.

The data was collected using the four sensors. The sensors were utilized to collect data in the form of analog signals, and the MCU includes an on-chip ADC that converts the analog signals to digital signals; these sensors will be attached to the MCU's analog pins. All data will be recorded and processed to the ThingSpeak server via the Wi-Fi data transmission module ESP32 to the main server. Figure 4.1 depicts a block diagram of the Real-time water monitoring system.

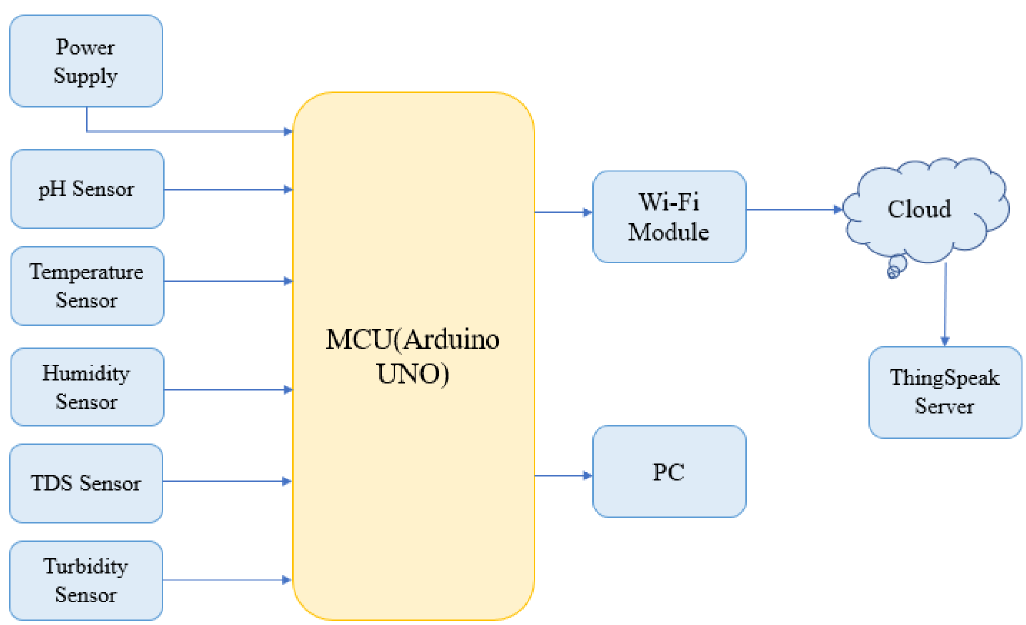

Fig 4.1 Block Diagram of Real-Time Water Monitoring System

4.2 Components:

4.2.1 Arduino UNO

It is an ATmega328P-based microcontroller board. Itconsists14 digital I/O pins, with 6 of them capable of generating PWM signals. As shown in figure 10, it also has 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. This board is flexible and uses a USB cable to connect to a computer. It can be powered by USB or an external power supply such as an AC to DC adapter or a battery. An external supply ranging from 6 to 20 volts can be used for supplying power, but 7 to 12 volts is the optimum voltage range. The circuit diagram of the Arduino UNO is shown in figure 4.2.

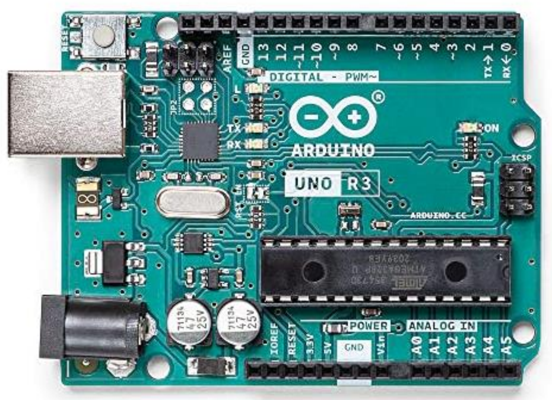

Fig 4.2 Diagram of Arduino UNO

4.2.2 ESP32-WiFi Module

ESP32 is an open-source firmware for Internet of Things platforms. It is made up by Espressif Systems. The Fire Beetle Board-ESP32 combines a dual-core ESP-WROOM-32 module with dual-mode communication with the MCU, Wi-Fi, and Bluetooth. During profound sleep, the electrical current is only 10A. The main controller aids two power distribution methods: USB and 3.7V internal lithium batteries. Because of its high processing power, Wi-Fi/Bluetooth, and deep sleep operating features, it is ideal for IoT Projects.

.

