Sensor System for Real-time Water Quality Monitoring

Elena Simonoska[*], Dijana Capeska Bogatinoska[*], Ile Dimitrievski[*], and Reza Malekian[**,***]
[*] University of Information Science and Technology "St. Paul the Apostle", Ohrid, N. Macedonia
[**] Department of Computer Science and Media Technology, Malmö University, Malmö, 205 06, Sweden
[***] Department of Electrical, Electronic and Computer Engineering, University of Pretoria, Pretoria, 0002, South Africa
elena.simonoska@cse.uist.edu.mk, dijana.c.bogatinoska@uist.edu.mk, ile.dimitrievski@uist.edu.mk, reza.malekian@ieee.org

Abstract **- Water pollution is a global issue that has an impact on the entire ecosystems' life cycles. Traditional sampling and laboratory testing techniques are labor-intensive and error-prone, making them ineffective for quickly detecting changes in water quality. This paper presents the development of a low-cost, portable and efficient prototype sensor-based system for monitoring water quality in real-time. The system consists of a microcontroller, temperature, turbidity, pH, and distance sensors, and an application for a visual representation of the data. Extensive testing was carried out to ensure uninterrupted operation. The prototype is a user-friendly sensor system that can be positioned close to the target area in order to assist in preventing environmental and biological harm. This can ensure safe, healthy, and sustainable water supplies for the communities, environment, and the economy. Continuous monitoring of water parameters can also help avoid critical situations. The experimental results demonstrate a successful development of a smart water quality monitoring system with potential applications in various scenarios.**

Keywords - Internet of Things; sensor system; water quality; water parameters; community services.

I. INTRODUCTION

Water is an essential resource for the survival of all living organisms and is vital for human. However, ensuring safe and clean water is a challenging task with the ever-increasing urbanization and the introduction of new solutions. The rapid pace of society has led to a deterioration in the quality of water, which has been affected by various factors, including sewage, industrial discharges, agricultural activities, and natural disasters such as floods and droughts. Regardless of the purpose of water usage, whether for drinking, domestic use, recreation or food production, it must be safe and readily available. Water is essential for public health, and it is crucial to establish and maintain a water quality balance. Otherwise, not only human health, but also the entire ecosystem can be severely damaged. Providing pure drinking water has become a major challenge worldwide, and many international governing bodies, such as the United Nations (UN) and the World Health Organization (WHO), are involved in efforts to ensure safe water everywhere in the world. In 2010, the UN General Assembly adopted a resolution stating that access to safe and clean water is a human right and is essential for full enjoyment of life [1]. The UN also highlighted five reasons for clean water to help communities to thrive, which include sustainable development, socio-economic development, energy and food production, health and survival, and healthy ecosystems [2]. The consequences of water pollution are numerous, and include reducing biodiversity, scarcity of drinkable water, diseases, mortality, destruction of animal and plant habitats, and acid rain [3].

Methods for monitoring quality of water in real-time [4] can ensure safe, healthy, and sustainable water supplies for the communities, environment and the economy. Additionally, monitoring water parameters in a watershed, rivers or lakes demonstrates how numerous natural and anthropogenic stressors may have an effect on quality of water [4].

Traditionally, water quality has been assessed by collecting water samples and testing in a laboratory. However, there is a need for a low-cost and quick solution to monitor water quality because real-time results are required. Our research work focuses on the development of an application for monitoring water quality by leveraging sensors that measure a range of water parameters and display them on the application. IoT solution increase the automation and reduce the impact of human errors in industrial applications. The obtained results are with increased reliability because testing is done at the spot and results are simultaneously delivered to user. The proposed system is versatile, as it can be adapted to various scenarios and use cases related to water quality. The application is available on both web and mobile platforms, and it provides users with the ability to track changes in water parameters in real-time. Furthermore, users can receive alerts when values are out of the range, view data in the form of charts, and constantly update values as they are received from the sensors. The proposed low-resources and low-time-consuming application will help people, especially those who require a cost-effective solution, to make informed decisions about water quality.

The rest of this paper is organized as follows. We summarize the literature review in section II. Section III discusses the proposed system, including the software and hardware requirements. The development of the system is detailed in Section IV, while testing and results are demonstrated in Section V. Next, we conclude the research work.

