The TAFU – BCS Award
2024-2025

Wireless-Sensor-Based Water Pollution Monitoring System - An Effective Way of Gathering Data to Aid Healthier Aquatic Ecosystems

Horizon
(Rachel Yang, Linh Le, Sophie Du, Samhitha Nadendla, Sophie Chow)

Executive Summary:

This report represents the Wireless-Sensing-Based Water Pollution Monitoring System aiming to provide real time measurements of the water quality in lakes and rivers. Exploiting the concept of Internet of Things (IoT) and open-source electronics Arduino platform, the system is built to automatically send reports and early warnings to authorities to take timely actions in preventing water pollution.

Introduction:

Many aquatic ecosystems, such as oceans, rivers, lakes, and even water bodies as small as local ponds, are home to tens of thousands of living organisms, from tiny microorganisms like algae or protozoa, to frogs, fish, ducks, and other larger marine animals. However, due to a 54% increase in number of sewage spills, as well as other pollutants such as agricultural runoff, industrial waste, and more, the English fish population has seen a tenfold rise in deaths over the past four years, with figures escalating from 26,690 to an alarming 216,135, as of 2023-2024 [1].

The Water Framework Directive and the Environment Agency are the two bodies in the UK playing key roles in monitoring and improving water quality [2]. While the Environment Agency has a crucial role to improve the UK's water quality, the questions here are whether the monitoring process is at expected level and how to measure the monitoring efforts from the Environment Agency. No clear or specific data has been found in order for us to have a complete picture of the overall water quality monitoring. The Environment Audit Committee's inquiry reveals different failures in the monitoring, governance and enforcement on water quality [3]. The reasons behind the lack of progress might be due to budget cuts, insufficiency of in-field work and political lobbying. Budget cuts have resulted in the shortage of staff taking water samples, analysing and assessing quality in laboratories and finally deprioritising in-field work, which directly affects the purpose of real-time monitoring for water quality. Such an alarming situation has stimulated us to find immediate solutions to tackle those problems.

In order to tackle the above mentioned problems, we propose a wireless-sensor-based water pollution monitoring system to test for harmful substances in the water that organisms live in. In addition, we will send a user-friendly report to local councils or environmentalists to show which harmful contaminants may be affecting an area or group of wildlife, and possible solutions that could be implemented to benefit these ecosystems. By putting this into action, we believe that it will reduce the pressure on the Environment Agency, promote the cooperation between local councils and the Environment Agency and increase the awareness of the importance of water quality control and methods to prevent water pollution within local communities.

Methodology:

In an effort to solve the mentioned problems above and improve sustainability, we have developed a relevant, sustainable, and innovative solution, taking inspiration from already existing water quality sensors and refining them to create a solution that combats a major problem in not only our local area, Barnet, but that can also be implemented on a global scale to help shape a more healthy and sustainable future for all animals in aquatic ecosystems.

We use Arduino, an open-source electronics platform, to build our water pollution monitoring system. Particularly adopting an Arduino board provides the ability to physically integrate different types of sensors required for our purpose. Many off-the-shelf Arduino boards are enabled with wireless communication technologies such as WiFi and low energy bluetooth. There are also possibilities to connect an Arduino board to the current mobile phone networks. Such wireless-connection capacity allows us to remotely monitor the sensors and collect required measurements of the sensors on the water quality. The programming language for Arduino is based on C/C++. Adopting Arduino for our project gives us ultimate support and resources from the open-source society.

We aim to develop low-cost prototypes of sensors to measure important parameters of water quality shown in Table 1. We then compared the data we gathered from testing to the World Health Organization (WHO) standard of clean water [Table 2], that defines typical values for ensuring good water quality. Recommendations will be sent to the authorities to make timely interventions if needed.

Table 1. Water quality factors, and the risks they pose to wildlife if imbalanced.

