




A Review of Portable Water Quality Measurement System Using Arduino Sensor

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Article Info	Abstract
Received 28/03/2024	Monitoring water quality is essential for identifying current issues and changes in water sources over time. Conventional water quality monitoring methods still rely on collecting on-site samples for later examination in environmental labs. The development of open-source, inexpensive hardware based on the Arduino platform has enabled the creation of low-cost, portable, and site-specific measurement platforms. As a result, the project's objective is to develop a biosensor device (BSD) using an Arduino Uno and sensors. Turbidity, pH, Temperature, and Electrical Conductivity are the sensors that have been interfaced with it. They are all electrically linked to the mother Arduino drum, and each sensor has been programmed to display its measured values. Following the individual calibration of each sensor, we ensured that the sensor data were consistent with one another. Water contaminated with <i>Escherichia coli</i> was diluted to ensure the device's precision. Furthermore, tap water, distilled water, and Aquafina water were compared to the standard records for each type. The correlation between the results suggests that the device measurements were precise.
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1. Introduction

Given that water is essential for life, its protection is both ethically and legally justified. Due to industrialization, rapid development, rising living standards, and reliance on irrigated agriculture, demand for freshwater has dramatically increased, particularly for swimming pools and opulent spas [1].

Contaminants, including organophosphate herbicides, basicity, pathogenic bacteria, acidity, heavy metals, and pathogenic wastewater, may release diverse environmental contaminants such as *Escherichia coli*. Alongside its diminishing quantity, freshwater is increasingly scarce globally due to its poor quality. Consequently, several countries have prioritized preventing the discharge of harmful effluents into the environment. [2], [3]. Given that waterborne diseases pose a significant public health threat, water treatment is a universal objective. The WHO (World Health Organization) has prioritized the provision of safe drinking water systems globally owing to the significant health risks posed by waterborne illnesses.

In the United States, almost 76 million instances of waterborne diseases are documented annually [4]. In Bangladesh,

waterborne poisoning accounts for one in five deaths in the country [5]. To properly repair freshwater resources, it is essential to detect potential threats to public health and safety and prevent the spread of waterborne illnesses by first assessing the water's physicochemical characteristics and pollutants, whether biological or chemical [2], [6].

Diverse analytical techniques, such as wet chemistry, electrochemistry, HPLC (high-performance liquid chromatography), GC-MS (gas chromatography-mass spectrometry), and gas chromatography, may be used to evaluate water quality. Many of these techniques require expert operators, sample pretreatment, and are expensive and labor-intensive, but others (for example, GC and GC-MS) exhibit high sensitivity and precision. Furthermore, these methods are not suitable for applications that require quick results, such as monitoring in underdeveloped countries or remote areas that require an instant response. Assays that can quickly and easily screen for potentially harmful substances are essential for these applications. Furthermore, when it comes to swiftly identifying Internet water pollution, the methods discussed above are not up to the task.

Furthermore, although most *E. coli* strains are considered safe, specific serotypes have the potential to transmit lethal infections and result in fatalities. Consequently, it is imperative to identify *E. coli* as a fecal indicator bacterium [7]. Traditional incubation methods for detecting this indicator organism, however, require 18 to 72 hours to produce results [8].

Biosensors have been used in specific contexts due to their mobility, sensitivity, and potential for automation and online applications [2], [3]. Consequently, the volume of scholarly publications on biosensors has increased in recent years [9].

Acoustic transducers detect frequency variations, whereas optical transducers detect changes in absorbance, fluorescence intensity, and reflectance. Electrochemical transducers detect variations in the current or voltage. The human nose is an exceptionally sensitive and selective biosensor. The human nose, with its low detection thresholds, can qualitatively identify a diverse array of chemicals and provide a general assessment of their concentrations. Olfactory receptors in the nose detect odors. The olfactory nerve cells function as transducers, converting information from the olfactory membranes into electrical responses that are subsequently sent to the brain. In this context, the brain functions as a microprocessor, analyzing responses and transforming them into sensations or impressions.

This research aims to achieve the following objectives:

1. Developing a localized system for the safe detection of biological and chemical contaminants in water.
2. Inventing innovative modern methods with new ideas to investigate water pollutants. [Using the Arduino system].
3. To make well-informed decisions about the present and future of water quality management. Water quality tracking is used to identify current, continuing, and emerging issues to ensure conformance with drinking water standards and safeguard other valuable uses of water.