II. Literature Review – an Overview

The extensive literature review conducted in order to initially formulate a solution to the problem, as well as to decide on the most suitable methodology for designing the individual components of the proposed system, led to the utilization of the works developed in [3] and [5]. These works were used to gain an understanding of the impact of water on both the environment and living beings, with the WHO [5] providing numerous studies and figures to illustrate the effects of water pollution on human health. Several recent research works [6], [7], [8], and [9] consulted to gain an in-depth understanding of what water quality is and its parameters. Hassan Omer et al. [9] provided a summary of water classifications based on the values of its parameters. Furthermore, various research works were consulted to explain the hardware used in the proposed system. Research works in [10], [11], and [12] provided detailed information regarding the origin, operating capabilities, and development of models of the Raspberry Pi. The authors in [13], [14], and [15] provided details on the sensors, which form the core of the system, and their classification. Azzuni et al. [16] analysed various alternatives for measuring water quality, ultimately leading to the conclusion that the proposed system outperforms other solutions in several aspects. The first alternative is laboratory testing, which is inconvenient due to the need for sample transportation and is thus open to external factors which may affect the results. Additionally, it is a slow process as the procedure is not done on-site. The second option is remote sensing, with remote sensors attached to satellites or aircrafts to take images of water bodies at different wavelengths, allowing the detection of the presence of certain substances. This process is contactless and can only detect visible changes. The third option is less common and involves observing the behaviour of organisms in normal conditions, followed by controlled changes to observe how the organisms respond. However, the results may be unreliable as the organisms may be affected by other factors.

The manual nature of the aforementioned alternatives, which require human involvement, increases the likelihood of human error. This necessitates the development of a smart, automated system which can monitor water in real-time, thus increasing reliability as external factors are not present.

III. Proposed System

Our proposed system for smart and real-time water quality monitoring is an Internet of Things (IoT) solution which utilizes a Raspberry Pi microcontroller (MCU), four sensors, and additional hardware for the successful interconnection between them. This is further supported by a web application with unlimited access from a variety of devices.

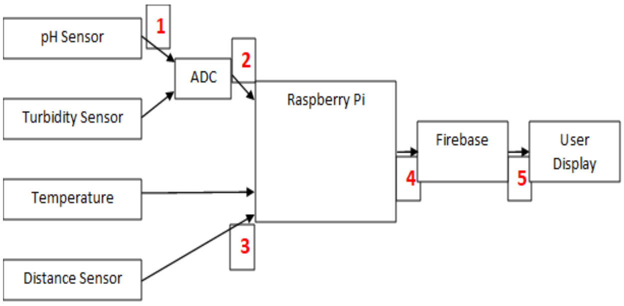

Figure 1. System's interfaces

The system has five types of connections, each with a distinct purpose and every one of which is necessary for the proper functioning of the system. The system's interfaces are given in Fig. 1.

The user can observe the measured data on their device, and the data is organized by the system, but must be taken from a database. The data in the database is retrieved from the MCU, which interacts with the sensors.

To ensure the successful functioning of the project, there are four categories of requirements that must be considered:

A. *Functional Requirements*

Functional requirement defines the actions that must be performed by the system to allow users to accomplish their tasks and utilize its capabilities. There are two ways to access the application; as an administrator and as a user.

B. *Non-Functional Requirements*

Non-functional requirements define the quality attributes of the system and describe how well the system should function. The attributes that are evaluated are: usability, accessibility, interoperability, learnability, portability, scalability, and security.

C. *Performance Requirements*

The performance requirement refers to the operating capabilities of the system in terms of accuracy, response time, and memory. The performance of the hardware and software components is essential for the proper functioning of the system and managing data correctly. This includes:

- Programming the sensors to read every 5 minutes.
- Updating the database with new data every 5 minutes.
- Refreshing the dashboard page every 1 minute.
- Comparing the measured values with reference values to classify the sample.
- Organizing the data into a table for better visual representation.
- Displaying the maximum, minimum value, their difference, and current value on the parameter page.