Fig 4.3 Diagram of ESP32

4.2.3 ThingSpeak Server

ThingSpeak is an application that collects data from multiple sensors, such as temperature, pH, turbidity, and many more. Basically, it is an IoT application. To utilize this server, the user must first log in. The data collector will collect the data and transfer it to the Wi-Fi module (ESP32), after which the data will be sent to the Thingspeak server, where it will be updated and processed into MATLAB code, and the data will be reacted to by some warning sound.

4.3.4 pH sensor

The Analog pH Sensor Kit is created specifically for Arduino controllers, it includes a simple, convenient, and practical connection. It has a power indicator LED, a BNC connector, and a PH2.0 sensor interface. The readings can be measured by connecting the pH sensor to the BND connection and linking the PH2.0 interface into any Arduino controller's analogue input port. The pH value is easily obtained if pre-programmed.

Fig 4.4 Diagram of pH sensor

4.3.5 Dht11 sensor

The DHT11 is a low-cost digital temperature and humidity sensor. This sensor can simply be interfaced with any microcontroller, such as Arduino, Raspberry Pi, and others, to detect humidity and temperature in real-time.

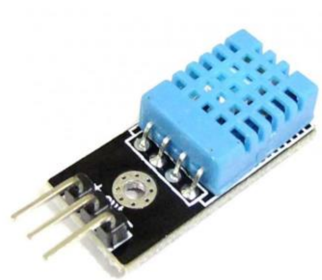

Fig 4.5 Diagram of Dht11

4.3.5 TDS sensor

TDS Water Quality Testing Probe Measures Total Dissolved Solids (TDS) levels in water, which can be used to assess water quality. It accepts 3.3/5V input voltage and output voltages of 0 2.3V, making it easily compatible with all Arduino boards.

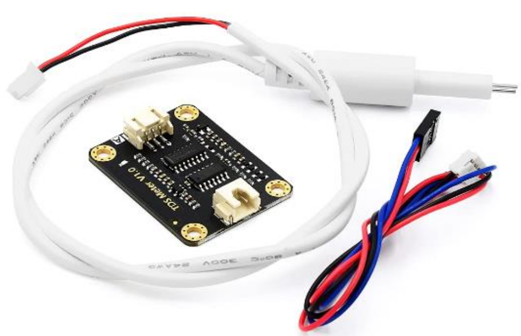

Fig 4.6 Diagram of TDS sensor

4.3.5 Turbidity sensor

The Arduino turbidity sensor measures turbidity to detect water quality. It detects suspended particles in water by measuring light transmittance and scattering rate, which vary with the amount of TSS in the water. The level of liquid turbidity rises as the TTS rises. This Arduino turbidity sensor can output both analogue and digital signals. Because the threshold in digital signal mode is changeable, you can choose the mode based on the MCU. Turbidity sensors can be used for river and stream water quality measurements, wastewater and effluent measurements, sediment transport investigations, and laboratory measurements.

