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Original Article

Development of IoT Based Water Pollution Identification to Avoid Destruction of Aquatic Life and to Improve the Quality of Water

R. Amuthakkannan[1], Mahmood Hamed Awadh Al Yaqoubi[2]

[1,2]Department of Mechanical and Industrial Engineering, National University of Science and Technology, Muscat, Sultanate of Oman.

[1]Corresponding Author : amuthakkannan@nu.edu.om

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Abstract *- Water pollution is a serious global environmental issue that is still growing rapidly due to the massive development in the industrial field and the increased human activities. Changes in the physico-chemical properties of water affect its quality due to contamination. Polluted water results in severe impacts on public health and the environment, which will cause the spread of dangerous diseases and the destruction of aquatic life. Due to these reasons, a functional and smart method for monitoring water quality is essential to detect water pollution. Therefore, this study aims to implement Internet of Things (IoT) technology for monitoring water quality by using a Remote Control (RC) boat to provide real-time monitoring of water quality of different parameters by providing GPS locations. Previous research in monitoring water quality was reviewed and included in this study to be evaluated and compared with the proposed smart method of monitoring water quality. The RC boat will contain a system designed to have three sensors (pH, temperature and turbidity) and a GPS module integrated with a built-in Sim card, which transfers the measured parameters of water quality and GPS locations to the server, which can then be monitored using a phone application. The experimentation of the RC boat was conducted in three spots to identify different parameters. As a result, the overall water quality of the natural creek does not meet the water quality standards as determined by the World Health Organization (WHO) and is highly contaminated. This project is a smart water quality monitoring technique which is expected to contribute to detecting and controlling water pollution problems worldwide since traditional water quality monitoring is considered a challenge and might be inaccurate.*

Keywords - *Water pollution, Physico-chemical properties of water, Water quality, IOT technology, Real-time monitoring, Aquatic life.*

1. Introduction

Water is necessary for life to exist and should be safe, appropriate, and accessible. The supply of water is the highest priority to all countries around the world. Achieving the above three requirements has a direct effect on protecting public health with the incredible increase in water pollution that requires continuous monitoring. According to (Jerry, 2022), water pollution is defined as the discharge of pollutants into underground water or lakes, streams, rivers, estuaries, and seas to the level that the contaminants interfere with beneficial water usage or the natural ecosystems.

Water pollution may involve the discharge of energy into bodies of water in the form of "Radioactivity" or "Heat". In addition, putrescible organic waste, pathogenic bacteria, toxic chemicals, fertilisers and nutrients of plants, sediments and petrochemicals may all contaminate water bodies. Water contaminants arise from "Point Sources" or "Dispersed Sources".

Channels or pipes used for the discharge from sewage systems and industries are classified as "Point Source". A "Dispersed Sources" is a large region from which various contaminants mix with the body of water, such as the runoff from agricultural regions. "Pathogens" and "Putrescible Organic Compounds" are mostly found in domestic sewage due to the fact that "Pathogens" are discharged in medical waste; sewage from towns and cities includes pathogens that severely impact public health. Putrescible organic matter poses a unique challenge to water quality. The dissolved oxygen concentration of the water decreases when organics degrade naturally in sewage by bacteria and other microbes. As identified by Son et al., 2020, various indices of water quality were developed to evaluate the level of pollution in water bodies. These indices are the Water Quality Index (WQI), Organic Pollution Index (OPI), Comprehensive Pollution Index (CPI), Eutrophication Index (EI) and Trace Metal Pollution Index (TPI). Monitoring water quality of water resources and controlling pollution requires a huge

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effort since the traditional method of monitoring forces operators to scan the entire water body. Therefore, this RC boat represents an easier water quality monitoring solution to determine polluted water body spots. Pollution of water poses severe risks to the public health and the environment. Water with poor quality, e.g. the quantity of Dissolved Oxygen (DO) should be above 6.5-8mg/L in water, and pollution in water poses risks to enterprises that depend on the water with high-quality requirements. Moreover, the people who live in the coastal areas, where the influence of water quality and physico-chemical properties of water are abundantly obvious, require protection from its harmful consequences.

2. Literature Review

Pasika and Gandla, 2020) built a cost-effective and smart system to monitor water quality in the tank using the Internet of Things (IOT) to send the measured values to the cloud. The smart designed by the researchers has four different sensors, which are pH, ultrasonic, turbidity and DHT-11, to measure the parameters of pH level, water level in the tank, turbidity, temperature and humidity of the atmosphere. The researchers used the microcontroller "Arduino Mega" as the processing module and the Wi-Fi module Node MCU "ESP8266" for transferring data to the cloud. The four sensors were integrated into the Arduino board, and since pH and turbidity sensors are analog sensors, they were connected to the analog pins of the Arduino. On the other hand, the ultrasonic and DHT-11 were connected to the digital pins. The system's entire data will be processed by the microcontroller and uploaded to the "Thing Speak" server using the Wi-Fi module, which is set to update the results every 20 seconds. Based on the results, the researchers found that the pH voltage reached 2.39 V (at 20:28h) with the corresponding pH value of 5.74 (Nernst Equation).

The turbidity voltage was measured as 4 V (at 21:08h), indicating the turbidity value of 676 NTU (by the equation). The water level in the tank measured by the ultrasonic sensor was 44cm. DHT-11 sensor measured the temperature as 34.2C and humidity as 33% (21:12 h). According to the results, the researchers determined that the water was contaminated. Mukta et al., 2019 conducted research to determine the quality of different water resources by applying IOT technology for continuous water quality monitoring to observe the variations in the physico-chemical parameters. In this study, the researchers used four different sensors to determine water quality: the pH sensor (SEN0161), temperature sensor (DFR0198), conductivity sensor (DFR0300) and turbidity sensor (SEN0189). All these sensors were integrated with the microcontroller "Arduino Uno", and the data provided by the sensors was analysed using "Fast Forest Binary Classifier" to develop an application on the desktop to determine whether the water is clean or not. The researchers ran different tests to check the system is working and then collected 60 samples of drinkable water (natural, impure, potable). Based on the results, the researchers found that 80% of water samples have exceeded the acceptable pH range as determined by WHO (6.5-8.8) with an average temperature of 25.13C. The researchers also found that the turbidity of some samples was 0 NTU, which is very clean water (not more than 5 NTU), but the turbidity value was more than 500 NTU in most contaminated samples with a very high conductivity as compared to the clean water (recommended is 0.3-0.8 $\mu s/cm$). In this paper, the researchers were able to create a smart solution to monitor water quality by implementing IOT (Figure 1) and classifying the tested samples as drinkable or not by developing an application on the desktop.

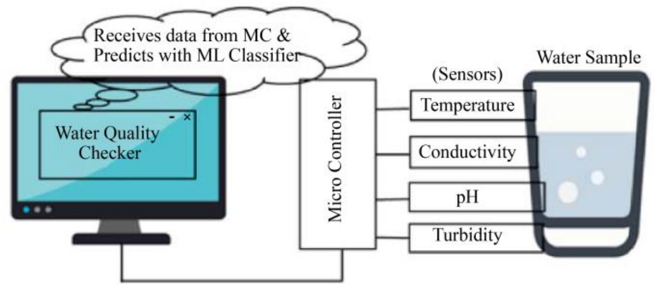


Fig. 1 Smart water quality monitoring system (Mukta et al., 2019)

Chowdury et al., 2019, prepared three sensor nodes in different locations in a river containing different probes of sensors which are able to measure the parameters such as dissolved oxygen and turbidity in one node, pH and temperature in the second node and then conductivity, total dissolved solids and salinity in third node. The researchers used Arduino Mega as the processing module, and the sensors were integrated. The Arduino Mega can collect the digital and analogue signals from the sensors and process these data to the Wi-Fi module ESP8266 to perform the wireless communication to transfer the data to the PC/LCD/Mobile for analysis. If the value does not exceed the threshold, it will display "Good"; otherwise, it will display "Bad". For the first test, the researchers obtained a pH level of 7.18, a temperature of 46.19C, turbidity of 7 NTU, and ORP of 720 mV, and the system displayed the quality as "Good". In the second test, the researchers obtained a pH level of 4.28, a temperature of 31.67C, turbidity of 2 NTU and conductivity of 1300$\mu s/cm$. In this paper, the researchers were able to build a real-time monitoring system to check river water continuously with the ability to determine if water quality is good or bad to use. The researchers also concluded that IOT technology provides more reliability, speed and accuracy in determining water quality.