D. Hardware and Software Requirements

Hardware and software requirements include components that are necessary for the system to operate. These requirements are prerequisites for the system.

These components are described below:

A. Hardware Description

The main components of the project are the Raspberry Pi 4 Model B microcontroller and the sensors. The sensors are used to measure four characteristics of the water quality: pH, temperature, turbidity, and depth.

a) pH Sensor

This sensor is used to measure how acidic or basic the water is, ranging from zero to 14. All solutions with pH ranging from zero to 7 are classified as acidic, while samples between 8 to 14 are categorized as basic. Solution of pH 7 is considered as a neutral. Most water plants and animals require an environment of a specific pH, and water with a pH of 11 or higher causes irritation. The pH sensor used in this system has a measuring range from 0 to 14, a temperature range from 0 to 60°C, and a response time of $\leqslant$ 1 minute.

b) Temperature Sensor

This sensor is used to measure the temperature of the water. The reference value of drinking water is different from the temperature of a fishpond, for example, or the temperature of industrial water cannot be compared with the temperature of the lake. Temperature is important because it affects the status of the water, such as conductivity, chemical and biological reactions, maximum dissolved oxygen concentration, and pH. Temperature is also crucial for organisms in the ecosystem, as they have preferred regimes and cannot adjust to changes. The temperature sensor used in this system has a measuring range from -55 to 125° C and a response time of $\leqslant$ 750 ms.

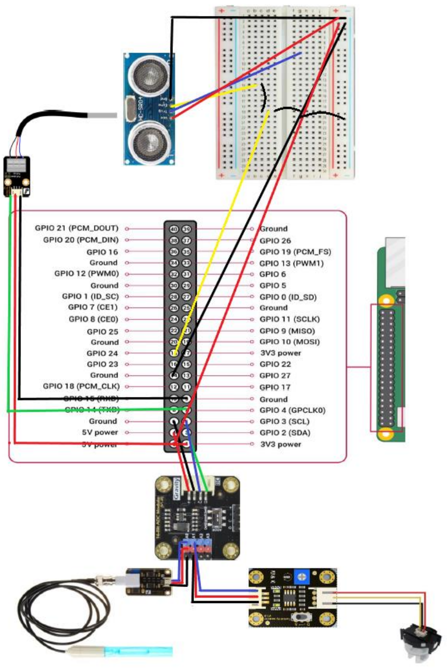

Figure 2. System schematic diagram

c) Turbidity Sensor

This sensor is used to measure the clarity of the water. Excess turbidity can cause illnesses, especially if the water is used for drinking. High turbidity water also affects the overall wellbeing of organisms living in the water. The turbidity sensor used in this system has an operating temperature of 5 to 90° C and a response time of $\leqslant$ 500 ms.

d) Distance Sensor

This sensor is used to measure the level of water in a closed system or in water surfaces such as rivers, lakes, seas, or oceans. Monitoring the water level is used to detect the absence of water in the system, or to check if the level is within permissible limits. The distance sensor used in this system has a measuring range from 0.3 m to 4 m, and a response time of ~ 32 ms. Two resistors, 1kΩ and 2kΩ, are added for connecting the distance sensor to the microcontroller. The value for second resistor is approximately 2kΩ but the system uses two 1kΩ resistors in serial connection.

The schematic diagram of the solution is given in Fig. 2.

B. Software Description

The whole application is divided into three parts: Raspberry Pi, Front-End, and Back-End.

a) Raspberry Pi

Operates on Linux and the Python scripting language is used for programming. The communication between the user and the Pi is done using the terminal, known as the command line interface. All hardware-related codes are written in scripts.

b) Front-End.

HTML, CSS, and JS are used for creating a user-friendly application.

c) Back-End.

PHP, specifically the Laravel PHP framework, is implemented for the back-end programming. The reason for choosing Laravel is that it provides all the features required to build a modern web application, including: routing, validation, caching, queues, file storage, and middleware. It also allows for easy communication with the database.

d) Database.

Two databases are used for the purposes of the project: MySQL and Firebase. Firebase is used for interacting with the sensors, and the data is displayed on the user dashboard through Laravel. The MySQL database is used for storing the registered users and posted news.