Parameter	**Risks posed to wildlife**
pH	- Acidic water can reduce the ability of corals to build their calcium carbonate skeletons, weakening aquatic ecosystems - Shellfish species have difficulty forming shells, potentially leading to increased mortality rates and decreased reproduction - Impaired respiratory systems and difficulty breathing, due to acidic water

	- Changes in pH can lead to nutrient imbalances, creating harmful algal blooms due to excessive nutrients
Turbidity	- Increased turbidity can limit the amount of light penetrating water, affecting the growth of aquatic plants and algae, reducing the amount of food and oxygen available for other animals - Particles in turbid water can clog the gills of fish and other aquatic organisms, impairing their breathing
Dissolved Oxygen (DO)	- Low levels of dissolved oxygen can lead to respiratory stress of fish, who rely on this to breathe through their gills - Larvae of fish and amphibians can fail to develop when lacking oxygen, causing a decrease in population due to insufficient reproduction rates - Species requiring higher levels of dissolved oxygen may die off, leading to loss of biodiversity
Total Dissolved Solids (TDS)	- Many fish and other species rely on specific water conditions for breeding - if TDS levels fluctuate due to pollution, breeding success can be impaired, leading to a decline in population - Higher TDS can increase the solubility and mobility of toxic metals and pollutants. For example, in areas with high TDS, substances such as lead, mercury, or arsenic is more likely to be consumed by organisms, leading to bioaccumulation and poisoning
Temperature	- Extreme cold or heat can cause aquatic/marine animals to require

	extra energy to maintain body temperature, potentially slowing down metabolism rates - reducing feeding, growth, and reproduction. Heat stress could also cause dehydration, exhaustion or heat stroke - Temperature increase could also impact dissolved oxygen levels, as warmer waters mean less solubility of dissolved oxygen, causing difficulty breathing in many species, particularly types of fish

Table 2. Water quality parameters with WHO standard of clean water.

Parameter	**WHO standard**	**Units**
pH	7–8.5	-
Turbidity	1–5	NTU
Dissolved Oxygen (DO)	5–6	mg/L
Total Dissolved Solids (TDS)	<=500	ppm
Temperature	15	°C

Note: rows highlighted in grey indicate the relevant data compared to the sensors we used in our prototype solution.

Development:

Concept:

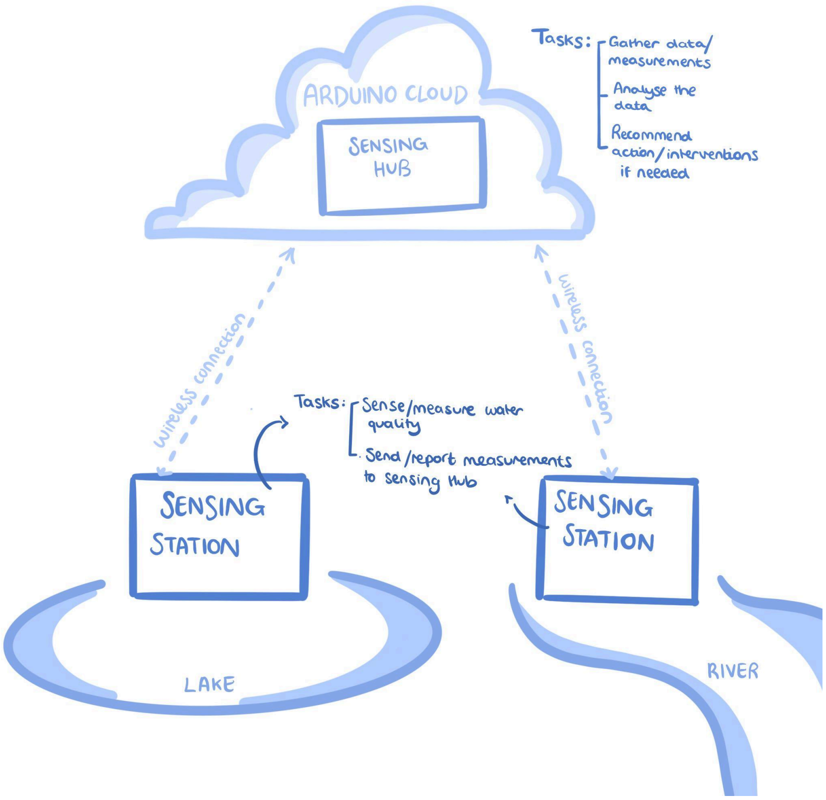

Figure 1: Wireless-sensor-based water pollution monitoring system

As shown in Figure 1, our proposed wireless-sensor-based water pollution monitoring system comprises two main components: a sensing station and a sensing hub.