Abraham and Susan, 2017 determined the sources of heavy metals and trace elements in the "Kilembe Mine Catchment Water" (Kilembe mine is in Western Uganda) that represent around 15 mt left in the river due to mining and their concentrations. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used to determine the elements in the different samples which were collected from "mine water, mine tailings, Nyamwamba River water, mine leachate, public water sources, and home water samples". The researchers collected a total of 61 samples from these locations, and each sample was filtered and acidified. Additionally, another 43 sediment samples were collected using a plastic scoop to scrape the riverbed. The samples were transferred to "Makerere University" in plastic bags and were air-dried in the lab for two weeks before being sieved to less than two millimeters and kept in plastic zip-lock containers. Then, using three modes, ICP-MS was used to determine the concentrations of elements such as Fe, AL, Zn, and Cu. Tailing and sediment samples were examined in duplicate for quality assurance. The "Enrichment Factors" of the sediments were calculated to determine the contamination level by using the formula

$$EF = \frac{\left(\frac{m}{Fe}\right) \text{Sample}}{\frac{M}{FE} \text{ background}} \quad (1)$$

In this study, the researchers used different parameters to determine the level of pollution in the river, which are Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Ag, Cd and Pb. According to the results obtained, the average concentrations in "mg.kg-1" of Cu (3320), Ni (131), Co (112), and As (8.6) in "Mine Tailings" were much higher than the global average crust and were being released into the catchment. The "Underground Mine Water" and "Leachate" achieved higher average concentrations in "mg.L-1" of Co (3430), Ni (590) and Cu (9470) and compared to "Uncontaminated Water Background" values which were much higher. Add to that, Mn and Fe exceeded the standard limits for drinking water with values in "μgL-1" of Mn (649) and Fe (2612) while the standards are Mn (400) and 200 (Fe) as determined by "WHO". The results obtained from this paper are given in Table 1.

In addition, the researchers found that Cu and Co obtained the highest "Enrichment Factors" in the sediments with more than 1.5 compared to other metals, as shown in Figure 2.

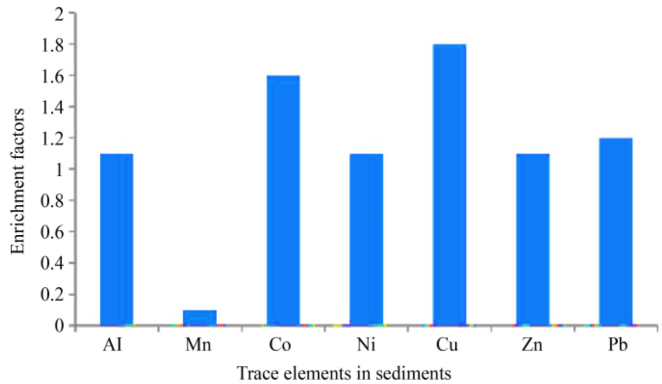


Fig. 2 Values of Enrichment Factors (Abraham and Susan, 2017, p. 284)

Table 1. Obtained results of heavy metals & Trace elements concentrations (Abraham and Susan, 2017, p. 286)

Sources	**Tap Water (n=6)**		**Water well (n=1)**	**Gravity flow water**		**Domestic water**		**Drinking water thresholds (μgL^{-1})**
Element	**Range**	**Mean ± SD**		**Range**	**Mean ± SD**	**Range**	**Mean ± SD**	
Al	0.12-51.3	24.8 ± 20	21.9	14-15.3	14.7 ± 1	2.4-4835	699 ± 1419	200[c]
Cr	0.0-0.58	0.27 ± 0.18	0.34	0.22-0.24	0.23 ± 0.01	0.32-5.54	0.92 ± 1.5	100[b]
Mn	0.3-3.4	1.64 ± 1.1	649	2.91-4.59	3.75 ± 1.2	0.57-254	61.1 ± 76.3	400[a]
Fe	0.9-121	62.8 ± 61	2612	17.8-23.4	20.6 ± 4	4.5-7179	885 ± 2063	200[c]
Co	0.02-1.21	0.34 ± 0.44	2.43	0.27-2.39	1.3 ± 1.5	0.03-66.1	20.4 ± 23.4	40[d]
Ni	0.02-1.1	0.48 ± 0.37	1.21	0.57-1	0.8 ± 0.3	0.6-16	5.6 ± 5.73	70[a]
Cu	0.3-6.5	3.1 ± 2.54	2.37	2.66-3.3	2.9 ± 0.5	2.9-119	36.1 ± 47	2000[a]
Zn	0.0-82.2	30 ± 32	5.88	27.4-174	101 ± 104	4.8-104	47.1 ± 49.1	3000[a]
As	0.0-0.2	0.08 ± 0.04	0.91	0.05-0.06	0.05 ± 0.01	0.06-0.82	0.21 ± 0.24	10[a]
Cd	0.0-0.01	0.01 ± 0.01	0	0.01-0.01	0.01 ± 0	0.0-0.07	0.03 ± 0.02	3[a]
Pb	0.0-0.57	0.25 ± 0.19	0.22	0.29-0.58	0.44 ± 0.21	0.19-3.2	0.66 ± 0.85	10[a]

Table 2. Quality standards of drinking water by WHO & ICMR (Kumar, 2022, p. 3)

Parameters	Standards (Sn)	Recommending agency	Unit weights (Wn)
pH	7.0 to 8.5	ICMR	0.218176
TDS	500	WHO	0.003708
TA	120	ICMR	0.01545
TH	300	ICMR	0.0061816
Chloride	250	ICMR	0.0074179
Sulphate	250	WHO	0.0074179
DO	5	ICMR	0.37089
BOD	5	ICMR	0.37089

Kumar, 2022 has done research to identify the physico-chemical properties and "Water Quality Index (WQI)" in the lower regions of the tropical river systems in Kerala State, India, which are Karamana, Vamanapuram and Neyyar. After considering the tidal impact on these three rivers, the researchers determined five different sites for sampling were determined in each of the three rivers with a 2km distance between each site in the river. Therefore, 15 samples of surface water (5 samples from each river) were collected and contained in pre-cleaned plastic bottles over the three major seasons, which are "Post-Monsoon" in December, "Pre-Monsoon" in March and "Monsoon" in July. The samples were immediately examined to determine the Physico-chemical properties of each sample. During the sampling, the samples' PH and conductivity were measured using The "Portable Water-Quality Analyser -Multilane F/ SET-3, WTW-". The Dissolved Oxygen was also measured on-site and calculated using the "Winkler Technique" with "Azide Adjustment". An unseeded "Dilution Method" and a 5-day incubation were used to determine BOD. The obtained results were compared to ICMR (India) and WHO (International) standards, as shown in Table 2.

The physico-chemical parameters which were determined in this study by the researchers are Total Dissolved Solids (TDS), pH, Total Hardness (TH), Sulphate, Total Alkalinity (TA), Biological Oxygen Demand (BOD), Dissolved Oxygen (DO) and Chloride. Based on the obtained results, the researchers found that the concentrations of TDS, pH, TA, Chloride and BOD in all rivers during the season "Pre-Monsoon" due to several reasons, such as high temperature and bathing in the rivers. The maximum concentrations of TDS observed in the three rivers were 1510 mg/L in Neyyar, 516 mg/L in Karamana and 7140 mg/L in Vamanapuram, which is the highest concentration, while the maximum concentrations of chloride were 312.7 mg/L in Neyyar, 270 mg/L in Karamana and 2664 mg/L in Vamanapuram. Using the Water Quality Index "WQI" method, the rivers Neyyar, Karamana and Vamanapuram achieved an average WQI of 66.2, 64.5, and 65.9, respectively, classified as "Poor". The WQI of Nayyar is given in Table 3.

Table 3. WQI of Nayyar (Kumar, 2022, p. 4)

Station no	PRM	MON	POM
N1	74.7	58.34	70.51
N2	72.3	66.11	59.96
N3	69.55	60	57.2
N4	68.8	64.12	64.07
N5	82.36	69.65	59.59
Average	73.54	63.65	61.66
Note: Seasonal avg=66.2			

According to Spanton and Saputra, 2022, a study was conducted to investigate water pollution in Tuban by identifying seawater's physical, chemical and biological properties. The researchers adopted a special methodology to measure the pollution level in the collected samples. The researchers have taken samples from five different locations in the cost of Tuban district based on the activities held on the cost, which are fish auction, industry and tourism while taking population into consideration. The sampling process of seawater was done after cleaning the tools and the bottles containing the seawater samples, which were determined to be taken from a distance of 10 to 20 m from the seashore and 1 m depth from the seawater surface. The researchers divided the samples taken for each test as the following samples for the Dissolved Oxygen (DO) test, samples for the ammonia test, samples for the Biochemical Oxygen Demand (BOD) test, samples for the Chemical Oxygen Demand (COD) test, and samples for Heavy Metals test and inspection of seawater samples. After that, the physiochemical properties of these samples will be compared to the "Quality Standards of Environment Decree No. 51/2004" given in Table 4. After determining the physiochemical properties, the results were analysed using the STORET method to evaluate pollution levels in these different locations. The parameters considered in this study include Physical parameters: Temperature (Co) and TSS (ppm). Chemical parameters: pH, salinity (permil), DO (ppm), BOD (ppm), COD (ppm), ammonia, Fe (ppm). Biological parameters: Plankton (cell/100ml).