IV. DEVELOPMENT OF A SYSTEM

The proposed sensor system is designed to provide real-time water quality monitoring. This system comprises measuring instruments, communication between the microcontroller and database, and communication between the database and Laravel application. Fig. 3 illustrates the data delivery process to the user.

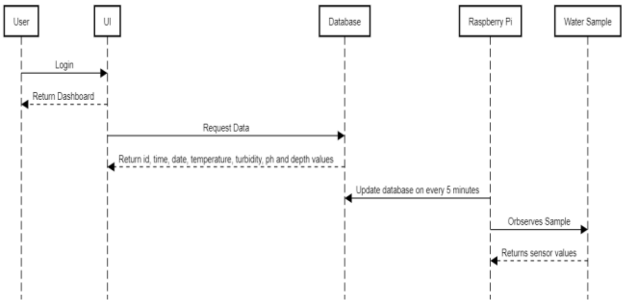

Figure 3. Sequence Flow Diagram

The starting point of this system is an application developed in Laravel, providing users with all relevant information related to the system. Any user, registered or not, can access the site and utilize the items in the navigation menu. Requests are made when the user performs an action, such as accessing a page, submitting a form, posting news, or updating news. Depending on the action, the route supports different methods.

Users of the system can access their dashboard, which provides a visual representation of the measured data. The data is retrieved from the database and organized in a table.

Users may be unregistered (visitors) or registered (admin and authenticated user). The application also provides constant support to its users, managed by the admin. The admin is responsible for ensuring that changes made to the system are reported to the users immediately. However, there is no limitation on what is published, and the admin can post any article that users may find useful and interesting. Furthermore, the admin has a mailbox for messages from users.

When the user logs in, they are redirected to the parameters dashboard. This page provides a menu for the user to choose from the parameters, and there are links to a full guide on using the system and relevant news. Fig. 4 shows the home page, which contains cards displaying the current values and notifications based on the parameter value, as well as a table with the measured data starting

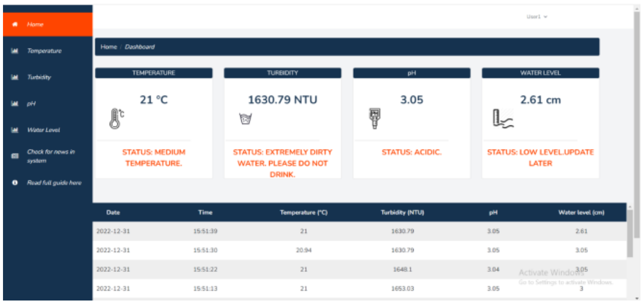

Figure 4. User Dashboard

from the latest added record. The data is organized in six columns: date, time, temperature, turbidity, pH, and depth.

The menu items and cards are clickable, directing the user to the desired parameter. Fig. 5 displays what appears after the temperature card or temperature sidebar item is clicked. There is also a message that shows the status of the particular parameter, the current temperature, minimum, maximum, and their difference. The same page with the corresponding parameter appears when clicking the rest of the items.

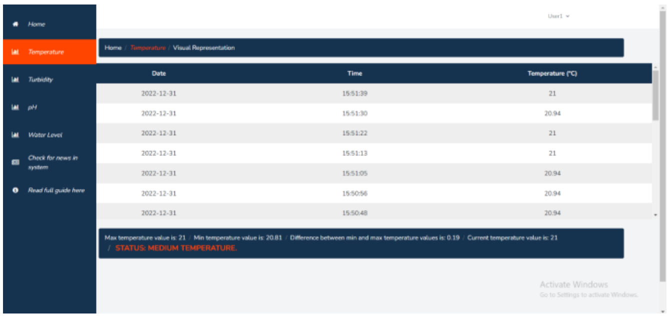

Figure 5. Temperature page

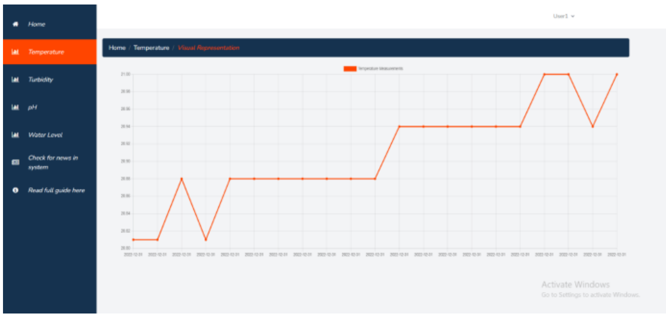

Figure 6. Temperature Graph

Proposed system is dependent on a constant current flow. The system can be adapted to work without constant flow by powering Raspberry Pi with batteries, power banks or other power sources. Moreover, it is an alternative which ensures stability in cases of defects.