Fig 4.7 Diagram of turbidity sensor

4.4 Hardware:

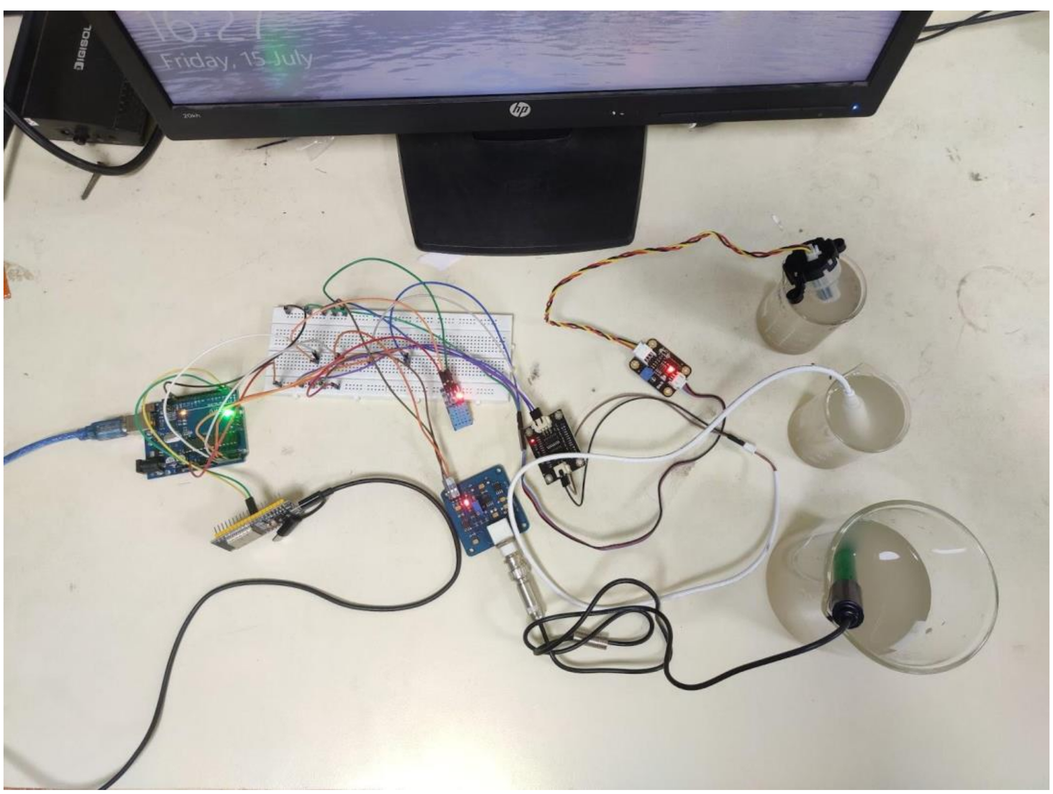

Fig 4.8 Hardware of Proposed System

4.5 Results:

The sensors value in Arduino serial monitor have been shown in the figure 4.9.

Figure 4.10 shows the same parameters values being updated in the ThingSpeak server.