According to Abdulla, Jamil and Aziz, 2020, water quality was analysed in the lakes of "Darbendikhan" and "Dokan", Iraq Kurdistan, by determining heavy metal content that threatens both drinking water and aquatic life in these lakes. The researchers collected water samples from raw water, tap water and tank water from "Darbandikhan" and "Dokan" Lakes. These samples were contained in a plastic sampling container of 1 liter. By using nitric acid, the pH level of the samples was altered to 2. All of the samples were cooled and brought to the lab as quickly as possible, where they were held at 4 degrees Celsius before the examination. The heavy metals were determined using "Inductively Coupled Plasma-Optical Emission Spectroscopy" (ICP- OES) by applying the standard technique. Add to that, the researchers collected a number of 18 fish samples of ages 1, 2, and 3 years from "Darbandikhan" and "Dokan" lakes and stored them in a plastic icebox before being transported to the laboratory freezer at 18ºC. Parts of chest and tail muscles were removed completely from each fish sample, and an amount of 50 grams was inserted in a drying oven for 72 hours at 70ºC. Then, it was converted into ash after 72 hours at 550ºC in a muffle furnace. After that, the researchers measured the heavy metal content in these samples. The researchers determined three main parameters in analysing the heavy metal content in the collected samples, which are lead (Pb), copper (Cu) and cadmium (Cd). Based on the results obtained from the analysis, the researchers found that the "Darbandikhan" lake has the highest concentrations of heavy metal content of Pb and Cu, where the concentrations of Cu (μg/L) in tank water, tap water and raw water were 56.4, 56.9 and 56.9 respectively. The concentrations of Pb (μg/L) in tank water, tap water and raw water were 387.4, 413.4 and 921, respectively. The concentrations of Cd (μg/L) in tank water, tap water and raw water were 387.4, 413.4 and 921, respectively. On the other hand, the "Dokan" lake has the highest concentrations of Cd (μg/L) in tank water, tap water and raw water, which were 42.5, 41.9 and 43.9. The researchers determined that heavy metal content in both lakes and fish exceeded the standards identified by WHO.

Table 4. Quality standards of seawater (Spanton & Saputra, 2022, p.106)

No	Parameter	Unit	Requirements	Tests Of Techniques
Physics				
1	Smell	-	Not smell	Organoleptic
2	Flavour	-	normal	Organoleptic
3	Colour	TCU	max. 15	Spectrophotometry
4	Total Dissolved Solids (TDS)	mg/l	max. 1000	Gravimetry
5	Turbidity	NTU	max. 5	Spectrophotometry
6	Temperature	˚c	Air Temperature 3°c	Thermometer
Chemistry				
7	Iron (Fe)	mg/l	max 0.3	AAS
8	Hardness as $CaCO_3$	mg/l	max. 500	Titrimetric
9	Chloride (Cl)	mg/l	max 250	Argentometry
10	Manganese (Mn)	mg/l	max 0.1	AAS
11	pH	-	6.5 – 8.5	pH meter
12	Zinc (Zn)	mg/l	max. 8	AAS
13	Sulphate (SO_4)	mg/l	max 250	Spectrophotometry
14	Copper (Cu)	mg/l	max. 1	AAS
15	Chlorine (Cl_2)	mg/l	max. 5	Titrimetric
16	Ammonium (NH_3)	mg/l	max 0.3	Spectrophotometry (Nessler)
Inorganic Chemistry				
17	Arsenic (As)	mg/l	max. 0.01	AAS
18	Fluoride (F)	mg/l	max 1.5	Spectrophotometry
19	Chrome Hexavalent (Cr^{6+})	mg/l	max 0.05	AAS
20	Cadmium	mg/l	max 0.003	AAS
21	Nitrate (NO_3)	mg/l	max 50	Spectrophotometry (Brucine)
22	Nitrites (NO_2)	mg/l	max 3	Spectrophotometry (NED)
23	Cyanide (CN)	mg/l	max 0.07	Distillation
24	Lead (Pb)	mg/l	max 0.3	AAS
25	Mercury (Hg)	mg/l	max 0.001	AAS
Microbiology				
26	Plankton	Sel/100 ml	not bloom	MPN
27	Total Coliform Bacteria	APM/ 100 ml	Negative	MPN

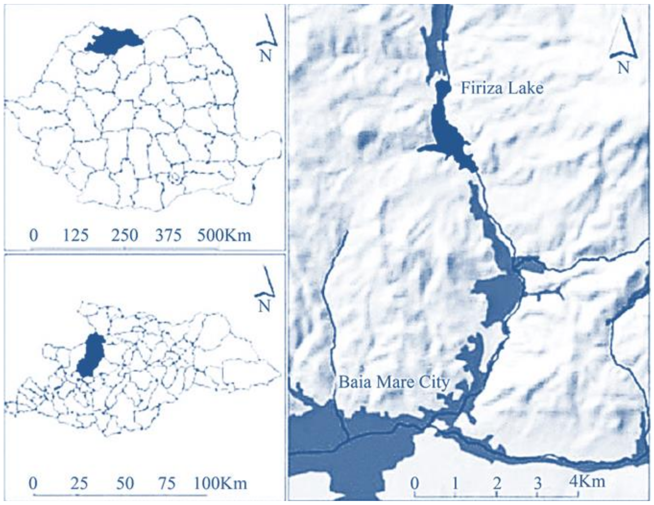


Fig. 3 Sampling locations in Strimtori-Firiza reservoir (Dippong et al., 2018, p. 221)

According to (Dippong et al., 2018), this research was done to evaluate the surface water quality of the Strimtori-Firiza reservoir, Northwest Romania, by determining the physico-chemical properties of each sample collected (Figure 3). The sampling locations were initially chosen near the right margin of the lake, which is surrounded by county roads, entertainment activities by visitors (such as boating and swimming) and fisheries, which represent a total of 18 different locations. Other places in the lake's mainstream were chosen to analyse the various parameters of water. The physico-chemical characteristics were examined within 48 hours of the sampling.

The samples were refrigerated until the tests were completed. For each sample, the pH level was measured by a pH meter, conductivity was measured by conductometer, chloride ions concentration was calculated by using Mohr method, ammonia was determined by "Berthelot" method using spectrophotometer, nitrates were measured by "Molecular Absorption Spectrometry" method and metals concentrations (mg/L) such as Mg and Ca were determined using "Flame Absorption Atomic Spectrometry (FAAS)" technique.

The researchers considered the parameters pH, nitrates, ammonium, electrical conductivity, chloride, calcium and magnesium as the physico-chemical parameters to analyse water quality. Based on the results obtained, the average results in the 18 samples achieved a pH level of 6.8, NO3- ions of 3 mg/L, NO4- ions of 0.04 mg/L, Cl- ions of 15 mg/L, conductivity of 63 μS/cm and Fe of 0.3 mg/L with the corresponding Maximum Allowable Limit (MAL).

According to Rahman, Jahanara and Jolly, 2021, a study was conducted to evaluate water quality in Truga River, Bangladesh, by determining the different physico-chemical properties of the samples and identifying the major sources of pollution. Water samples were obtained from four different locations through the river, which are "Gabtoli Bridge", "Birulia Bridge", "Ashulia Station", and "Tongi Riverport". 12 Water samples of 1 L each were taken over the different seasons: winter (Dec-Fe), summer (Mar-May), rain season (Jun-Aug), and before winter (Sep-No). From Dec 2018 to Nov 2019, the researchers collected the samples 12 times at 30-day intervals. During the low tidal period, water samples were obtained at each location in the mid-stream at a depth of roughly 10 to 20 cm. To separate suspended solids, the samples were filtered by using the filter "Whatman 41". Then, the samples were left for five days to calculate Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The solution "alkaline potassium iodide" was applied after sampling to protect the water samples for further analysis in the lab.

The researchers determined 12 parameters for analysing the physicochemical properties of water, which are pH, turbidity, temperature, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Total Alkalinity (TA), concentration of chloride ion (Cl-), Dissolved Oxygen (DO), Total Hardness (TH), COD and BOD. Based on the results obtained, the researchers determined that the winter season contained the largest deterioration of water quality parameters of high turbidity, pH, TA, Cl, COD, BOD, EC, TH, and TDS values and low concentrations of DO. The performed cluster analysis showed that winter season months obtained the highest concentrations of these parameters—the obtained variations in the values of the determined physico-chemical parameters during a period of 12 months. Starting from Dec 2018 to Nov 2019 were represented graphically (Figure 4). The Physico-chemical Parameters Values for different seasons are given in Table 5.

The mean values of these parameters during the four seasons obtained undesirable measurements of BOD (37.56mg/L), DO (1.19mg/L), chloride (86.01mg/L), COD (239.72mg/L), turbidity (32.31NTU), and EC (1 132.6mS/cm). In this research, the physico-chemical parameters in the Truga River were determined to evaluate water quality. The samples were collected in four different seasons, and the results obtained in each season were compared to each other by using certain analysis methods. The researchers concluded that the river is highly polluted and suggested properly managing the waste. However, the researchers did not clarify at what depth the samples were taken during the high tidal of the river and what procedures or precautions were adopted. According to (Malakootian, Mohammadi and Faraji, 2020), this study was conducted to investigate the quality of resources for drinking water in Urmia Lake, Iran, by analysing the physico-chemical properties of the samples by providing health risk assessment based on these parameters. The water samples were taken from wells from 16 different sampling locations. From each of the designated sampling locations, two samples were taken.

The water samples were kept in 2 L plastic bottles washed first (thrice) with double distilled water and nitric acid.