2. Background

The first biosensor was created by an American biochemist [10]. The Clark electrode, also known as the oxygen electrode, is the electrode in this biosensor that measures blood oxygen levels. After that, a gel containing an enzyme that oxidizes glucose was applied to the oxygen electrode to measure blood sugar. In line with this, the enzyme urease was used to measure urea in bodily fluids, including blood and urine, using an electrode designed explicitly for NH_4^{++} ions. The market offers biosensors from three different generations. In the first type of biosensor, the product's reaction spreads to the sensor, triggering an electrical response. In the second form, the sensor and the response work together, with the help of mediators, to improve response quality. In the third kind, there is no intervening intermediary between the response and the reaction. Natural water, process water used in the food industry during production, and wastewater before discharge into natural watercourses all require strict regulation to ensure their quality. Biosensors are a powerful alternative to conventional analytical

methods for this purpose. The objective is to supply safe water of the necessary quality regarding heavy metal contamination. The fundamental features of biosensors are their rapid response time, precision, high sensitivity, and low production cost.

3. Biosensor Definition

Biosensors can quantify levels of various harmful compounds (pesticides, heavy metals, and biological contaminants) in both food and water. Depending on the parameters necessary for tracking the contaminants, biosensors can be adapted to measure various analytes that affect water safety and quality [11], [12].

3.1. Working Principle of Biosensors

Signal transduction underlies the functionality of biosensors. Some examples include a bio transducer, a bio-recognition device, and a monitor, processor, and amplifier in an electrical system.

By acting as a bioreceptor, the bio-recognition component can establish communication with specific analytes. This interaction is measured by the transducer, which then produces a signal. The correlation between signal output intensity and analyte concentration is linear. The electrical system then processes and amplifies the signal.

3.2. Types of Biosensors

Biosensors could be classified according to the type of transmission they utilize:

- Resonant Biosensors – These devices use an acoustic wave transducer coupled with a bioreceptor. The relationship between the drug and the bioreceptor uses a shift in the bioreceptor mass. This assessment, along with the end users' interpretation of the resulting number, alters the acoustic transducer's oscillation frequency [13].
- Optical Detection Biosensors – These sensors consist of protein molecules bonded to a silicon wafer via covalent bonds. The antibodies become inactive on the wafer when it is exposed to UV radiation. Following wafer dicing and placement in the analyte, a diffusion grating forms, producing a signal that can be detected and amplified [14].
- Thermal Detection Biosensors – Temperature sensors are linked to the bound enzymes. The analyte's interaction with the enzyme kickstarts a heat reaction. A heat reaction test can be used to determine the amount of the substance present [15].
- Ion-sensitive Biosensors assume that ions alter the electric potential at a semiconductor surface, and this assumption must be valid. Potential modifications can be quantified, facilitating the evaluation of the necessary amount [16].
- Electrochemical Biosensors – These sensors rely on the fact that the presence of ions generated by different chemical reactions alters the electrical characteristics of the analyte solution. After this adjustment, the analyte concentration can be determined [17].

3.3. Advantages of Biosensors

The key benefits of biosensors include the following:

- High specificity.
- Quick and consistent determination.
- Minimal chemical consumption during testing.
- Capability to quantify non-polar molecules that conventional equipment is unable to assess.
- Quick response period.
- inexpensive.

A biosensor's performance is evaluated using several features. Following is a list of some of the crucial desirable characteristics:

Selectivity: Bio elements typically exhibit excellent analyte specificity, are durable under normal storage conditions, and are compatible with a variety of tests.

Precision, accuracy, reproducibility, and linearity are required for the signal to operate within the desired range [18].

Biocompatibility: Implantable sensors must function successfully in vivo and be biocompatible.

Biosensors should be strong and resilient. The biosensors currently on the market are short-lived and cannot withstand harsh environmental conditions [19].

Contamination: Ensure that no chemicals or biological materials seep from the equipment.

Size and cost: A biosensor must be reasonably priced, portable, easy to use, and usable without expert assistance. Additionally, effectiveness and environmental friendliness.

3.4. Applications of Biosensors

The principal function of a biosensor device, which integrates a biological element with a physicochemical detector, is to identify analytes. Biosensors can be used for a variety of purposes. These devices offer better sensitivity & stability than standard procedures, making them relevant in the medical, food, and maritime industries. These sensors have gained significant popularity recently and are helpful in the fields listed below.