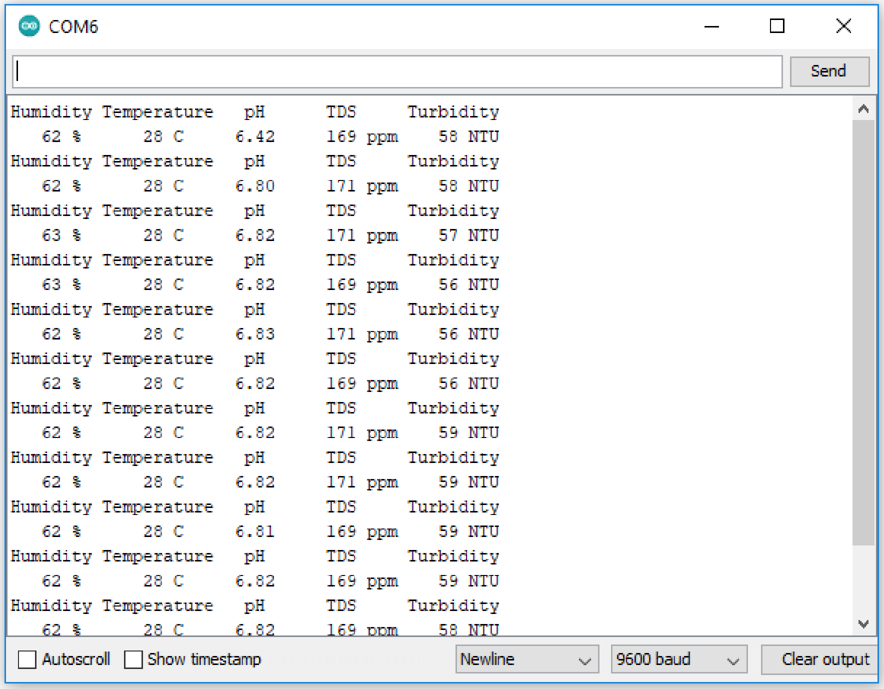

Fig 4.9 Parameter values on serial monitor

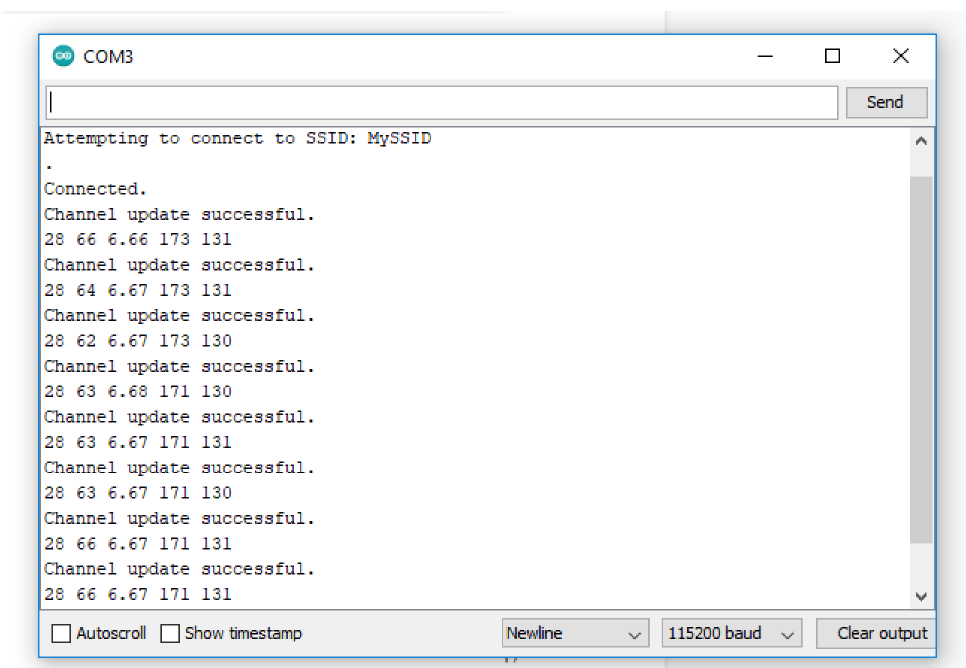

Fig.4.10 Updating parameter values in ThingSpeak server

The real time graphical representation of the parameters in the Thing Speak server has shown in Fig.4.11 to 4.15.