The application provides graphs for a better visual representation of the measured parameters, available for

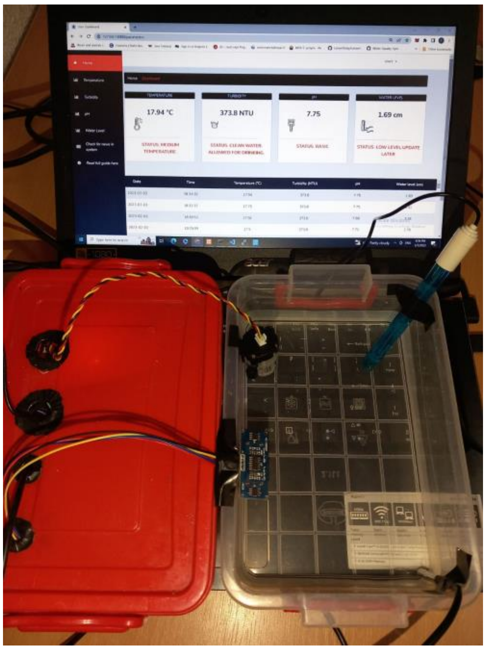

Figure 7. System prototype

all parameters. Fig. 6 shows an example of the temperature graph.

Every water source can be exposed to contamination due to agricultural, industrial, or domestic activities. Water can be harmed by heavy metals, pesticides, chemicals, oils, and other pollutants. The developed application determines the status of the water based on the values of the temperature, turbidity, pH, and level parameters using the classification given in [17], which are potable, palatable, contaminated, and infected.

Fig. 7 presents the system prototype, both the hardware and the software.

V. TESTING AND RESULTS

The development of the sensor system for real-time water quality monitoring necessitated extensive testing to adjust the formulas used to calculate the final values, as well as to determine the correct interval of measurement since the sensors had different response times. To assess the accuracy and reliability of the system, three phases of testing were conducted: unit testing, integration testing, and system testing. To validate the results obtained by each unit, different samples of water were used to ensure that the system works in different environments.

A. *Unit Testing*

Unit testing was the first step in evaluating the performance of each sensor. At this stage every unit is tested one by one to check accuracy and reliability of results. The unit testing phase validates that each unit of the software performs as designed.

a) pH Unit Testing

For assessing the correctness of the system measurements, the results were compared to the reference values of each sample. Fig. 8 presents examples of the samples used, while Table I shows the measurements obtained and their corresponding reference values [18]. At this stage, the value of each sample was tested and categorized as acidic, neutral, or basic depending on the measured value.

Figure 8. Liquid Samples

TABLE I. PH COMPARISION OF EXPECTED AND OBTAINED VALUES

Substance	***Vinegar***	***Wine***	***Rain***	***Milk***	***Pure Water***	***Baking Soda***
Expected Value	2.8	4	6.5	6.8	7	8.3
Expected Category	Acidic	Acidic	Acidic	Acidic	Neutral	Basic
System Value	2.76	4.09	6.38	6.69	7.24	8.19
System Category	Acidic	Acidic	Acidic	Acidic	Basic	Basic
Error Rate	1.42%	2.25%	1.88%	1.61%	2.25 %	1.32

b) Temperature Unit Testing

Two samples were used to evaluate the temperature readings. The results obtained by the sensors are displayed in Fig. 9.