3.5. Some of the Major Applications of Biosensors are Listed Below

- Common healthcare checking.
- Metabolites measurement.
- Screening for sickness.
- Insulin treatment.
- Clinical psychotherapy & diagnosis of disease.
- Agricultural and Veterinary applications [6], [20].
- Processing & monitoring in Industrial.
- Medical Diagnosis

- Drug improvement, offense detection.
- Diagnostic & Clinical.
- Ecological pollution control.
- Study & Interaction of Biomolecules.
- Industrial & Environmental Applications.
- Detection of Crime.
- Monitoring of Environmental Field.
- Development of Drug.
- Quality Control.
- Pharmaceutical Manufacturer & Organ Replacement.
- Process Control in Industries.
- Food analysis [21]-[26]

Over the last 30 years, biosensor technology has evolved from rudimentary, inexpensive components to the integration of multiple sensor systems into a single device that can detect various analytes, yielding a compact design more suitable for mass manufacturing. The objective of the microscale technology under development for the biosensor industry is to facilitate sample preparation, diagnosis, and processing on a singular chip

4. Arduino Uno

The open-source, free Arduino software is used to develop cathodic schemes. The Arduino platform combines a microcontroller with an application, or IDE (Integrated Development Environment), that runs on a monitor and is used to modify and synchronize computer code with the actual board. The Arduino program was developed in part by beginners in electronics.

The Arduino does not require an external programmer for code uploads; they can be done via a USB connection. The Arduino IDE utilizes a streamlined version of C++ to enhance learning and execution. Arduino offers a standardized form factor that classifies microcontroller activities into an expanded array of valuable features.

Table 1 presents a literature review of the Arduino Uno used in various water resources **applications**.

4.1. Design and Development:

The following aspects are essential for developing a fundamental prototype system designed for water quality monitoring:

- A variety of sensors to gather pertinent environmental data.
- A central microcontroller running software that can read analogue data and output it as digital data.
- A portable laptop with the software required to receive the digital data, present it on an intelligible screen, and power the microcontroller.

Table 1. The literature review of Arduino Uno used in various applications.

Application	Problem	Advantages	REF.
Common healthcare checks	PH value, Chlorine value, Turbidity	High specificity.	[27]
monitoring the Quality of drinking water	volume and quality monitoring of drinking water and various water-related diseases.	Fast response time	[28]
dams, farms, and every other possible water resources.	to check the pollution level in the water	user-friendly application and cost-effective system	[29]
Eliminate water wasting and energy loss in the residence.	recognize the water level	hassle-free model and provides optimal water consumption	[30]
Water levels in the well and tank	water quality, pH level, and Gas	An advanced intelligent system embedded with controllers and sensors	[31]
Monitoring, observation, and water contamination assessment	pH, temperature, turbidity, and dissolved oxygen	Fast, continuous measurement and Fast response time easier to access and more user-friendly for ordinary people, and more than that, the system operation will be easier	[32]
Quality of industrial wastewater monitoring	water level monitoring		[33]
water in the open-well or bore-well.	turbidity and electric conductivity monitoring	low-cost and efficient device	[34]
wastewater quality and characterization			

The Uno R3 Arduino board, depicted in Fig. 1, serves as the primary component of the monitoring system. It is an ATmega328-based microcontroller board with three key characteristics:

1. There are six analog input ports on the Arduino, designated A0 through A5, that allow for the direct connection of up to five analog sensors.
2. Two power sources, labeled 5 volts and 3.3 volts, with integrated voltage regulation, are used to energize the sensors.
3. A USB plug that is compatible with USB cables and can be used to connect to a microprocessor, as shown in Fig.1.

Connected the four sensors, which are (turbidity, temperature, Electric conductivity, and pH sensors), to the Arduino, and then programmed them into the computer to display the results directly and correctly in the computer Excel program.

4.1.1. Temperature sensor

A temperature sensor is an electrical device that quantifies ambient temperature and transforms this data into a digital representation; it is used as an instrument to record, track, or convey temperature changes.

Often, a thermocouple or resistance temperature indicator collects temperature data from a specific source and converts it into a form that a tool can understand. Additional uses for temperature instruments include environmental controls for HV and AC systems, food distribution, medical platforms, chemical handling, and automobiles under the heading of food-

monitoring and control systems. The thermometer, which measures the temperature of solids, liquids, and gases, is the most important and widely used type of temperature sensor, as shown in Fig. 2.