The sensing station is built from an Arduino board equipped with the pH, turbidity, dissolved oxygen (DO), total dissolved solids (TDS) and temperature sensors. The sensing station periodically takes samples of the water and reports the obtained measurements to the sensing hub. The sensing station is designed with a low-energy-consumption approach with solar power rechargeable batteries.

The sensing hub is an Arduino script/programme deployed on the Arduino Cloud platform. The sensing hub collects data from the sensing station, analyses the data and compares it against the WHO standard for clean water to make recommendations for the authorities. The recommendations will then be sent to the authorities/councils with their preferences such as emails or text messages.

The sensing station and sensing hub communicate with each other via a wireless channel, which can be either WiFi, bluetooth or mobile phone system.

Although wireless-sensor-based systems are popular and there are projects on water monitoring available on the internet, to the best of our knowledge, this is the first work providing timely recommendations to authorities/local councils on water pollution analysis following WHO standard.

Inspiration:

As frequent visitors of our local park, the lakes and its inhabitants are like the chief jewel of each of our trips there. Subsequently, when we all heard about this project, we immediately thought of our local park. It is a wonderful place with a thriving environment which one can relax in and enjoy. However, we realised the increasing significance of climate change and its detrimental effects upon the earth, also having a toll on our local park and others globally. In our research, we realised that climate change can affect water quality as higher water temperatures aggravate many forms of water pollution [4]. Realising this, we decided to dedicate our project on preserving our local park's lakes and the lives of its inhabitants. To maintain a safe environment for the organisms living there, we thought of creating a water monitoring sensor system which could record different factors like temperature, total dissolved solids, etc. efficiently to save our precious time of preserving lakes and other forms of water bodies not only in our local park, but also around the world.

Research:

Our proposed system has been based on the internet-of-thing (IoT) technology with the readiness of Arduino hardwares and cloud services. Machine learning tools will be adopted to develop our data analysis feature.

Impact and Justification:

Our wireless-sensor-based water pollution monitoring system aims to provide real time information of the water quality in lakes and rivers. It informs the authorities of the early degradation of the water environment hence swift interventions can be taken to protect the water. Our system will significantly reduce the human resource spent on field trips to collect water samples.

Creative Process:

We started with the idea of measuring the water quality in two lakes near one of our team members, i.e., the lakes covering an area of 126 acres in Stanborough Park, a beautiful countryside park, on the outskirts of Welwyn Garden City, Hertfordshire . We found Arduino as a suitable platform for us to integrate the required sensors into a single system. We built our proof of concept prototype with the TDS sensor. After carrying out our initial tests on the lakes, we asked ourselves how to make use of the measure data to help the council make early interventions to protect the water resources. We thought of a central system to gather and process information. Luckily we came across with the IoT technology and the availability of the Arduino Cloud service.

Approach and Implementation:

Design Process:

Our innovation is intended to be implemented in the following steps:

- Proof-of-concept sensing station: to build a sensing device to measure the TDS of water using an Arduino board and a TDS sensor; to write a code for the Arduino board communicating with the TDS sensor.
- Testing the proof-of-concept sensing station: to verify the integration of the TDS sensor on an Arduino board.
- Integrate full range of sensors: to connect pH, turbidity, dissolved oxygen and temperature sensors to the Arduino board; to update the code for the Arduino to work with newly integrated sensors.
- Testing the fully integrated sensors on the Arduino board.
- Build a sensing hub: to connect the sensing station to the Arduino Cloud service and to develop a program to collect the data from the sensing station.
- Testing the communication between the sensing station and sensing hub: to verify both sensing station and sensing can work well.
- Develop the program for analysing data and make recommendations for authorities/councils: to adopt AI tools for data analysis and recommendations.
- Testing the program: to ensure all the functionalities of the program working as expected.