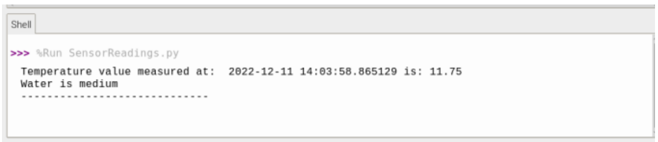

Figure 9. Temperature Sensor Readings

c) Turbidity Unit Testing

Three samples were used to test the turbidity sensor. Fig. 10 and Fig. 11 show the results for two of them.

Figure 10. Turbidity Sample 1

Figure 11. Turbidity Sample 2

TABLE II DISTANCE COMPARISION OF EXPECTED AND OBTAINED VALUES

	Measurement 1	***Measurement 2***
Expected Value	10.00 cm	4.00 cm
System Value	10.27 cm	3.98 cm
Error Rate	2.7%	0.5%

Note that turbidity sensor reacts on particles in water, not on water colour.

d) Water Level Unit Testing

To compare the measurements with the ruler and the sensor, two different distances were used and the results are summarized in Table II.

B. *Integration Testing*

This phase of testing was used to prove that all sensors worked together and were able to measure the water parameters accurately. Three samples were tested and the results are displayed in Figures 12 (Sample 1) and 13 (Sample 3). Sample 1 was clear water with a pH that was within the expected range and a turbidity that was expected to be between 0 and 1. Sample 2 was a mixture of milk and water, resulting in a reduction of the pH from 7.7 to 6.95, and an increase of turbidity due to the milk.

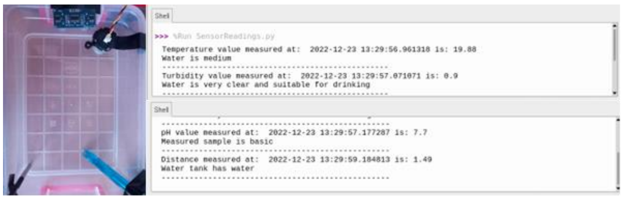

Figure 12. Integration Testing, Sample 1

Sample 3 was a mixture of water, milk, sand, and baking soda, which affected the pH of the previous solution from 6.95 to 9.01, and drastically increased the turbidity due to the sand.

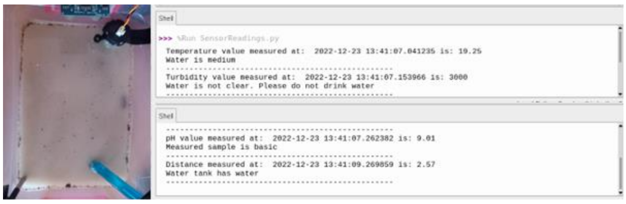

Figure 13. Integration Testing, Sample 2

C. System Testing

The aim of this phase of testing was to prove that the sensors, the communication with the database, and the Laravel application were all functioning properly. First, the parameters were measured, then sent to the database, and displayed on the user dashboard (Fig. 14). Fig. 15 demonstrates that the data inserted into the database was successfully retrieved on the dashboard. The table also starts with the most recent record, and the time, date, and

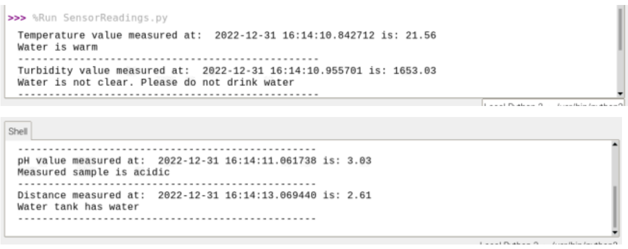

Figure 14. Parameter values obtained

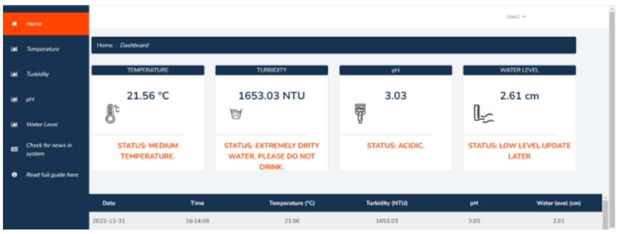

Figure 15. Parameter in dashboard

values all correspond to those in the Shell.