Figure 1. Arduino Uno board.



Figure 2. Temperature sensor.

4.1.2. Turbidity sensors

Devices used to evaluate a solution's turbidity or opacity, as well as the concentration of total dissolved or suspended particulates.

A turbidity sensor is an analytical device that measures the turbidity of liquids. They are practical and effective instruments for assessing the purity and particulate matter of solutions, including water. Turbidity sensors are used across several sectors to minimize waste, enhance production, and evaluate water quality. Turbidity sensors measure the amount of light scattered by suspended particles in a liquid, such as water. Turbidity escalates with the concentration of total dissolved solids (TDS) and total suspended solids (TSS) in a liquid.

The purity of water can be measured with the help of turbidity sensors, which measure a substance’s cloudiness or haziness (turbidity).

Samples with minimal concentrations of TSS and TDS benefit more from light diffusion. Alternatively, turbidity in samples with high TDS and TSS concentrations can be detected by observing a decrease in light intensity in the transmission stream. Turbidity sensors, as shown in Fig. 3, depend on light to measure turbidity; hence, it is essential to minimize ambient light when using them.



Figure 3. Turbidity sensor.

4.1.3. pH sensor

The conventional method of detecting water levels uses a pH sensor, a specialized and important piece of equipment. This instrument can determine the acidity and alkalinity of various liquids, including water. The standard pH scale ranges from 0 to 14. When the pH of a substance is 7 or above, it is comparable to that of freshwater. Anything with a pH value below 7 is considered more basic, whereas anything with a pH value over 7 is considered more alkaline. To determine the pH change, the voltage output of the anticipated process was compared with that of the known technique, and the power of the difference was used to calculate the pH. A similar approach is used to compute alkalinity, as illustrated in Fig. 4 and Fig. 5.



Figure 4. pH sensor.

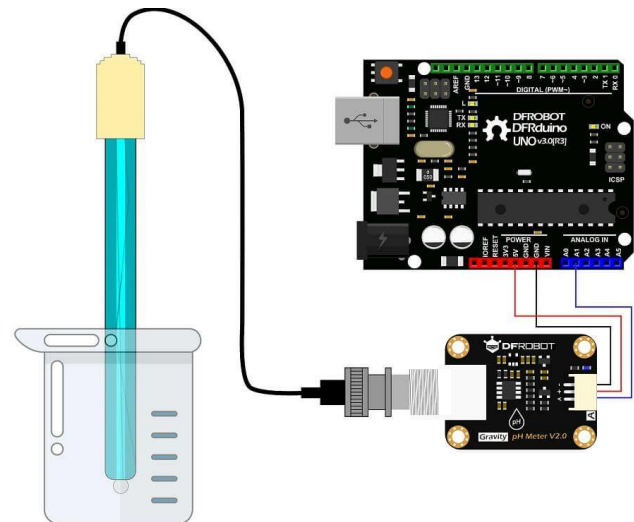


Figure 5. pH connected to Arduino.

4.1.4. Electric conductivity sensor

Electrical conductivity, or EC, is the capacity of a substance to carry an electric charge. Positively and negatively charged ions may be created during the dissolution of salts and other substances in water. Because these free ions in the water transmit electricity, the electrical conductivity of water is a function of the ion concentration. Salinity and total dissolved solids (TDS) are used to determine the EC of water, which helps assess its purity. As water purity increases, conductivity decreases. For instance, pure water is almost an insulator, while saltwater is a very effective electrical conductor.

The conductivity of water is primarily affected by positively charged ions such as calcium, potassium, sodium, and

magnesium. The most prevalent negatively charged ions are sulfate, carbonate, chloride, and bicarbonate. Although nitrates and phosphates only add a negligible quantity to conductivity, they are essential to all life forms. Rain, geology, and evaporation are the three primary natural effects on EC in water. Examples of human effects include road salt, leachate from septic systems and landfills, impermeable-surface runoff, and agricultural runoff, as presented in Fig. 6.