Then, the bottles were filled with water samples. The water samples' pH, temperature and turbidity measurements were determined at the sampling site. Nitric acid was used to maintain a pH level of 2 and then stored at 4°C to conduct other physico-chemical tests. Assessments of "Non-carcinogenic" risk and "Carcinogenic" risk were established using "Monte Carlo Simulation" and were represented using the "Hazard Quotient (HQ)" and "Excess Lifetime Cancer Risk (ELCR)" methods. The researchers considered the parameters pH, temperature and turbidity as well as the concentrations of nitrate (NO3−), calcium (Ca2+), sodium (Na+), sulfate (SO42−), potassium (K+), chloride (Cl−) nickel (Ni), cadmium (Cd), copper (Cu), arsenic (As), zinc (Zn) and lead (Pb). Based on the results obtained, the average pH measurement was 6.9 ± 0.24, which satisfies determined standards by WHO. However, the average turbidity measurement was 0.5 ± 0.2 NTU, much less than the standard 10 ± 0.02 NTU.

The researchers found that both anions and cations concentrations in all samples did not exceed the standards as determined by WHO, where the SO42− had the highest average concentrations among the anions of 84.07 mg/L while the Ca2+ had the highest average concentrations among the cations of 72.25 mg/L.

By using the "Hazard Quotient" index, as shown in Figure 5, it was found that there are no concerns about the concentrations of Zn and Ni in the lake, while the concentrations of Cd and as were high and exceeding the standards.

The physico-chemical properties of the drinking water of Umria Lake were identified to assess the water quality of this reservoir. "Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES)" was used to measure these parameters, which affected water quality and were compared to WHO standards. Additionally, risk assessments of the heavy metal content were provided by calculating the "Hazard Quotient" index for each metal. The researchers determined that the lake is polluted with heavy metals and nitrates. However, the researchers did not clarify at what depth these water samples were taken and the reasons for the presence of heavy metals in wells.

Table 5. Physico-chemical parameters of Turag River water in four distinct seasons recorded at four stations from December 2018 to November 2019. (Values Rahman, Jahanara and Jolly, 2021, p. 142)

Season	**Temperature (°C)**	**pH**	**Turbidity (NTU)**	**DO concentration (mg/L)**	**Cl^- concentration (mg/L)**	**TA (mg/L)**
Winter	21.92 ± 0.08	8.09 ± 0.11	37.83 ± 2.28	0.42 ± 0.09	102.83 ± 2.92	281.16 ± 23.7
Summer	26.62 ± 0.15	6.74 ± 0.15	35.11 ± 1.09	0.60 ± 0.20	92.58 ± 0.43	273.16 ± 4.01
Rainy Season	25.90 ± 0.02	6.95 ± 0.13	28.12 ± 1.31	2.04 ± 0.23	69.51 ± 3.44	215.10 ± 17.10
Pre-winter	23.39 ± 0.12	7.48 ± 0.05	28.19 ± 1.46	1.70 ± 0.35	79.10 ± 2.54	210.05 ± 20.34
Season	**BOD_5 concentration (mg/L)**	**COD concentration (mg/L)**	**EC (µS/cm)**	**TDS concentration (mg/L)**	**TSS concentration (mg/L)**	**TH (mg/L)**
Winter	45.66 ± 2.42	280.75 ± 5.84	1335.74 ± 46.86	782.08 ± 18.97	127.83 ± 6.48	328.00 ± 10.40
Summer	44.33 ± 2.07	253.12 ± 5.47	1297.91 ± 34.34	722.50 ± 9.90	128.83 ± 4.20	284.42 ± 6.96
Rainy Season	28.08 ± 3.45	193.25 ± 6.35	923.72 ± 36.98	519.66 ± 21.81	90.08 ± 7.05	204.83 ± 4.83
Pre-winter	32.16 ± 2.58	231.75 ± 9.20	973.03 ± 66.41	579.58 ± 27.60	87.41 ± 3.86	236.16 ± 7.50

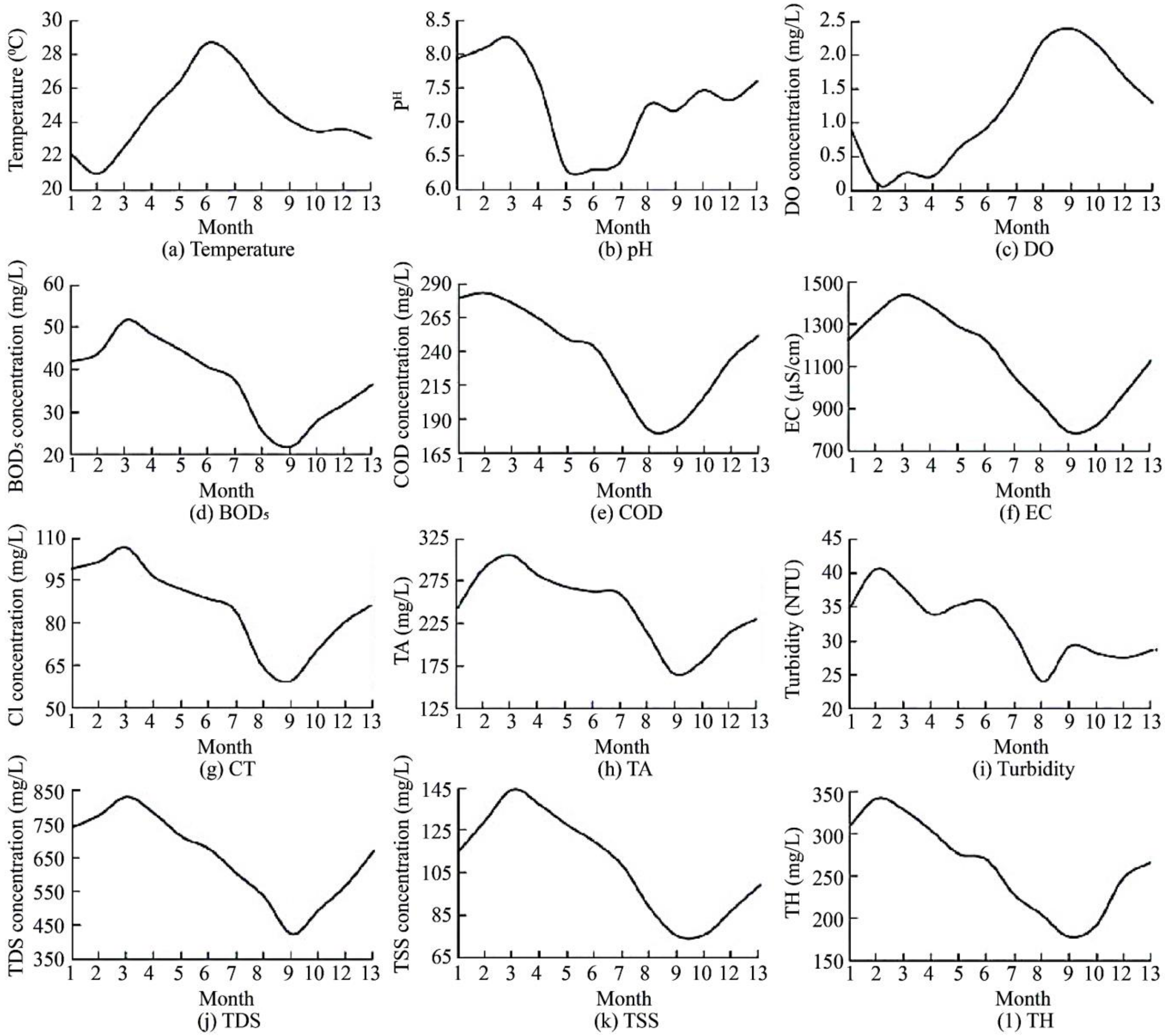
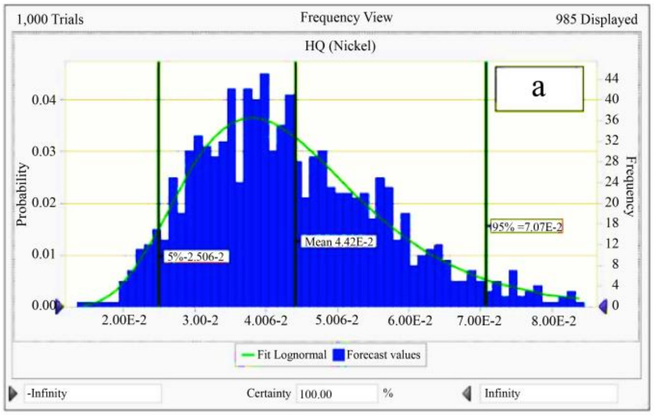


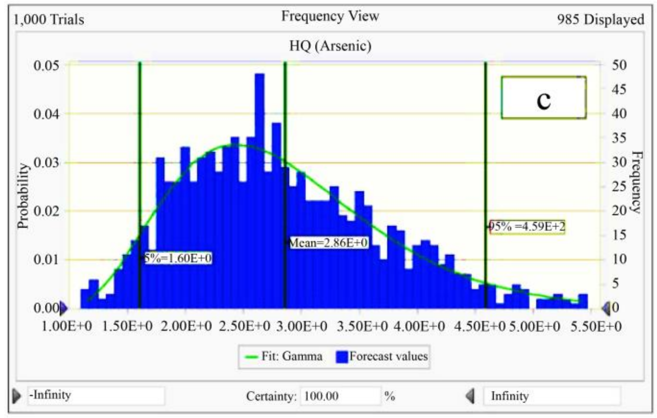
Fig. 4 Physico-chemical parameters values (Rahman, Jahanara and Jolly, 2021, p. 142)

Olasoji et al., 2019 investigated the quality of 12 different resources of water and 2 processed water in Nigeria's Southwest for household usage and drinking purposes. During the dry season, 28 samples were collected from Ground Water (GW) and Surface Water (SW) sources in and around the research region. The researchers used "Flame Atomic Absorption Spectrophotometer (FAAS)" to determine the concentrations of the parameters temperature, total alkalinity, pH, CO2 and chloride content, acidity and heavy metals. Based on the results, the measured physico-chemical parameters of water fulfilled the required standards. However, Faecal Coliform Bacteria were found in all of the samples. The researchers concluded that all water resources are polluted and cannot be utilised based on the quality analysis done.