Technological Framework:

We used Arduino Nano RP2040 as our main board due to its built-in wireless connectivity and efficient performance for real time data processing capabilities. For the TDS sensor we have used the Sarini Analog TDS sensor as it has been designed for domestic water laboratory and scientific research. We also chose a 1.8 inch full color TFT LCD module to display the measured results on our proof-of-concept sensing station. We selected a Belkin power bank for our sensing station. We used Arduino IDE to program our sensing station.

Challenges Faced:

We first tried our sensing station with an old Arduino Nano ESP32. After connecting the TDS sensor with the board and running the code, the sensing value was not correct as it was too high for our testing mineral water. We changed to an Arduino Uno R3 board. The result was correct. We concluded that the old Arduino Nano ESP32 might have some problems. Unfortunately, the Arduino Uno R3 board does not have built-in wireless connections. We decided to buy an Arduino Nano RP2040 and it works perfectly.

Prototype:

The signal pin of the TDS sensor was connected to the analog pin A1 of the Arduino board.
For the TFT LCD display the pin connections are as follows:

- SCL pin is connected to digital pin 11 of the Arduino board.
- SDA pin is connected to digital pin 10 of the Arduino board.
- RES pin is connected to digital pin 8 of the Arduino board.
- DC pin is connected to digital pin 7 of the Arduino board.
- CS pin is connected to digital pin 6 of the Arduino board.

Both TDS sensor and TFT LCD are powered by the 3.3V on the Arduino board.
The Arduino board is powered by a Belkin power bank.

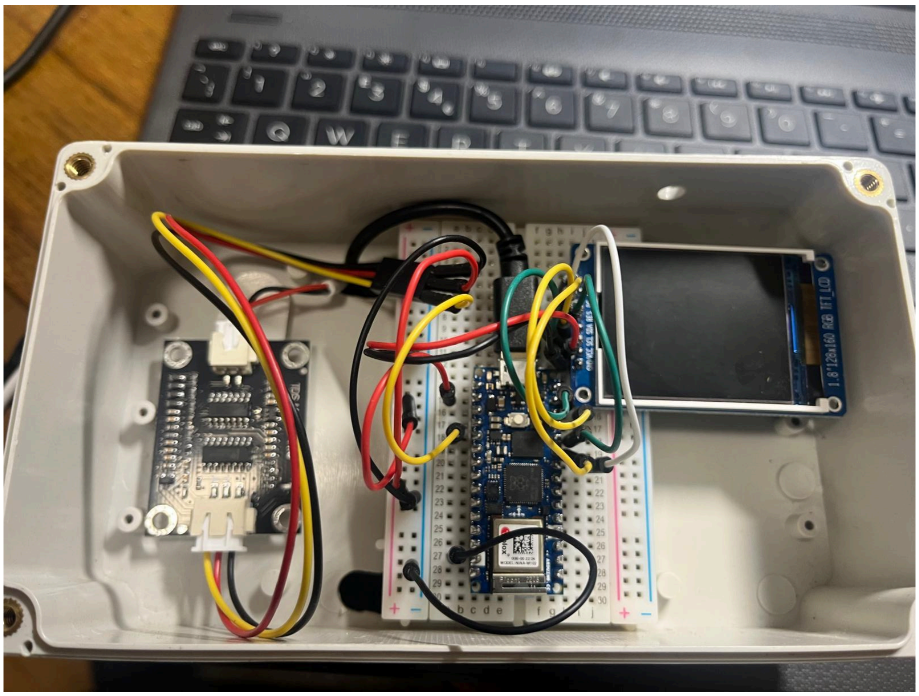

Figure 2: The proof-of-concept sensing station from the front.

Figure 3: The proof-of-concept sensing station from the back.