VI. CONLUSION

In conclusion, the proposed smart and real-time water quality monitoring system helps in detecting water parameters and issues in quality in early stages. It is an effective, robust and scalable platform which can be expanded with more sensors to ensure more precise insight into water quality and to address the growing demand for environmental monitoring and protection. The system can be used for a variety of purposes, with the potential to help protect the environment and living organisms. Through continuous monitoring of water parameters, harmful consequences can be avoided. This system has the potential to benefit many industries and organizations, such as healthcare, agriculture, industry, and ecological societies, and could greatly enhance our everyday lives. Additionally, the availability of both web and mobile versions makes it accessible to a wide range of users, providing them with direct insight into the results.

REFERENCES

[1] "UN General Assembly, The human right to water and sanitation: resolution adopted by the General Assembly", A/RES/64/292, 2010.[Online].Available: https://www.refworld.org/docid/4cc926b02.html. [Accessed: 19-Oct - 2022].

[2] "Why is Clean Water Important to Communities?", Healing Waters Media, 2021. [Online]. Available: https://healingwaters.org/why-do-communities-need-clean-water/#:~:text=Unsafe%20water%20causes%20water-borne,%2C%20and%20hygiene%20(WASH). [Accessed: 22- Oct - 2022].

[3] V. Lakshmikantha, A. Hiriyannagowda, A. Manjunath, A. Patted, J. Basavaiah, and A. A. Anthony, "IoT based smart water quality monitoring system", Global Transitions Proceedings, vol. 2, Issue 2, 2021, pp. 181-186, ISSN 2666-285X, https://doi.org/10.1016/j.gltp.2021.08.062.

[4] N. Cloete, R. Malekian, and L. Nair, "Design of Smart Sensors for Real-Time Water Quality Monitoring", IEEE Access, Vol. 4, pp. 3975 - 3990, 2016.

[5] World Health Organization (WHO), "Drinking water", 2022. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/drinking-water

[6] D. Dunea, "Water Quality: Factors and Impacts", Intechopen, 2022. DOI 10.5772/intechopen.96701. ISBN 978-1-83969-548-3

[7] S. Geetha, and S. Gouthami, "Internet of things enabled real time water quality monitoring system". Smart Water 2, 1, 2016. https://doi.org/10.1186/s40713-017-0005-y

[8] S. Pasika, and S. T. Gandla, "Smart water quality monitoring system with cost-effective using IoT". Heliyon, vol.6, issue7, E04096, 2020. DOI:https://doi.org/10.1016/j.heliyon.2020.e04096

[9] N. Hassan Omer, "Water Quality Parameters," Water Quality - Science, Assessments and Policy, Jul. 2020, doi: 10.5772/intechopen.89657.

[10] G. Halfacree, "The Official Raspberry Pi Beginner's Guide (The Official Raspberry Pi Beginner's Guide: How to use your new computer)", Raspberry Pi Press; 4th edition, 2020.

[11] A.K. Dennis, "Raspberry pi computer architecture essentials: Explore raspberry pi's architecture through innovative and Fun Projects", Birmingham, UK: Packt Publishing, 2016.

[12] W. Gay, "Advanced Raspberry Pi: Raspbian Linux and GPIO Integration", Apress, 2nd edition. 2018.

[13] B. Charan Patel, G. R. Sinha, and N. Goel, "Introduction to sensors", Book chapter in book: Advances in Modern Sensors, 2020. DOI: 10.1088/978-0-7503-2707-7ch1

[14] J. Fraden, "Handbook of Modern Sensors: Physics, Designs, and Applications" (5th ed. 2016), Springer, 2015.

[15] D. Perlstein, "Classifying Different IoT Sensors & Their Uses – Axonize Types of IoT Sensors", Axonize, 2019.

[16] A. Azzuni, "Design, implementation, and evaluation of an online water quality monitoring system in Lake Saimaa, Finland", 2014. DOI: 10.13140/RG.2.1.3420.6561

[17] N. Hassan Omer, "Water Quality Parameters," Water Quality - Science, Assessments and Policy, Jul. 2020, doi: 10.5772/intechopen.8965

[18] Periodic Table of the Elements - pH. (n.d.). [Online]. Available: http://coolperiodictable.com/resources/acids-and-bases/pH-of-some-common-substances.php