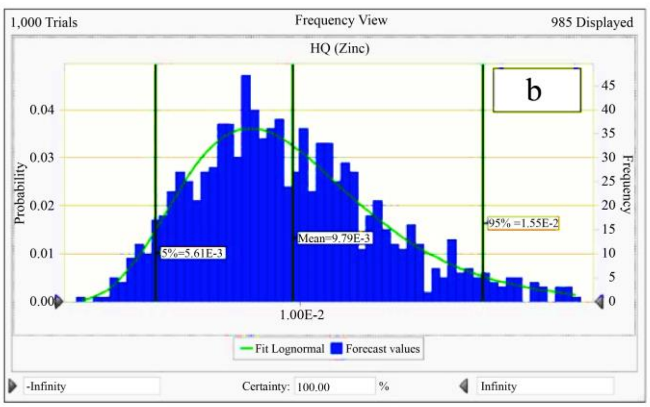
Son et al., 2020 analysed the quality of water in the Cau River by using a combination of the "Water Quality Index (WQI)" and "Pollution Index (PI)". The researchers selected 22 points in the river for collecting the water samples. The samples' physico-chemical parameters were measured using a spectrophotometer, and the heavy metals were measured by using "Atomic Absorption Spectrophotometer (AAS)". Then, the WQI and PI were applied to evaluate the pollution level in these samples. According to the results, WQI shows that the river is at pollution level 3 (suitable for irrigation), while PI shows that the river is severely polluted. The researchers concluded that the pollution level of the river varies due to seasonal and geographical factors based on the quality analysis done.



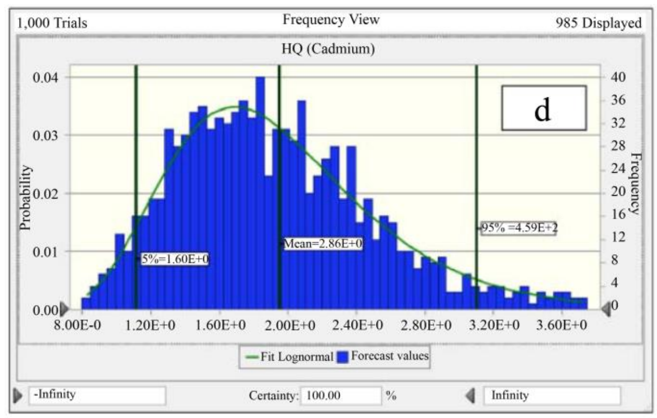
(a)



(c)



(b)



(d)

Fig. 5 HQ Index for Ni (a) & Zn (b) As (c) & (d) Cd (Malakootian, Mohammadi and Faraji, 2020, p. 6)

Our previous study, discussed the importance of boat automation in their review paper. Since the proposed system is an autonomous Remote-control boat, careful construction of the boat is required to collect the data and transfer data, which is required by many modern communication tools. Our previous study discussed in their article related to the inclusion of modern technologies in boats, reliability in the boat movement, communication from the boat to the control room, etc.

3. Materials and Methods

The proposed new technique has two separate systems designed for the research work. The first system is the Smart Water Quality Monitoring (SWQM) system that contains three sensors, which are pH sensor (SKU SEN0161), turbidity sensor (SKU SEN0189) and temperature sensor (DS18B20) as well as a GPS module (NEO-6M).

For data processing, a microcontroller (MCU) will be used, which is "ESP32 Sim800L", which has a built-in sim card module for the purpose of transferring data to the Blynk server in which data are displayed through the mobile application. The second system is the boat movement system, which contains DC motors (x2), a motor driver, Arduino Uno and a Bluetooth module where the boat's movement will be controlled through another mobile application.

4. Smart Water Quality Monitoring (SWQM) System

As shown in Figure 6, the sensors of pH, turbidity and temperature, as well as the GPS module, are integrated with the ESP32 Sim800L, which processes the data and transfers it to the "Blynk" server through its own built-in sim card module by which the end user can monitor the water quality and GPS locations through Blynk mobile app.

Fig. 6 SWQM system block diagram

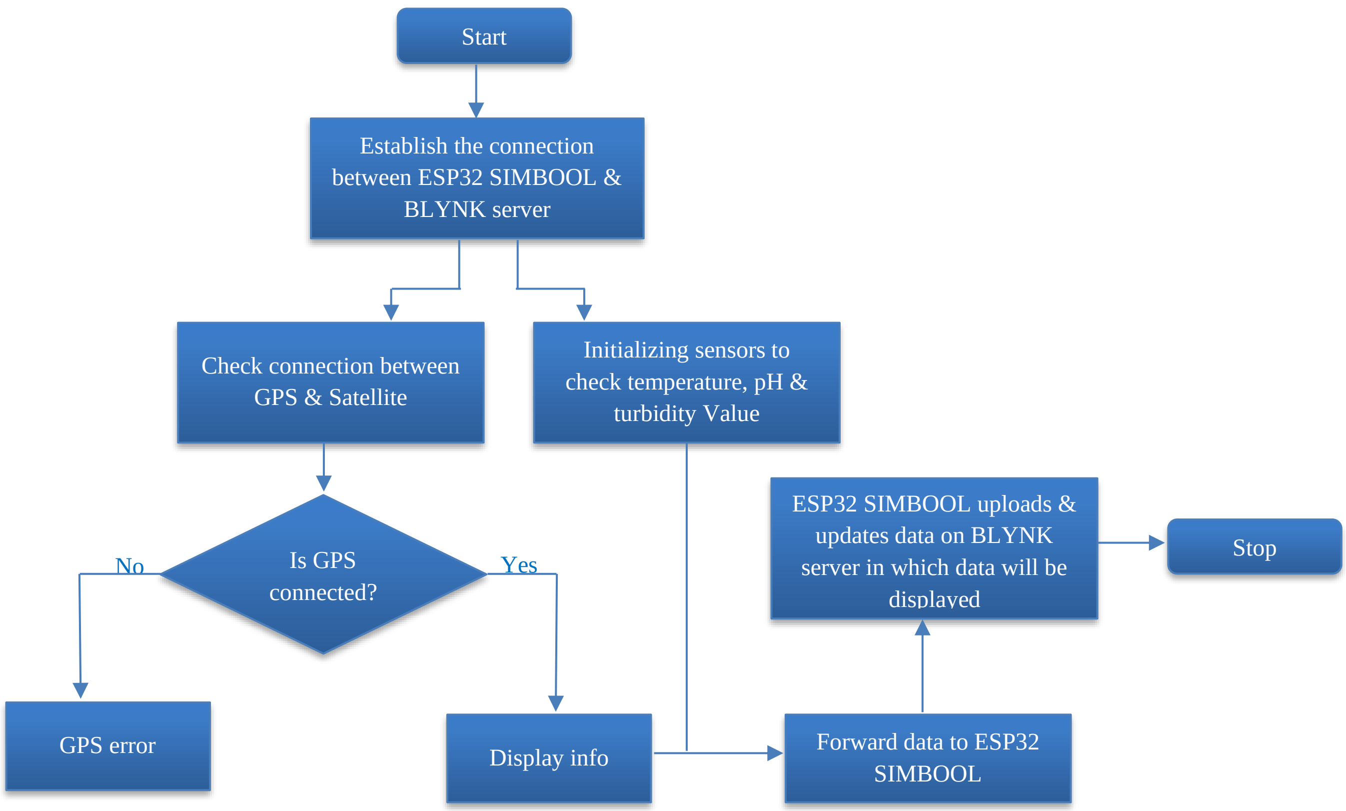


Fig. 7 SWQM system flowchart

The flowchart shown in Figure 7 above illustrates the working principles and processes of the SWQM system. The connection to the Blynk server will be established when the system is started. After that, two processes will occur at the same time. The first process is connecting the GPS to the satellite; if the GPS is connected, an order is given, "Display Info", to allow the GPS to read the latitude and longitude information; otherwise, there will be an error. The second process is initialising the sensors to measure pH, turbidity and temperature. The data from the sensors and GPS module will be directed to the ESP board, which will upload the data to the Blynk server. The circuit design for SWQM is given in Figure 8.