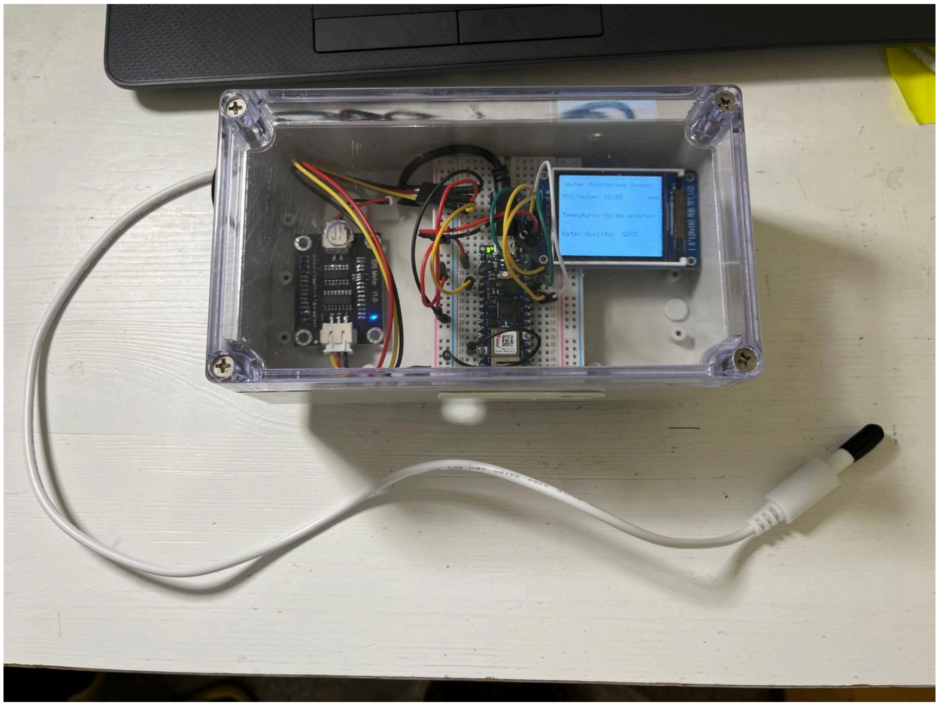

Figure 4: The proof-of-concept sensing station with the front cover and powered up.

Figure 5: Rachel and Linh tested the proof-of-concept sensing station at Stanborough Park.

Impacts & Sustainability:

Intended Impact:

Water quality is directly linked to sustainable development since it impacts ecosystem functioning, human health and economic development. Accurate and real-time data on water quality to detect environmental changes from the early stages is of the most importance. Although the use of water quality sensors is not a new approach to water quality monitoring, our innovation is to provide early recommendations for authorities to tackle water pollution with no requirement on field trips to collect water samples.

Firstly, one major impact that this system has upon the world is its capacity to save time for data collection and action analysis. Instead of taking time to physically gauge the measurements and analyse this afterwards, there will be no need for human intervention which can cause changes in wildlife patterns. The constant data tracking makes it much easier to document the evolution of a lake's water quality. It will also help environmental scientists to know which lakes to work out and which ones not to, helping them to identify the conditions of a lake in comparison with others.

Secondly, the application of water monitoring sensors will consistently and effectively monitor a lake's water quality, hence preventing the degradation of lake ecosystems by offering early warnings for councils and authorities to take quick action. The specific measurements of pH and total dissolved solids can help organisms living in the ecosystem have a more suitable habitat (ie: a more clean and natural water in the lake). These gauged amounts help identify the degree to which the lake is contaminated with various harmful substances. Similarly, the accurate and real-time data helps conservationists to know how far they should work on improving or conserving a specific factor which may affect the lake's water quality. The clear and concise directions means that the lives of many organisms living in polluted lakes could have a longer life span. This could also prevent the extinction of some already endangered or vulnerable organisms living in lake ecosystems. In addition, the current state of lakes and how to solve the issues which may be prevalent can provide similar solutions to polluted lakes in the future, making this sensor system not only sustainable for present times but also sustainable for future generations.