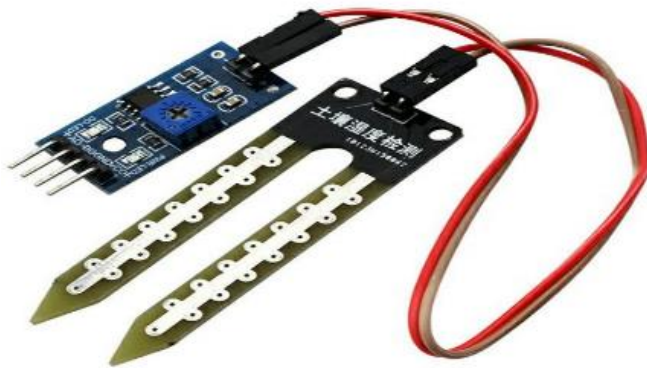


Figure 6. EC Sensor.

The following illustrates the interfacing of numerous sensors, actuators, and other devices with Arduino without requiring code, as shown in Fig. 7.

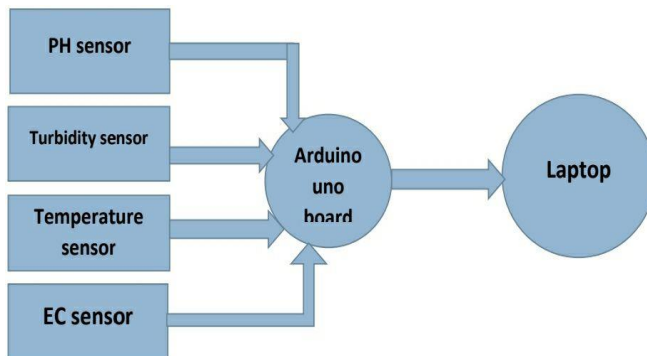


Figure 7. Interfacing various sensors with the Arduino Uno.

Carried out a series of procedures against E-Coli bacteria and also applied to the chemical component of water contaminants, so performed many operations to assure the accuracy of the device readings.

5. First part: Biological

In this review study about E.coli bacteria

5.1. E.Coli group of Bacteria

5.1.1. Description

The variety of bacteria that support dyspepsia and flourish in the intestines of people and warm-blooded animals includes Escherichia coli strains.

While the majority of E. coli bacteria are harmless to humans, some serotypes may induce serious sickness and may necessitate food recalls. The advantageous strains often present in the gut microbiome synthesize vitamin K2 and inhibit the colonization of the intestine by pathogenic bacteria. Escherichia coli disseminates throughout the environment via fecal matter. In fresh feces under aerobic conditions, the bacterium multiplies rapidly for the first three days, but the number of organisms it can support declines thereafter. [35].

Escherichia coli is a rod-shaped, facultatively anaerobic, Gram-negative, non-spore-forming member of the coliform group of bacteria that belongs to the family Enterobacteriaceae, as presented in Fig. 8.

It is this ability to produce the enzyme D-glucuronidase that makes them more detectable and identifiable [36]-[39]. The complete coliform technical guideline document provides more detail on the genus of organisms known as coliforms.

With the development of whole-genome sequences and the use of sophisticated molecular characterization techniques, the E. coli species' complexity has been better appreciated [40]-[42]. Genotypic alterations enable the classification of E. coli strains into several phylogenetic groups (A, B1, B2, C, D, E, F). The physical and biological attributes of strains across different populations differ, as do the fecal and environmental contexts in which they have been identified, as well as their tendency to induce illness [43]-[48]. Further study is required to elucidate the real consequences of these variances on drinking water microbiology and their implications for human health [7], [42].

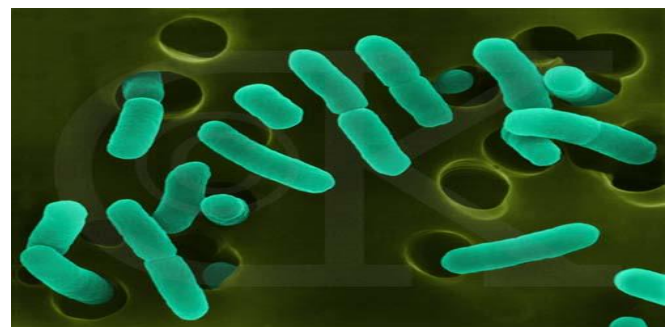


Figure 8. E.coli group [36].

5.1.2. Sources

In the large intestine of humans and other mammals that maintain body temperature, E. coli accounts for about 1% of the total biomass [49]. According to several studies [47], [49]-[51], human feces contain 10⁷ to 10⁹ E. coli cells per gram. Domestic animal feces typically contain between 10⁴ and 10⁹ cells per gram [47], [52]-[54], albeit this number can vary significantly. Although E. coli is a common member of the gut flora, certain strains of this bacterium can create digestive issues that can also result in more serious health problems, such as renal failure, hemolytic uremic syndrome, and hemorrhagic colitis.