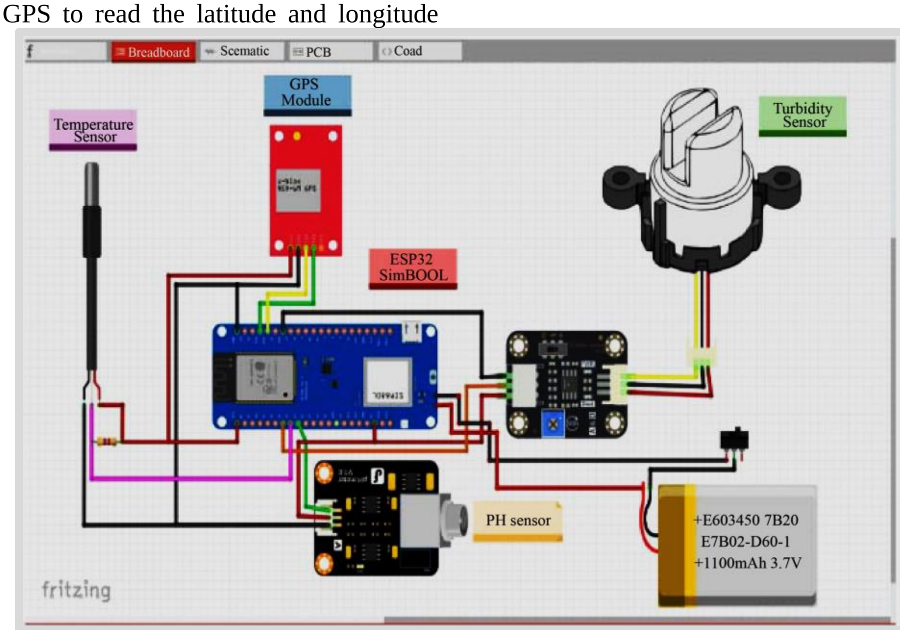


Fig. 8 Circuit connections of SWQM system

Fig. 9 Boat movement system block diagram

5. Boat Movement System

The microcontroller "Arduino Uno" is integrated with a Bluetooth module, and the motor driver is connected to the 2 DC motors. Android phone is to be connected to the Bluetooth module by which the movement will be controlled through the "Bluetooth RC" android application.

The Bluetooth module delivers the received signals to Arduino Uno, which forwards the orders to the motor driver, which will run the motors based on the given orders. The block diagram of the boat movement system is shown in Figure 9.

The flowchart in Figure 10 illustrates the working principle and processes of the boat movement system. When the system is started, the connection between the Bluetooth module and the mobile phone will be established. After that, a condition is provided to check whether Bluetooth is connected. If it is connected, the signals from the phone by the "Bluetooth RC" application are sent and received by the Bluetooth module, which will transfer it to the Arduino Uno, which will forward the signal to the motor driver and operate the two motors according to the required direction as applied through the application. Otherwise, the first process will be repeated if the Bluetooth module is disconnected from the phone. Figure 11 shows the connections between the components of the water movement system. The pins of the motor driver N1, N2, N3 and N4 are connected to the pins of the Arduino Uno, which are numbers 9, 10, 11 and 12, respectively. The Bluetooth module is connected to the Arduino Uno through two pins which, 0 for TX and 1 for RX.

6. Implementation

The connection of the sensors to the ESP32 Sim800L board was made based on the signal provided by each sensor, whether analog or digital. For the pH sensor and turbidity sensor, the obtained signal is in the analog form.

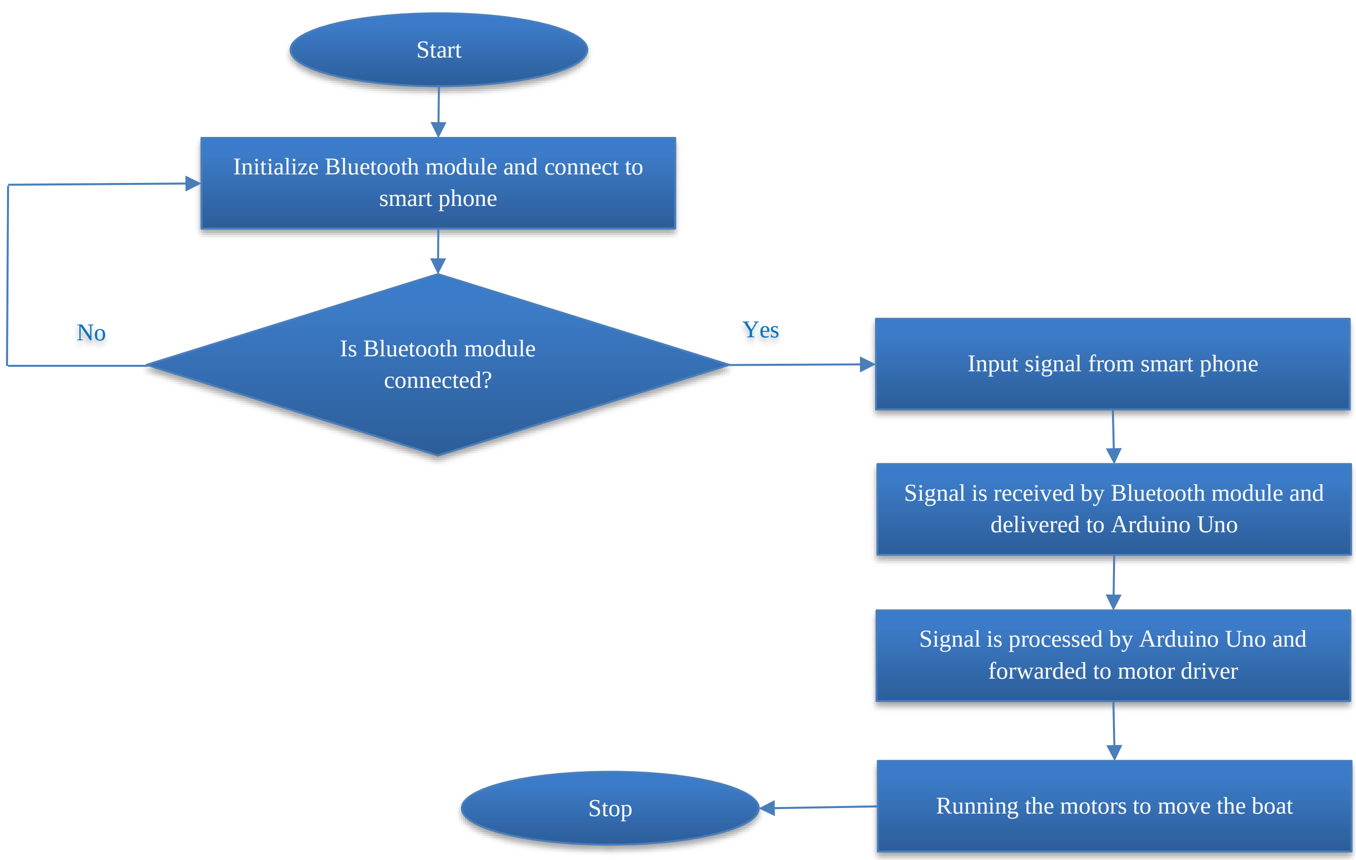


Fig. 10 Boat movement system flowchart

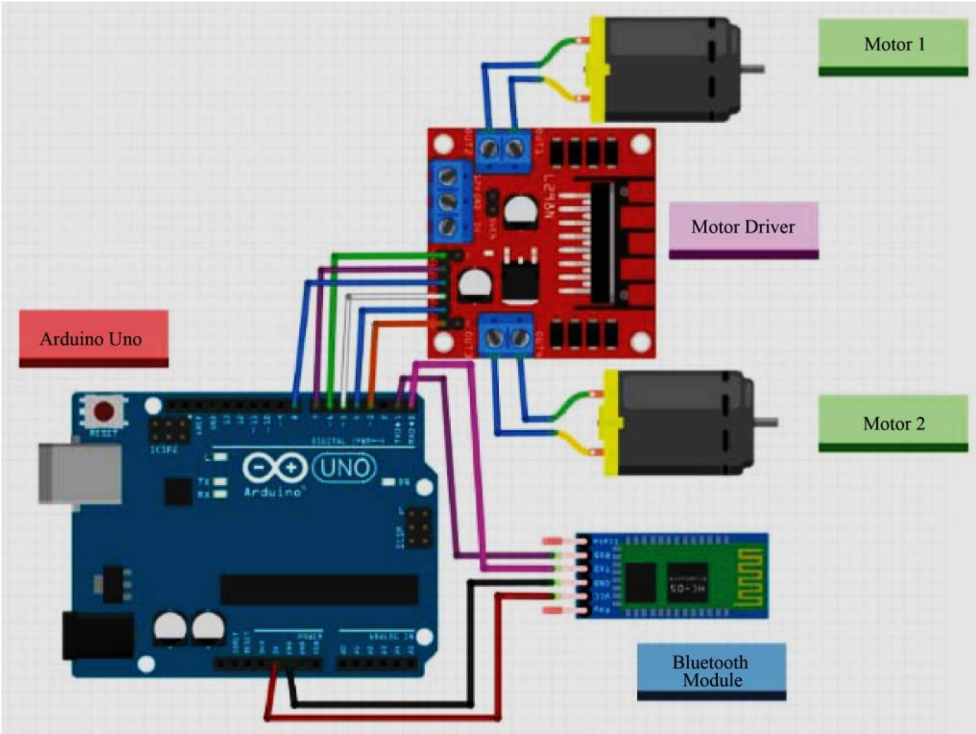


Fig. 11 Circuit connections of boat movement system

Therefore, they were connected to the analog pins of the ESP board, where the pH sensor is connected to pin number 25, and the turbidity sensor is connected to pin number 32.