Thirdly, the use of water quality sensors helps to detect harmful substances in water sources, that have ultimate impact on human health. A real-time, comprehensive and long-term data collection helps to create trending analysis for public health bodies to develop effective strategies to prevent water-related illnesses. Furthermore, the application of water quality sensors helps to prevent water users especially in lakes and ponds from polluted water and ensure health safety.

Finally, reliable data from water quality sensors can be shared with local councils for very early warnings, instant actions and reduce the effects of environmental changes on water resources. Then local authorities can create and implement appropriate strategies for sustainable development. It will also reduce the pressure on the Environment Agency, promote the cooperation between local councils and the Environment Agency and increase the awareness of local communities in the importance of water quality control and methods to prevent water pollution.

Goals:

Our goal is to use this water monitoring sensor to firstly tackle the levels of fish death rate and to boost fish reproduction. Often, the environment and its levels of turbidity influences the living patterns of fish, for example, sediment from soil erosion coats fish eggs, stopping them from hatching. This leads to a decrease in the population of fish, making them prone to endangerment. Not only this, harmful chemicals like those found in pesticides and agricultural runoff kill fish, increasing their mortality rate and decreasing their life span. However, with the use of this water monitoring sensor system, it is ensured that these lethal substances can be tracked and analysed at an early stage, helping fish populations to attain a higher level of survival. By immediately detecting and recording results while offering advice to solve issues in the lake ecosystem, councils can be alerted as soon as possible if there are any drastic changes which may affect the living and breeding patterns of fish.

The compact structure of the water monitoring system makes the product easy to install in lakes and does not require too much construction which may disturb the typical patterns of fish and other organisms living in the ecosystem. The compact figure would make it adaptable to the size of any lake whatsoever and practical for all circumstances. Moreover, the fact that it can use the location of the lake to determine the ideal measurements for the lake's environment helps the product to be accessible and relevant to all places in the world. This system is not used by environmentally harmful materials, meaning that it is ethical to use this to gauge the quality of water.

Scalability & Feasibility:

Our system can be scaled up to for multiple sensing stations installed at different locations in wide areas. The system can also be scaled up to multiple regions by having multiple sensing hubs each serving one region.

Our next goal is to use water monitoring sensors on a wider environment including sea and ocean.

By equipping solar power for each sensing station our system can sustainably operate with minimal human interventions. The connections between the sensing hub and sensing stations can be realised by various wireless communication methods such as WiFi, Bluetooth, mobile phone systems, long range (LoRa) communication approach, or even satellite communication. This ensures the practicality of our system.

Future Development:

Next Steps:

- Integrate full range of sensors: to connect pH, turbidity, dissolved oxygen and temperature sensors to the Arduino board; to update the code for the Arduino to work with newly integrated sensors.
- Testing the fully integrated sensors on the Arduino board.
- Build a sensing hub: to connect the sensing station to the Arduino Cloud service and to develop a program to collect the data from the sensing station.
- Testing the communication between the sensing station and sensing hub: to verify both sensing station and sensing can work well.
- Develop the program for analysing data and make recommendations for authorities/councils: to adopt AI tools for data analysis and recommendations.
- Testing the program: to ensure all the functionalities of the program working as expected.

Future developments for the water monitoring sensor will focus on trying to include other functions such as measuring the amount of dissolved oxygen (DO), turbidity (water clarity) and levels of microbial contamination. Oxygen is key in the survival of all organisms living in the lake ecosystem and dissolved oxygen, especially, is used for fish which they absorb directly from the water into their bloodstream through their gills. Monitoring the levels of dissolved oxygen, can help environmental scientists to examine the quantity of DO that fish receive. This data can be then used to help scientists know which places lack oxygen so that human help can be used to improve the quantity and quality of DO in a particular lake ecosystem. This data can also help scientists understand the causes of some possible behavioral or physical changes to fish. The measurement of turbidity and microbial contamination can document the degree of water clarity and the number of pathogens which may be present in the water. Similarly, this data can help scientists identify which lake ecosystems are good and which especially need human help which saves time.