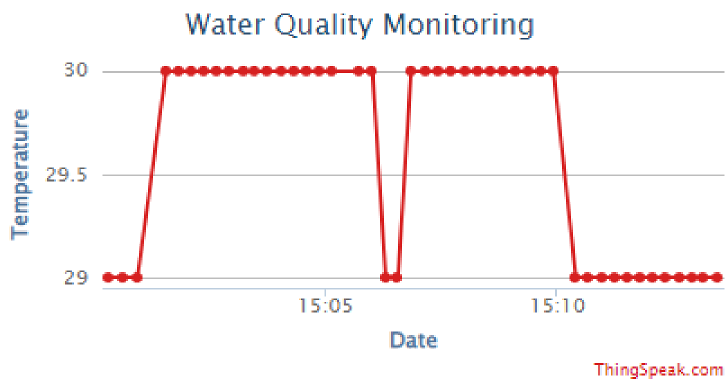

Fig.4.11 Temperature output in ThingSpeak Server

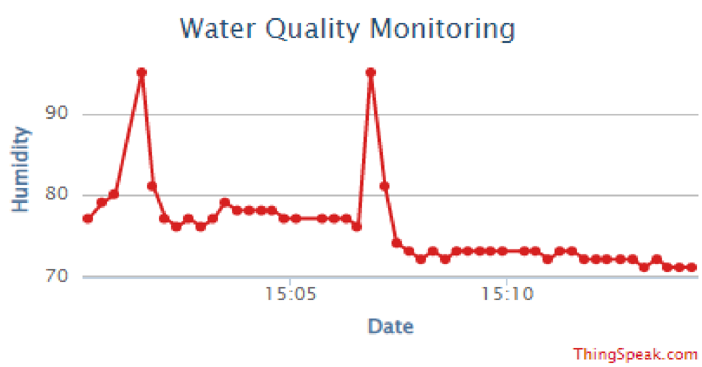

Fig.4.12 Humidity output in ThingSpeak Server

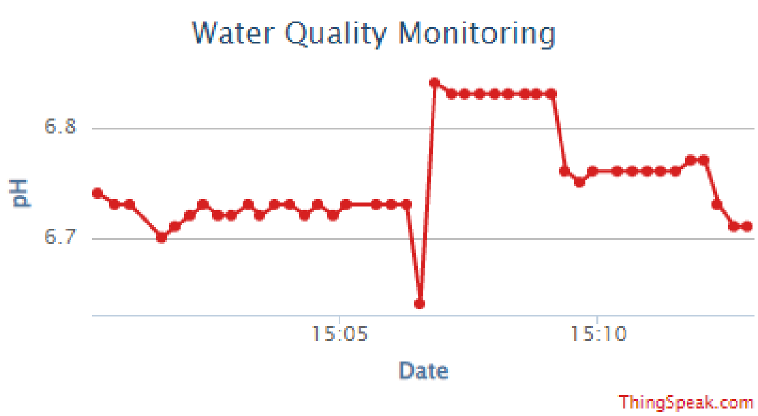

Fig.4.13 pH output in ThingSpeak Server

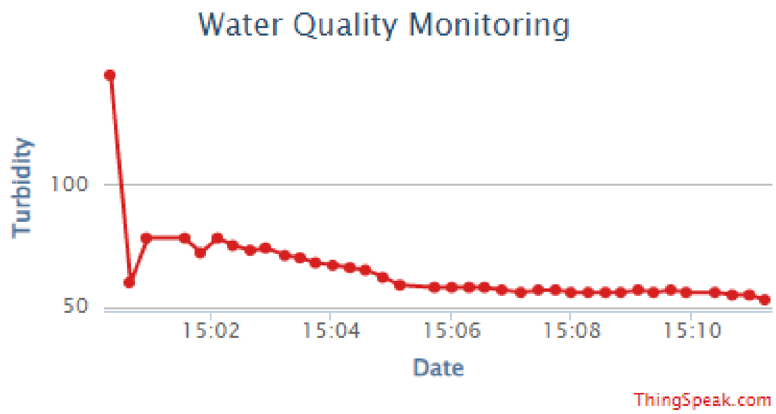

Fig.4.14 Turbidity output in ThingSpeak Server

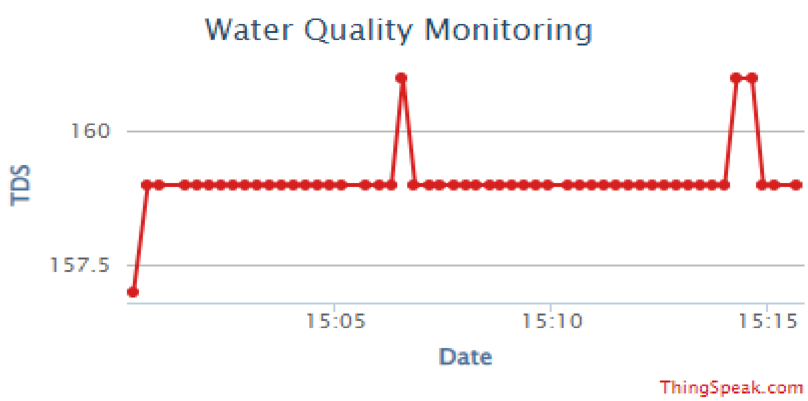

Fig.4.15 TDS output in ThingSpeak Server

4.6 Comparison Table

Table 4.1 Comparison Table

Ref	Technology used	Cloud	Monitoring Parameters				Remarks
			pH	Temp	TDS	Turbidity	
[43]	PIC32MX220F032B and Zigbee	No	Yes	Yes	No	No	The data communication range of this system is very low and cloud technology and tds sensor has not been used.
[45]	Raspberry pi 3 and inbuilt Wi-Fi	Yes	Yes	Yes	No	Yes	The cost of the system is very high as the cost of Raspberry pi 3 is very high.
[46]	Arduino Atmega 368 and GSM Module	Yes	Yes	Yes	No	No	Real time Monitoring is not available in this system.
[50]	Arduino Uno and Raspberry pi 3	Yes	Yes	No	Yes	No	In this system Raspberry pi 3 has been used as a data communication unit which makes the total cost of the system very high
[53]	Arduino Uno and NodeMCU	Yes	Yes	Yes	No	Yes	The system uses Nodemcu which is an old version of Esp32.
[57]	Arduino Atmega238 and ESP8266	Yes	Yes	Yes	No	Yes	The system uses Esp8266 which is also an old variant of Esp32.
Proposed System	Arduino Uno and ESP32	Yes	Yes	Yes	Yes	Yes	The proposed system uses Esp32 which has better bandwidth and frequency than Esp8266 and Arduino uno has been used for low-cost purpose.

Chapter 5

Conclusion and Future Work

5.1 Conclusion

In this Thesis work, an IoT based WQM system has been successfully developed. The device can measure five water parameters in real time: pH, turbidity, temperature, TDS, and humidity. Further, the system can monitor for 24 hours without human intervention. The mainboards used in this Thesis for data logging and cloud transmission are Arduino Uno and ESP32. ThingSpeak is the cloud function employed in this work as it can store data, process data, and interact with MATLAB.

To summarize, the Thesis objectives have all been met completely; which are measuring pH, total dissolved solids (TDS), and turbidity to monitor the water quality, derive a correlation between water parameters and UV absorption and to implement an Internet of things (IoT) based water quality monitoring technology for efficiently monitoring of water quality in Real Time.

5.2 Future Work

Several recommendations for future work can be made to improve the overall water quality monitoring of this IoT based work. To begin, LoRa devices can be used to replace ESP32 as data transmission devices, because they consume significantly less power than ESP32 and can transmit at a greater range. Second, as the logging system collects more data, Artificial Intelligence and Machine Learning can be implemented in the cloud server to make predictions based on the water quality parameters logged into the cloud. Finally, more sensors can be added to the system to monitor additional parameters and make more decisions based on the monitored results.

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