Certain E. coli strains can also cause urinary tract infections. In both animal and human feces, non-pathogenic E. coli strain concentrations are higher than pathogenic strain concentrations [55]-[58]. Therefore, even during outbreaks, non-pathogenic E. coli will predominate during a fecal contamination episode

[59], [60]. Point sources, such as industrial effluents and waste, septic systems, leaky municipal sewers, and non-point or dispersed sources, such as discharge from rural, natural, and urban areas, are all potential contributors to fecal pollution in surface water and groundwater [46], [60]-[65].

5.2. Survival in Nature

Temperature, the types of microflora present, sunlight exposure, the type of water used, nutrient availability, and the presence of additional microflora all influence the survival duration of E. coli in various environments, including surface water, treated distribution water, and groundwater. [65]-[67]. Thus, predicting the behavior of E. coli populations in complex environments presents considerable difficulties [66]-[68]. In natural surface waters at temperatures ranging from 14 to 20 °C, E. coli typically survives for 1 to 10 weeks [69]-[74]. Research indicates that at 10 °C, E. coli may persist in groundwater for 3 to 14 weeks [70], [75]. Research on the persistence of E. coli in aquatic environments has shown that both non-pathogenic strains and the highly pathogenic E. coli O157:H7 have comparable survival rates in groundwater and surface waters [76]-[83].

E. coli can reach a state known as viable but nonculturable (VBNC) under the pressures of the aquatic environment. In this form, they remain alive and can be revived when the right conditions arise, but they cannot grow on lab media [84]. Numerous bacteria have been found to use the VBNC state as their primary means of survival [85], [86]. A deeper understanding of the VBNC condition in drinking-water-related bacteria is required [86].

5.3. Culture Growth in Laboratory

E. coli grows best around 37 °C (98.6 °F); however, some lab strains can grow at temperatures as high as 49 °C (120 °F). Lysogeny broth or any medium containing glucose, ammonium phosphate monobasic, sodium chloride, magnesium sulfate, potassium phosphate dibasic, and water are examples of defined laboratory media in which E. coli can grow. Aerobic or anaerobic respiration can support growth using a wide range of redox reactions, such as the oxidation of formic acid and hydrogen, the oxidation of pyruvic acid and amino acids, and the reduction of substrates like oxygen, hydrogen, nitrate, and trimethylamine N-oxide.

6. Second Part: Chemical

The section on chemical constituents indicates that zinc and copper were used individually, and distilled water was tainted with these metals. A series of dilutions was prepared in water for each sample, followed by electrical conductivity measurements to verify the accuracy of the sensor readings and assess its efficacy and reaction time. Research indicates that when pure water is contaminated with a single element, the results are accurate; however, if many organic components are introduced into pure water, the sensor cannot discern the conductivity of each component individually and can only measure it collectively for all elements present. Consequently, development in this section was halted, and attention was

shifted to the biological pollutants segment, namely Escherichia coli, as shown in Figs. 9 and 10.



Figure 9. Copper dilutions.

7. Conclusion and Future Work

The water quality monitoring system has reached stability and can be used for real-time tracking, as evidenced by its parameters. The water recognition sensor monitors pH, turbidity, electrical conductivity, and water temperature, which are indirect indicators of biological contaminants, and can automatically display water quality. It is inexpensive, easier to monitor, and does not require any outside help. pH measurement is crucial for assessing the acidity or alkalinity of water, which is vital for ascertaining its appropriateness for many purposes. Turbidity measurements facilitate the detection of potential pollutants by providing insights into water quality and suspended particle levels.



Figure 10. Zn dilutions.

The oxidation-reduction potential (ORP) quantifies a substance's tendency to gain or lose electrons, reflecting its ability to participate in oxidation or reduction reactions. Temperature monitoring facilitates the evaluation of thermal fluctuations that affect aquatic ecosystems. Electrical conductivity tests provide insights into water salinity and mineral composition, enabling assessment of its suitability for specific applications,

The experimental system can be improved by adding sensors or other variables to measure additional parameters.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Zainab Sahel Muhsin proposed the research problem, developed the theory, and performed the computations.

Lubna Alzubaidi and Mohammed Ali Rasheed supervised the findings of this work.

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