For the temperature sensor, the obtained signal is digital (Digital Binary Output), and it is connected to the digital pin number 33 of the ESP board. The entire circuit is powered by 3.7V and fixed inside the covering case.

GPS module contains different ports for receiving (RX) and transmitting (TX) data through the serial protocol. Therefore, it was connected to two different digital pins in the ESP board, which are pin number 26 for RX and pin number 27 for TX. The integrated ceramic antenna is fixed outside the covering case where there are no objects which may disturb the antenna's connection to the satellite (directly facing the sky). The red LED blinks every second when the GPS module connects to the satellite.

The two DC motors are connected to the voltage output connectors of the motor driver, which controls the running process of the motors. The motor driver is connected to the Arduino Uno through its pins (N1, N2, N3 and N4), where N1 is connected to pin number 9, N2 to pin number 10, N3 to pin number 11 and N4 to pin number 12. The Bluetooth module is connected to the pin 0 for TX and 1 for RX. When the Bluetooth module receives the signal from the phone, it forwards the signal to Arduino Uno, which directs it to the motor driver. Finally, it operates the connected DC motors according to the given order. The installment of the motor, sensors and final RC boat model is given in Figures 12, 13 and 14.

The experimentation was carried out in a natural creek (called Khawr or Khor) on Al Hail beach of Sultanate of Oman, which experiences massive tourism and fishing activities and contains a fish market near the beach. All these activities contribute significantly to the increase of water pollution, which reduces water quality. Therefore, a number of three spots along the creek were selected for experimentation, which is "Spot 1", "Spot 2", and "Spot 3", as shown in the map of the study area in Figure 15. At each spot, the water quality was monitored using the RC boat and the physico-chemical parameters, which are pH level, turbidity and temperature, and the GPS location was monitored through the Blynk app. The obtained results are to be compared with the water quality standards as determined by the World Health Organization (WHO). Experimentation of RC Boat on the Creek is shown in Figure 16.

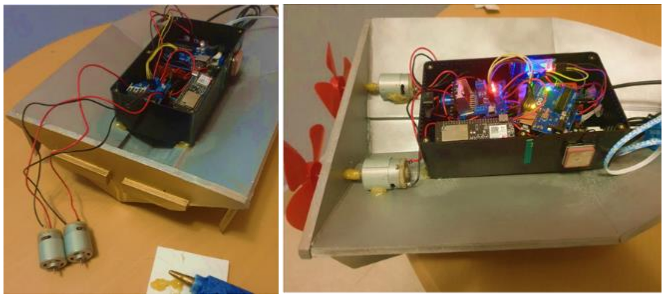


Fig. 12 Installment of the DC Motors & the two systems

Fig. 13 Instalment of the sensors in the front of the boat

Fig. 14 Final RC boat

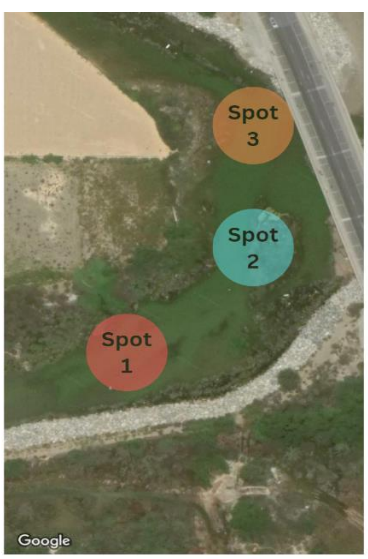


Fig. 15 Map of the study area

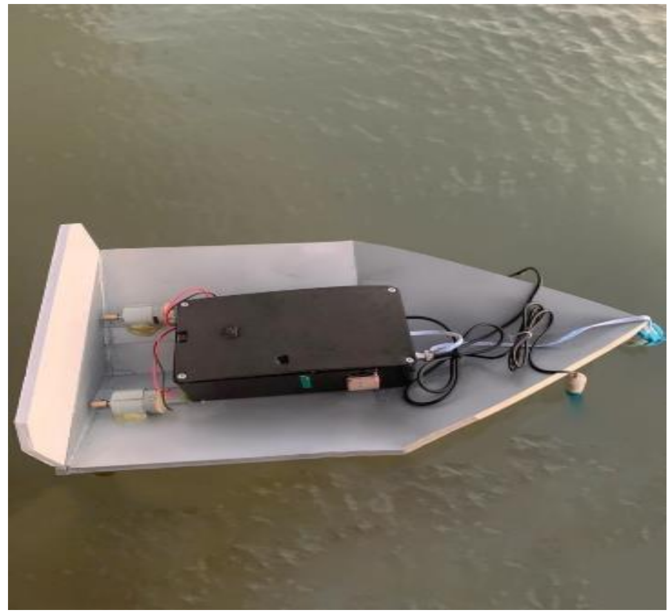


Fig. 16 Experimentation of RC Boat on the Creek

7. Results and Discussion

This section demonstrates the results obtained of water quality using the RC boat of the three different spots of the creek (or Khor).

Water Quality of Spot 1: The values of physico-chemical parameters displayed on the Blynk app are measured by the RC boat of spot 1 of the creek. This creek spot has a pH level of 7.91, turbidity value of 682.554 NTU and temperature of 27^{o}C. The obtained water quality data from the sensors is analysed and compared to the water quality standards determined by the World Health Organization (WHO) to determine whether the water is clean or polluted. Table 6 shows the quality standards of water streams. By referring to the water quality standards of the World Health Organization (WHO), the values of the physico-chemical are classified as water quality of "Spot 1" is poor.

Table 6. Water Quality Standards (World Health Organization, 2022)

Parameter	**Range**	**Remarks**
Temperature	20-30	Excellent
pH	6.5 – 8 * For Fresh Water	Excellent
	8-9 * For Sea Water	
Turbidity (NTU)	≤10 * For Fresh Water	Excellent
	15-30	Fair
	≥ 30	Poor

Table 7. Classification of the Parameters of Spot 2

Parameter	Value	Classification
pH Level	9.8	Above the Limit (Poor)
Turbidity (NTU)	2930.766	Extremely Turbid
Temperature (°C)	30	Good

Water Quality of Spot 2: Physico-chemical parameters displayed on the Blynk app as measured by the RC boat of spot 2 of the creek are considered to compare with WHO standards. This creek spot has a pH level of 9.8, turbidity value of 2930.766 NTU and temperature of 30oC. By referring to the water quality standards of the World Health Organization (WHO), the physico-chemical values are classified as shown in Table 7. Therefore, the water quality of "Spot 2" is extremely poor.

Water Quality of Spot 3: Spot 3 of the creek has a pH level of 9.45, turbidity value of 1035.687 NTU and temperature of 31oC. By referring to the water quality standards of the World Health Organization (WHO), the physico-chemical values are classified as shown in Table 8. Therefore, the water quality of "Spot 3" is very poor.

Table 8. Classification of the Parameters of Spot 3

Parameter	Value	Classification
pH Level	9.45	Above the Limit (Poor)
Turbidity (NTU)	1035.687	Highly Turbid
Temperature (°C)	31	Above the Limited

7.1. Variation of pH Level

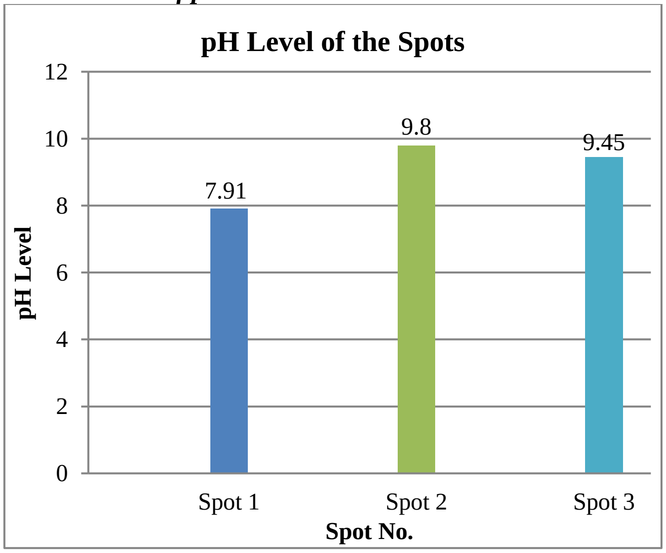


Fig. 17 Variation of pH Level

The graph in Figure 17 illustrates the variations in the value of pH level throughout the creek as divided into "Spot 1, Spot 2 and Spot 3".

All of the three spots had an alkaline value of pH level. "Spot 2" had the maximum pH level of 9.8, followed by "Spot 3" of 9.45, and both values are above the limit for seawater, and finally ", Spot 1" of 7.91, which is below the limit.

The high pH level in "Spot 2" and "Spot 3" might be due to the presence of different minerals, chemicals, pollutants and soil composition, which affect pH levels significantly.

$$Average\ pH\ Level = \frac{7.91 + 9.8 + 9.45}{3}$$

$$= 9.053\ (Above\ the\ Limit)$$

7.2. Variation of Turbidity Value

The graph in Figure 18 illustrates the variations in the turbidity value throughout the creek as divided into "Spot 1, Spot 2 and Spot 3.

"Spot 2" had the highest turbidity value of 2930.766 NTU, followed by "Spot 3" of 1035.687 NTU and finally "Spot 1" of 682.554 NTU.

The value of turbidity in the three spots is above the limit, and that might be due to the discharge of wastewater that increases the total suspended solids and also due to the presence of plankton and algae in the water.

$$Average\ Turbidity\ Value = \frac{682.554 + 2930.766 + 1035.687}{3}$$

$$= 1549.67\ NTU$$

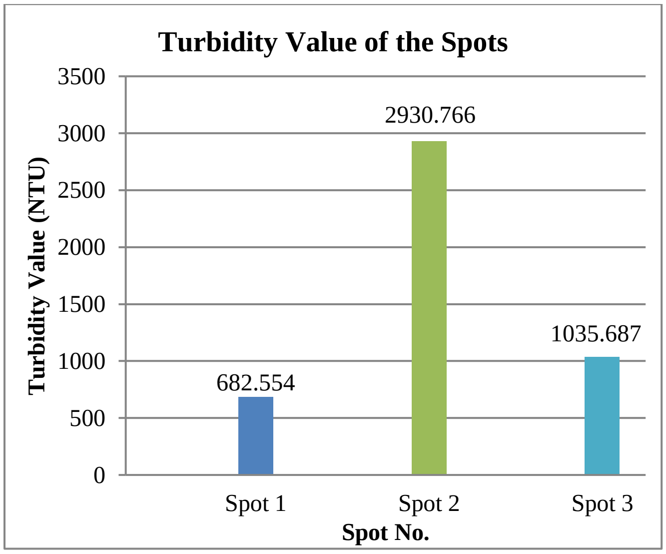


Fig. 18 Variation of turbidity value

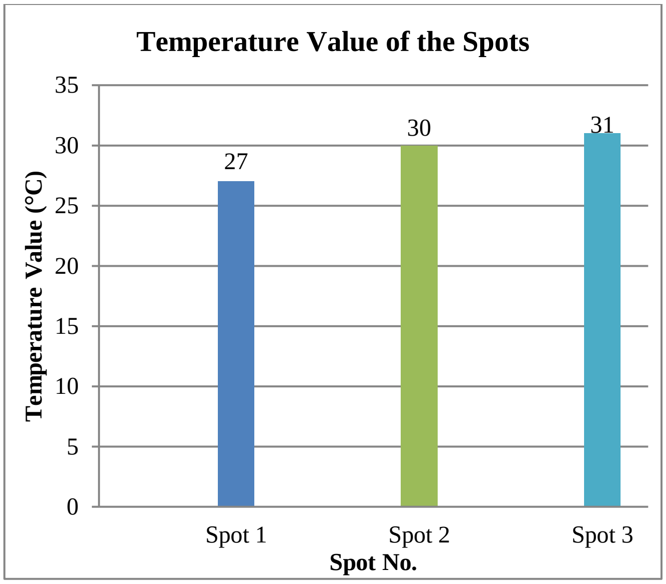


Fig. 19 Variation of temperature value

7.3. Variation of Temperature Value

The graph in Figure 19 illustrates the variations in the temperature value throughout the creek as divided into "Spot 1, Spot 2 and Spot 3. "Spot 3" had the highest temperature value of 31^{o}C, followed by "Spot 2" of 30 ^{o} C and finally "Spot 1" of 27 ^{o} C. This variation in temperature between the three spots is due to the variation of physical properties of water and solar variation, as each spot is subjected to different amounts of solar radiation and has different physical properties of water.

$$Average\ Turbidity\ Value = \frac{27 + 30 + 31}{3} = 29.33$$

8. Conclusion

In conclusion, an overview of the water pollution topic was discussed, and a genuine solution was proposed, which is the smart water quality monitoring technique using "RC Boat". The proposed research will continuously monitor water reservoirs to determine the physico-chemical parameters such as pH, temperature and turbidity, which affect water quality. Therefore, this work can provide real-time monitoring of water for the end user by using IOT (Internet of Things) technology by which the data is automatically transferred to the control room with the GPS locations of the water body. As compared to traditional monitoring, the RC boat represents an easier solution for water quality monitoring to determine polluted spots of water body, which is considered a serious threat to public health and business as it contributes to the spread of dangerous diseases that kills millions of people and destroys the aquatic ecosystem. Therefore, a comprehensive review was made of different research to reach such a cost-effective, accurate and functional method to monitor water pollution. The 3D design of the RC boat was provided with introducing the working principle of the smart water quality monitoring (SWQM) system and boat movement system that includes a GPS module and sensors of pH, temperature and turbidity as well as microcontrollers with the use of other tools, hardware and software to build the system with providing a detailed implementation and experimentations process done to the research work. The conducted experiment showed that there are variations in water quality in the three spots of the creek where water quality in "Spot 1" is determined as poor, "Spot 2" is determined as extremely poor and "Spot 3" is determined as very poor. Therefore, the overall water quality of the natural creek does not satisfy the water quality standards of the World Health Organization (WHO) since pH level and turbidity values are not in the acceptable range and the water is polluted. The RC boat represents a smart water quality monitoring strategy to detect and control water pollution problems in the world, while traditional water quality monitoring is regarded as challenging and might be inaccurate and not functional in large water bodies.

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References

[1] S.M. Abdulla, D.M. Jamil, and K.H.H. Aziz, "Investigation in Heavy Metal Contents of Drinking Water and Fish from Darbandikhan and Dokan Lakes in Sulaimaniyah Province - Iraqi Kurdistan Region," *IOP Conference Series: Earth and Environmental Science*, vol. 612, pp. 1-11, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[2] Mwesigye R. Abraham, and Tumwebaze B. Susan, "Water Contamination with Heavy Metals and Trace Elements from Kilembe Copper Mine and Tailing Sites in Western Uganda; Implications for Domestic Water Quality," *Chemosphere*, vol. 169, pp. 281-287, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[3] P. Vinoth Kumar et al., "Debris Monitoring and Clearance System Using IoT," *International Journal of Recent Engineering Science*, vol. 7, no. 2, pp. 36-41, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[4] Mohammad Salah Uddin Chowdury et al., "IoT Based Real-time River Water Quality Monitoring System," *Procedia Computer Science*, vol. 155, pp. 161-168, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[5] Thomas Dippong et al., "Assessment of Water Physicochemical Parameters in the Strimtori-Firiza Reservoir in Northwest Romania," *Water Environment Research*, vol. 90, no. 3, pp. 220-233, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[6] Jerry A. Nathanson, Water Pollution, Britannica, 2023. [Online] Available at: https://www.britannica.com/science/water-pollution

[7] Arun Kumar, "Physico-Chemical Attributes and Water Quality Index (WQI) Of Tropical River Systems," *Journal of Pollution Effects & Control*, vol. 10, no. 1, pp.1-5, 2022. [Publisher Link]

[8] Mohammad Malakootian, Amir Mohammadi, and Maryam Faraji, "Investigation of Physicochemical Parameters in Drinking Water Resources and Health Risk Assessment: a Case Study in NW Iran," *Environmental Earth Sciences*, vol. 79, no. 195, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[9] Monira Mukta et al., "IOT Based Smart Water Quality Monitoring System," *2019 IEEE 4th International Conference on Computer and Communication Systems (ICCCS)*, pp. 669-673, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[10] Mohamed Abdirahman Addow, and Abdukadir Dahir Jimale, "IoT-Based Real-Time Water Quality Monitoring for Sustainable Water Management: A Case Study in Somalia," *SSRG International Journal of Electrical and Electronics Engineering*, vol. 10, no. 8, pp. 170-175, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[11] Samuel O. Olasoji et al., "Water Quality Assessment of Surface and Groundwater Sources Using a Water Quality Index Method: A Case Study of a Peri-Urban Town in Southwest, Nigeria," *Environments*, vol. 6, no. 2, pp. 1-11, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[12] Arafat Rahman, Ishrat Jahanara, and Yeasmin Nahar, "Jolly Assessment of Physicochemical Properties of Water and Their Seasonal Variation in an Urban River in Bangladesh," *Water Science and Engineering*, vol. 14, no. 2, pp. 139-148, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[13] Sathish Pasika, and Sai Teja Gandla, "Smart Water Quality Monitoring System with Cost-Effective Using IoT," *Heliyon*, vol. 6, no. 7, pp. 1-9, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[14] Cao Truong Son et al., "Assessment of Cau River Water Quality Assessment Using a Combination of Water Quality and Pollution Indices," *Journal of Water Supply: Research and Technology-Aqua*, vol. 69, no. 2, pp. 160-172, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[15] Perdana Ixbal Spanton, and Abdul Aziz Saputra, "Analysis of Sea Water Pollution in Coastal Marine District Tuban to the Quality Standards of Sea Water with Using Storet Method," *Indonesian Journal of Marine Science and Technology*, vol. 10, no. 1, pp. 103-110, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[16] World Health Organization, Water-Sanitation, and Health, 2022. [Online]. Available: https://www.who.int/teams/environment-climate-change-and-health/water-sanitation-and-health/water-safety-and-quality/drinking-water-quality-guidelines