Potential Enhancements:

To enhance the water monitoring sensor, it is necessary for the data to be received, processed and analysed efficiently without the need of human processing and analysis which takes longer to identify the state of a lake ecosystem. Therefore, we will make an app which automatically records data which is sent from the water monitoring sensor. Instead of having people analyse the data, the app will automatically categorise the lake ecosystem into a state (such as least concerned or vulnerable) based on the statistics which are received. To make the conclusions as accurate as possible, the app will examine the lake ecosystem's climate and temperature beforehand as these factors may affect the results. Using the conservation status of the lake ecosystem, the app will then offer advice on what should be done in the future to conserve this place.

Roadmap:

- Integrate full range of sensors: 3 months.
- Testing the fully integrated sensors on the Arduino board: 2 to 3 months.
- Build a sensing hub: 3 months.
- Testing the communication between the sensing station and sensing hub: 2 to 3 months.
- Develop the program for analysing data and make recommendations for authorities/councils: 3 months.
- Testing the program: 2 to 3 months.
- Build a water pollution monitor app: 3 months.
- Testing the app: 2 to 3 months.
- Deploying at Barnet and Welwyn-Hatfield Councils: 12 months.
- Promoting to other councils: 12 to 24 months.

Conclusion:

Overall, the proposed water sensor system will measure the amount of chemicals in water, which will increase the understanding we have of how contaminated water can affect marine life in inland waters, and will help us solve the problem of contaminated water more efficiently and effectively in the future. By providing real-time monitoring, the sensor enables immediate responses to pollution, protecting ecosystems and public health.

The proposed sensor system can identify harmful substances like heavy metals, toxins, pathogens, or chemicals, and notify authorities about unsafe water, helping to lower the risk of waterborne diseases and health problems for nearby communities.

Automated monitoring gives us data to spot trends and predict contamination, helping manage water quality. It can also find pollution sources early, like runoff or sewage leaks, allowing us to act before damage happens. In case of a flood or dangerously high PH levels, the water sensor provides an early warning, allowing a quick clean-up. These sensors help protect aquatic life and preserve freshwater ecosystems.

It can also prompt investigations and interventions to stop pollution at its source and by doing this, protects the biodiversity of aquatic life in freshwater. This sensor system will prove invaluable in the task of protecting the life and diversity in our aquatic ecosystems and will not only be a useful tool in scientists' research but will also prevent the lives of the creatures in our ecosystems from being harmed.

Future developments for the water monitoring sensor will include measuring dissolved oxygen (DO), turbidity, and microbial contamination to assess lake health. Monitoring DO helps scientists understand fish survival and identify oxygen-deficient areas. The sensor will be integrated with an app to automatically analyze data and categorize lake ecosystems by their conservation status. The app will also offer recommendations for ecosystem preservation based on climate and temperature factors.

Through monitoring ponds, lakes, rivers and other bodies of water, water quality sensors provide evidence of whether industrial activities are adhering to established water quality standards, helping companies better understand environmental regulations, and in this way managing pollution levels and restricting the number of pollutants in the habitats of such aquatic ecosystems.

In summary, the water quality monitoring sensor system is an innovative development that could be implemented globally to gather data of different regions and bodies of water, and in the case of the data we gathered (and other cases where pollution levels require attention), inform councils or environmental specialists, and also suggest potential solutions to such issues such as turbidity, pH, TDS, PO, etc. We believe that this system could have a positive, lasting impact on global aquatic ecosystems, as well as raising awareness for other problems like this one to help shape a smarter, more sustainable future.

References:

[1]https://www.aquaread.com/blog/water-quality-management-uk/
[2]https://www.bbc.co.uk/news/science-environment-59955624
[3]https://www.theguardian.com/environment/article/2024/may/20/fish-deaths-in-englands-rivers-rise-tenfold-in-four-years
[4] https://archive.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf