Nigerian Journal of Technology (NIJOTECH)
Vol. 44, No. 4, December, 2025, pp. 621 - 633
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.2025.5256

ROBOTIC AND IOT DEVICES AND SYSTEMS FOR RIVER WATER QUALITY MONITORING AND MANAGEMENT: A SCOPING REVIEW

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ARTICLE HISTORY:
Received: July 06, 2025.
Revised: October 27, 2025.
Accepted: October 27, 2025.
Published: January 03, 2026.

KEYWORDS:
River water quality monitoring, Arduino, Raspberry Pi, IoT

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITORS:
Chidozie Charles Nnaji

FUNDING:
None

Abstract

Nowadays there is undoubtedly a need to monitor and manage water quality level. Regardless of geographic location, the problem of water pollution becomes ever more important. A starting point to address such an issue would be a detailed understanding of the water quality level through careful monitoring and smart management strategy. The use of Robotic and internet of thing (IoT) devices proves to be not only convenient in terms of easily available hardware, but also very cost effective and reliable. This scoping review captures an appropriate adoption of Robotic and IoT systems in river water quality modelling, with the Arduino and Raspberry Pi being the most prominent systems. The most frequently measured water quality indicators include pH, turbidity, conductivity, total dissolved solids, and temperature. This review also emphasizes the usefulness and efficiency of Arduino and Raspberry Pi in such settings. With the advancements of IoT devices, sensors and even artificial intelligence (AI), it could be very possible that in the near future fully autonomous systems might be used to gather precise and accurate water quality data.

1.0 INTRODUCTION

Present-day human activities are leaving adverse footprints on the environment as a result of the ever-rising demands imposed by the contemporary way of living. It is quite appalling that the outcomes of these activities are frequently overlooked. While there is a myriad of issues that have resulted from the negligent human behavior, it is crucial to highlight the issue of river water pollution. River waters globally have been polluted over the years with industrial discharge, agricultural runoff, and/or untreated sewage being identified as major contaminants carriers. Considering the fact that these open water bodies are a major source of water for a lot of people globally, river pollution has been and remains a threat to public health.

Several studies in this regard have revealed even fecal contamination of river water. For example, a dedicated study of the Asa River in Nigeria revealed fecal contamination, pesticides, crop wastes, and industrial effluents are among the factors contributing to poor river water and aquatic life quality [1]. Another example can be found in the assessment of the water quality of the Uturu section

HOW TO CITE:
Stojche, R. and Saso, K. "Robotic and IoT Devices and Systems for River Water Quality Monitoring and Management: A Scoping Review", *Nigerian Journal of Technology*, 2025. 44(4), pp. 621 - 633. https://doi.org/10.4314/njt.2025.5256

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of Aku River in Southeastern Nigeria [2]. Namely, the researchers have found that the values of total dissolved solids, total suspended solids, turbidity and nitrate of the collected water samples exceed the tolerable limits. The same study also stands out in terms of providing recommendations that could control the pollution of the river.

Furthermore, land use activities also impact the water quality. In a study where water samples from the Ala River in Nigeria were examined, it was found that heavy metals (iron and lead) were present in levels that exceed the safe limits [3].

Another study of the dissolved heavy metals content of the Jiulongjiang River water in Southeast China also provides an assessment of the water quality and health risks [4]. It was observed that the titanium, manganese, and antimony present in the river were above accepted limits at some sites. Surprisingly, the water quality index (WQI) measured indicates excellent water in the Jiulongjiang River, although water was of poorer quality at some other sites. Conclusively, the potential threat that antimony poses to human health was highlighted.

The growing interest in the importance of managing river water quality is particularly evident in the continuous research conducted in recent years on this subject matter. Several water quality modelling tools are emerging as a result of these scholarly studies. For instance, an artificial neural network-based solution through which the water quality can be efficiently predicted has been developed and used to evaluate and predict the Danube River (Romania) water quality for a period of over 9 years [5]. Another study [6] proposed a water quality prediction framework for IoT systems based on multi-source transfer learning. The study concludes that the proposed approach can successfully be used to train water quality prediction models that even have reduced prediction bias, however, sensors of same type had to be used in multiple monitoring points. Generally, the operations of ultrasonic water stage monitoring sensor have been analyzed in regard to sustainable water management [7], giving rise to a positive outlook on the use of these IoT tools and sensors in water quality modelling.

An interesting proposed system can be found in a study [8]. The system makes use of appropriate sensors to take real-time measurements of pH, total dissolved solids (TDS), turbidity, chloride, coliform, and E-Coli, of the Pamba River water in India. Although, the main controller used for the IoT system is not stated.

IoT systems can be used to improve efficiency in terms of electrical energy consumption, especially through home automation systems. An example of a such system can be found in [9]. The use of systems that improve electrical energy consumption efficiency can positively impact river water quality, especially in areas where most of the energy consumed is obtained through hydroelectric power.

Therefore, the need of systems that will assess the level of water pollution is highlighted once more. In the light of developing systems for enhanced environmental surveillance and responsive management practices, the integration of robotic and IoT devices into river water quality monitoring and management does hold promise.

To that end, the goal of this scoping review is to provide a comprehensive overview of existing research on the application of Robotic and IoT devices and systems in river water quality monitoring and management. By reviewing methodologies and findings of existing studies, this scoping review aims to identify key technological trends and attempt to pinpoint areas that entail further research.

2.0 METHODOLOGY

2.1 Search Strategy

The findings of this scoping review will capture the current trends in the use of Robotic and IoT systems for the purpose of river water quality monitoring and management. Towards the goal of the scoping review, some of the papers and studies on the topic were selected through browsing the Google Scholar academic search engine. Leveraging the capabilities of the Google Scholar Advanced search, studies were also filtered by searching through key words. Namely, a search was also performed to find studies where the following words "IoT", "Water" and "Quality" were present in the title. To adhere even more precisely to the topic of river water quality, in a consecutive search the keyword “River” was added to be included in the title. Another search was performed after including all keywords, i.e.: "IoT" and "Water" and "Quality" and "River".

Since the goal of this scoping review is to also assess the usage of robotic devices for river water quality monitoring and management, the focus should not entirely fall only onto “IoT” keyword. Therefore,

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another search was also performed where the "IoT" was replaced with "Robot". Further conditional search was performed, by the use of the following query 'allintitle: "Robot" and "Water" and "Quality" or "River"'. Through Google Scholar, articles where "device" and "river" and "water" and "management" appear in the title were also searched for. These different searches on Google Scholar ultimately yielded a total of 431 results.

A separate search for papers was also done on the PubMed bibliographic database by performing a free search and through the Advanced search functionality. The Advanced search on PubMed was performed by using the following query '"IoT" or "Internet of Things" and "River" and "Water" and "Quality"' which yielded only 13 results, from which, most articles had restricted access. By changing the query to optionally include the word "River", and by filtering only articles with "Free Full Text", other relevant articles could be selected for the scoping review from the total of 3099 found results, resulting in total of 3112 results from PubMed. It should be noted that many of those were not relevant for this review. It can be concluded from this search that many authors perhaps intentionally chose to leave out the word "River", perhaps to not limit the application of their system only to river water, but water bodies in general. In the PubMed searches, "Review" articles and articles with "Retracted" status were excluded. Some papers were found through citations from other papers or through similar papers suggestions on PubMed.

2.2 Study Selection

Having in mind that the idea of this scoping review is to address the contemporary trends on the topic, the selected papers for this review reflect work and research done by authors since 2011. Hence, some older papers have been excluded. There were no geographic constraints set while searching for papers because the topic of the review is relevant on a global scale.

Regarding the inclusion criteria, for the purpose of this scoping review, studies with open access have been selected, while those papers that have been found with limited access have been excluded. The title and content of the paper had impact on the decision whether to include or exclude that paper. As previously mentioned, those papers that included the mentioned key words in the title have been included. Some papers that have been excluded have focused more heavily on topics connected to waste water and sewer systems monitoring, hence they were deemed not that relevant for the purpose of this scoping review. A paper that focused more heavily on fish detection in water was also excluded. Review papers were excluded, as well as some duplicate papers.

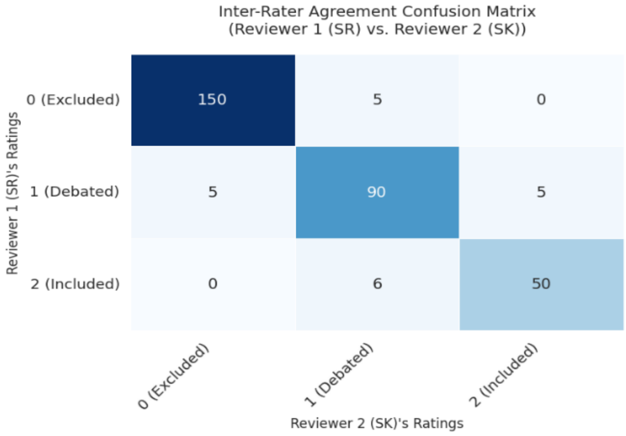

Figure 1: Confusion matrix representing the reviewers' ratings

Two reviewers (SR and SK) independently from each other screened the identified publication by analyzing their title and abstract as well as their full text where available. Following the defined inclusion and exclusion criteria each study was assessed on a three-point scale where 0-means not relevant, 1-may be relevant, 2-fully relevant. Afterwards an average score was computed for each study. Those studies that received a score 0 from both reviewers were automatically excluded, while those that received a score 2 from both reviewers were included for further study. All other studies were considered as a partial disagreement between reviewers and were additionally analyzed through common discussion.

The confusion matrix representing the initial independent scores by the two reviewers is presented in Figure 1. In order to determine the level of agreement between the reviewers the Cohen's kappa coefficient was calculated using the following formula:

$$k = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)} \quad (1)$$

Where *Pr(a)* represents the observed agreement (proportion of times reviewers agreed), while *Pr(e)* represents the expected agreement by chance. Computed Cohen's Kappa coefficient for this case is *k=0.89* that according to Landis & Koch criteria [10] $\kappa > 0.8$ represents almost perfect agreement between the reviewers.

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The PRISMA flow diagram for the study selection process is given in Figure 2. It provides a summarized flow of the screening process for relevant papers. The initial number of identified papers through searching is given in the first block of the diagram. In the following blocks, the process of screening and selection of studies is presented through numbers. It is stated how many duplicates, papers with retracted status, papers with restricted status, and irrelevant records were removed prior to the screening process. During the screening process, some studies were also excluded, ultimately reaching the number of studies that are considered relevant. while Figure 3 depicts the high-level overview of the relevant papers' selection process.

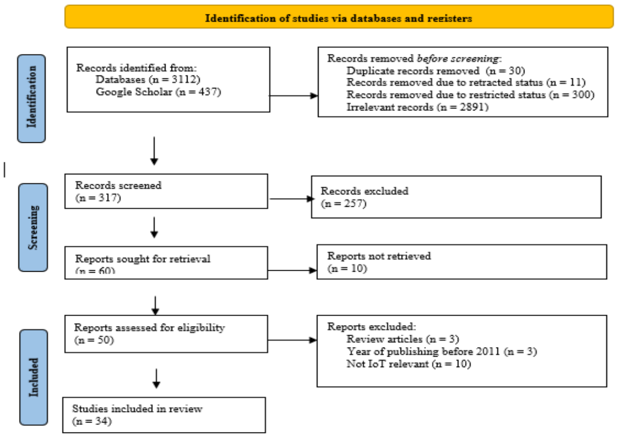

Figure 2: PRISMA flow diagram

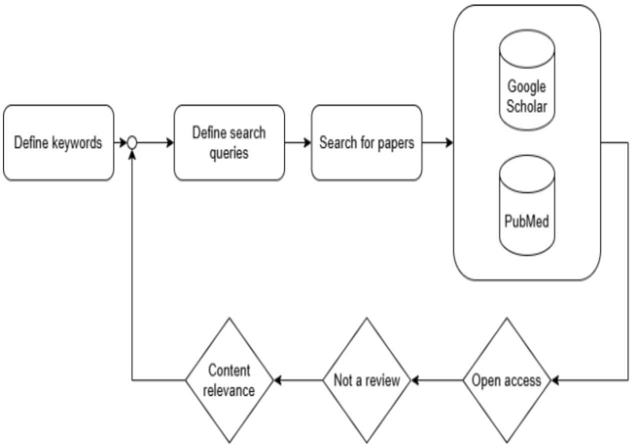

Figure 3: Research papers search strategy

2.3 Data Analysis

We have generated maps for key terms correlation, presented in Figure 4 and Figure 5, through VOSviewer, which is a free-to-use software tool for creating, visualizing, and exploring maps based on network data. To create such networks, VOSviewer can use bibliographic database files, reference manager files, or download data through an API [11]. VOSviewer enables the data to be analyzed and interpreted with scientific accuracy and visual clarity.

Figure 4 displays the correlation map between terms occurring three or more times in the selected studies, with full counting method selected, that takes into account multiple occurrences of the same term in one document. The fields from which data was extracted were title and abstract fields of the selected studies for this review.

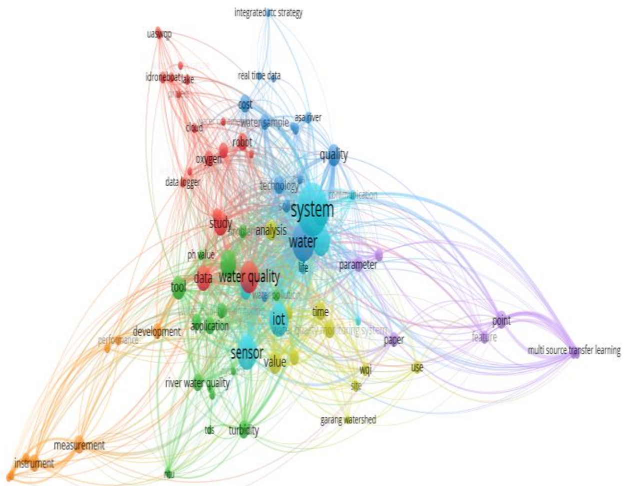

Figure 4: Correlation map of terms occurring minimum three times in the selected studies

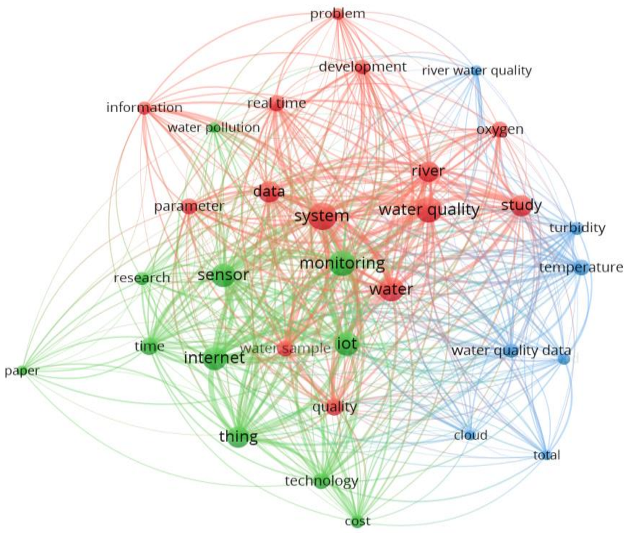

Figure 5: Correlation map of terms occurring minimum four times in the selected studies

Figure 5 shows the correlation map of terms occurring minimum four times in the selected studies, using the binary counting method, meaning that only the presence or absence of the term is evaluated, not taking into account the number of occurrences of the term within the same document.

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From the two maps, it can be seen which terms are being used most frequently. As expected, "IoT", "real-time monitoring", "water quality", "sensors" are among the terms that have bigger nodes and many links.

The data extracted from the found papers, relevant for this scoping review, mainly orbits around the microcontroller or microprocessor board used at the core of the demonstrated IoT system. Therefore, one grouping of the findings that emerge from this review could be made in terms of the used IoT hardware.

Namely, the grouping is based on the observation of large number of found studies where the use of Arduino boards is evident. Furthermore, other group of found studies take leverage of the Raspberry Pi board computers. The compact size and variety of easily available compatible components and sensors, make the Arduino and Raspberry Pi platforms very convenient for many IoT applications. Relevant sensors at the sensing level are common for both groups of studies.

3.0 RESULTS

Based on the study selection strategy, ultimately, a total of 34 studies have been selected for this scoping review.

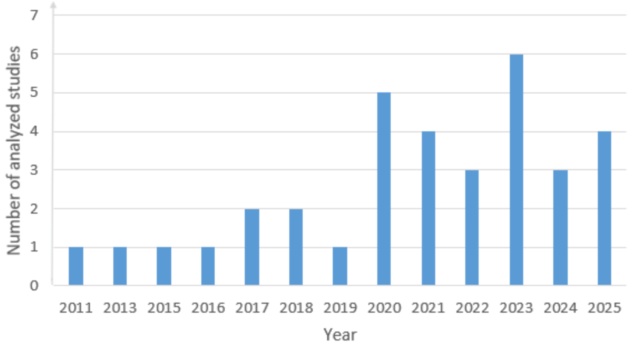

Figure 6: Number of analyzed studies per year of publishing

The number of analyzed studies per year of publishing is given in Figure 6. A significant number of the found papers use either Arduino or Raspberry Pi boards at the core of their system. Out of the 34 selected studies, 24 studies in total have been identified to either use Arduino or Raspberry Pi, out of which 18 studies in which Arduino boards are used and 6 in which Raspberry Pi boards are used as part of the IoT system. Figure 7 illustrates the usage ratio between Arduino and Raspberry Pi out of the 24 studies. The rest of the studies either provide background support to this study and put more focus on the need for water quality monitoring and contamination assessment, without necessarily relying on the use of IoT devices, or propose using IoT systems where the main controller is not disclosed.

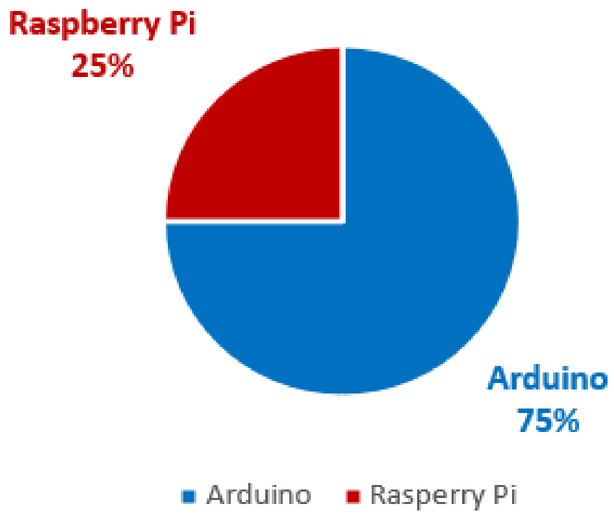

Figure 7: Usage of arduino and raspberry PI boards in analyzed papers

3.1 Arduino and ESP32

The Arduino board is used very often among the proposed systems for water quality monitoring. In other words, the larger number of reviewed studies use Arduino boards alongside relevant sensors for the data acquisition part of the whole system. Such example can be seen in the model proposed by the authors [12]. The authors tested their developed model on three different water samples, taking measurements of pH, turbidity, conductivity, carbon dioxide, humidity and temperature with the appropriate sensors.

Other authors [13] set the design of an IoT based system for water quality monitoring as an objective to their research paper with the ESP32 module at the heart of their proposed system. The ESP32 module relays data for monitoring through the Blynk app, which is compatible with IoT hardware. Their system incorporates appropriate sensors to take measurements of water turbidity, pH levels and amounts of organic and inorganic dissolved solids (TDS – total dissolved solids).

In their research, [13] selected to test their device in residential communities and tourist attractions on the Kapuas River, Indonesia. They tested their device on two locations over three days, and present the taken measurements in comparison with required values for

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quality of clean water. The authors conclude that the measured TDS and pH levels of the water flowing in Kapuas River meet the maximum permitted levels, although the measured turbidity exceeded the maximum permitted levels. From the measured pH levels, it was concluded that the Kapuas River water is alkaline.

Another example of a river water quality monitoring system is presented by the authors [14]. In their system the authors even go a step further and propose analysis of the gathered data by usage of a neural network model while also having in mind the problem of big data analytics and distributed processing. A very similar system is also proposed in the studies [15], [16], [17].

The authors of [18] present a very interesting water quality monitoring system where Arduino is used. They also performed a field test at the Malacca River in Malaysia, and performed comparison of the measured values against standard values.

Arduino is also used in the system presented by the authors of [12] who also compare the measured values against set thresholds. Usage of the Arduino platform is also evident in the system proposed by [19]. As demonstrated by authors [20] an Arduino board can be used as part of a solar powered instrument that can be used to detect water clarity and hence provide information about the water quality. The presented instrument can connect with other devices in an IoT environment and the authors also outline the benefits of its autonomous usage over manual measurements of water clarity taken by a Secchi disk. The authors conducted measurements in Ho Chi Minh City and in ponds in provinces of Mekong Delta, Vietnam.

In a study [21] water quality monitoring system where pH, turbidity, water temperature, and TDS sensors are connected to Arduino UNO R4 WiFi for data acquisition and message queuing telemetry transport (MQTT) protocol for efficient data transmission. The study focuses on monitoring the Citarum River water quality in Indonesia.

Another study [22] makes use of the Arduino MKR WAN 1310 board as part of water quality monitoring system named RiverTurb, that efficiently measures turbidity. The researchers validated the system in the Yzeron River catchment by deploying the sensor in the Chaudanne River, in France.

Example of the use of Arduino Leonardo board can be found as part of a real-time water quality monitoring system [23] where temperature, pH, turbidity, and DO, were measured.

As part of a water quality monitoring and analysis system, Arduino UNO board is used in a case study [24] to collect data about temperature, pH, turbidity, TDS, and DO, in the area of Sungai Pusu, Malaysia.

Authors of another study [25] also present an intelligent IoT system where Arduino is used. The collected sensor data is presented in real time through a Blynk app UI and even a machine learning model is integrated as part of the system.

The measured parameters are similar and common among most of the found studies, with a few variations.

3.2 Raspberry Pi

As part of their IoT solution, the authors [26], utilize the Raspberry Pi 3B board computer as part of a SCADA system. The data gathered from the sensors and the RTUs (remote terminal units) is received through LoRa modem. In their paper, they present and describe a test site on the Andijan Say River channel, Uzbekistan, although they have set up other stations as well.

The authors [27] present a system where they use sensors for temperature, turbidity and pH connected to the Raspberry PI board computer. The data from the sensors is read every 10 minutes and is then stored in database. The authors incorporate SMS notification mechanism in their system, in order to send notifications after recording some sudden changes in the water quality. Their system also provides the functionality to search the database and retrieve measured data for a specific date.

A very interesting use of the Raspberry Pi computer can be seen as a part of a prototype Unmanned Surface Vehicle (USV) presented by [28] that can be used to take measurements and visualize sensor data regarding the water quality. The same author presents an Unmanned Aircraft System (UAS) in another article [29] where he also uses the Raspberry Pi. The author conducted demonstration of the UAS at the Boise River in Idaho, USA. The measured water quality data is visualized through a graphical user interface. Graphical representation of the data is also common for most of the found studies.

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Other authors [30], in their detailed article, present a prototype of an amphibious Unmanned Aerial Vehicle (UAV). To determine the water quality, the device is equipped with pH, dissolved oxygen (DO), turbidity, and electrical conductivity (EC) sensors. It should be noted that in their design the authors actually also use an Arduino for data sampling and then transmit the data to a Raspberry Pi which is connected to a 4G-LTE dongle. In other words, Arduino is used for fast sensor data acquisition and Raspberry Pi for further data processing. The authors also performed an in-situ testing of the device at a lake near Ambattur, Chennai, India and also tested the collected water samples in a laboratory environment, confirming 98% accuracy in the measurements. The authors conclude that the lake water is of poor quality.

The authors [31] present a system where they use the Raspberry Pi along with an IoT module to achieve real-time monitoring of the water quality parameters such as pH, dissolved oxygen, temperature, turbidity, conductivity, similar to the measured quantities in other systems presented by the other authors.

3.3 Robotic Devices

The use of robotic devices for water quality assessment is indeed evident in some of the found studies. The authors [32] present in their paper the design and also conduct testing of a water quality detection robot. The robot can move accurately and can even dive underwater while performing real-time water quality detection. The robot collects data about water pH. temperature and dissolved oxygen (DO) and further integrates data storage and an early warning mechanism, leading to improvements in the field of water quality monitoring and management.

In other study, the authors [33] provide an overview of the GatorByte real-time water quality monitoring solution. The platform consists of hardware and software modules, uses low-cost sensors in contrast to other deployable sondes and hand-held units that also often come with a high cost and require skilled personnel to operate. The authors also highlight the GatorByte's wide range of sensor support, resilient housing design and ability to capture spatial changes in water quality. GatorByte uses an Arduino board that supports LTE-M (Long-term Evolution-Machine Type Communication) and NB-IOT (Narrow-band Internet of Things) capable microcontroller board. The authors deployed the GatorByte buoy at a pond at Center of Aquatic and Invasive Plants (CAIP), Gainesville FL, USA, and at Sweetwater branch creek (SWB), Gainesville FL, USA and compared results with data gathered with a Hydrolab HL4 sonde. The authors found some discrepancy while comparing the data due to sensor drift, stating that periodic calibration would resolve the discrepancies in the sensor values.

The authors [34] present the design of a robot boat that can determine the water quality through real-time water pH measurement. The use of the Ardupilot software, allows the boat to be operated automatically. The authors also tested the boat at Winongo River, Indonesia.

A prototype sailboat robot is presented by the authors [35] where they present the architecture of the real-time embedded system for water monitoring where the Raspberry Pi is used. Furthermore, [36] also propose a system where water quality can be assessed through a compact underwater robot, making use of Arduino and ESP32.

4.0 DISCUSSION

It can be concluded from the analyzed papers that both Arduino and Raspberry Pi are platforms that far exceed the scope of simple hobby projects. Both prove themselves as very suitable for IoT applications, with Arduino being more popular among the reviewed studies. They can definitely serve as convenient key modules for many real-world applications, including river water quality monitoring and management. Examples can also be seen from the reviewed studies where the researchers present robotic systems that can function even autonomously and regularly inspect water samples at set intervals. In many of the analyzed studies, cloud technology was used to store the gathered data from the measurements, while some studies even present the use of distributed processing.

Although different authors conducted studies and monitoring of the water level quality in different geographic areas, most of the studies incorporate a common mindset in the approach. This can be seen from the set of measured quantities. Most of the studies record and track the same parameters as water quality indicators. Some studies compare the measured data to standard values to determine the water quality. Some studies use machine learning models, some use deep learning models backed up by algorithms to analyze the recorded sensor data.

In future research we can most likely expect the analysis of sensor data to be supported and executed by trained AI models, resulting in faster feedback

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from the system. Such systems would probably be less prone to errors due to lesser human intervention. The use of AI could also enable the system to provide suggestions in terms of water quality control.

In the found studies there have not been much information on how to counter the pollution and maintain a healthy level of water quality. Even though this might be a task for other organizations within the community, it surely could be considered as a current limitation of the studies and possible future improvement. Another limitation for some of the studies was that their presented system was not tested in a real-world environment like other studies.

Some challenges concerning the actual proposed systems for water quality monitoring could also be linked to possible errors in sensor calibration leading to inaccurate measurements. Currently, sensor drift is also a challenge if the system is planned to be used for a longer period.

Further below, a table 1 and 2 summary of the cited literature is provided. The table contains summarized information about the main IoT controller used in the proposed system, a brief description of the topic of the paper, and the country, region, or river where the system was tested, if applicable or if provided in the paper.

Table 1: Summary overview of cited literature

References	IoT device	Thematic focus	Country/region
(Agade & bean, 2023)	Arduino	Real-time water quality monitoring solution.	FL, USA
(Almetwally et al., 2020)	Arduino	Efficient, low cost, smart monitoring system for water quality.	N/A
(Amirgaliyev et al., 2025)	Arduino	An intelligent IoT based water quality monitoring system.	Multiple locations, coordinates provided
(Chandrappa s et al., 2017)	Raspberry Pi	Real-time water quality assessment system.	N/A
(Chowdury et al., 2019)	Arduino	Presentation of an IoT river water quality monitoring system, aided by a neural network for analysis of the gathered data.	Bangladesh
(Esakki et al., 2018)	Ardiuno, Raspberry Pi	Prototype of an amphibious Unmanned Aerial Vehicle (UAV) used to determine the water quality.	Ambattur, Chennai, India
(Georgescu et al., 2023)	Water quality prediction.	An artificial neural network based solution for water quality prediction.	Danube River, Romania
(Gupta et al., 2021)	Arduino, ESP32	Compact underwater robot for water quality monitoring.	Jammu region, India
(Huang et al., 2020)	Main controller not disclosed	Design and test of a robot for aquaculture water quality assessment.	Weihe River, Yangling District, Shaanxi Province, China
(Ikhwan et al., 2023)	ESP32	Design of an IoT based system for water quality monitoring.	Kapuas River, Indonesia
(Khudaybergenov et al., 2020)	Raspberry Pi	IoT based SCADA system for water quality monitoring.	Andijan Say River channel, Uzbekistan
(Kolawole et al., 2011)	N/A	Water quality assessment study.	Asa River, Nigeria
(Lakshmikantha et al., 2021)	Arduino	Smart, cost-effective and simple IoT system for water quality monitoring.	N/A
(Liang et al., 2018)	N/A	River water quality assessment study.	Jiulongjiang River, Southeast China
(Mat nuri et al., 2024)	Arduino	IoT system for real-time water quality monitoring.	Malacca River, Malaysia

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Table 2: Summary overview of cited literature

References	IoT device	Thematic focus	Country/region
(Meng et al., 2017)	N/a	Cost-effective real-time control framework for water quality management.	United kingdom
(Miller et al., 2023)	Arduino, Raspberry Pi	A perspective of IoT technology used for water quality monitoring.	N/A
(Muniz et al., 2022)	Arduino	Real-time IoT river water quality monitoring system.	N/A
(P.m et al., 2023)	Arduino	Real-time IoT water quality monitoring system with big data analysis.	Chittagong City, Bangladesh
(Panagopoulos et al., 2021)	N/A	Study and analysis regarding the operation of ultrasonic water stage monitoring sensor.	Pikrodafni stream, Athens, Greece
(Pham et al., 2020)	Arduino	Solar powered instrument for automatic water clarity measurement in place of manual measurement by Secchi disk.	Ho Chi Minh City, Mekong Delta, Vietnam
(Prabowohendhi et al., 2020)	ESP8266	Robot boat for river water quality monitoring in real-time.	Winongo River, Indonesia
(Ryu, 2022)	Raspberry Pi	Unmanned aircraft system (UAS) for real-time water quality monitoring, sampling, and visualization.	Boise River, Idaho, USA
(Ryu, 2022)	Raspberry Pi	Presentation of a prototype low-cost open-source autonomous unmanned surface vehicle (USV) for real-time water quality monitoring and visualization.	Pond in Boise, Idaho, USA
(Silva junior et al., 2016)	Raspberry Pi	Architecture of a real-time embedded system for water monitoring as part of a prototype sailboat robot.	Rio Pium, Blue Lake, Alcaçuz Lake, Small River, Northeast Brazil
(Soheil Fakheri et al., 2023)	Arduino	Automated real-time system for water quality monitoring with big data analytics.	N/A
(Vijayakumar & ramya, 2015)	Raspberry Pi	Low-cost real-time monitoring water quality monitoring system.	N/A
(Zhou et al., 2021)	N/A	Water quality prediction framework for IoT system.	Hong Kong
(Saputra et al, 2025)	Arduino	Water quality monitoring with MQTT.	Citarum River, Indonesia
(M. Gisi et al, 2025)	Arduino	Water quality monitoring through turbidity measurement.	Yzeron River catchment, Chaudanne River, France
(S. Syafrudin et al, 2025)	Arduino	Real-time water quality monitoring system.	Garang watershed, Indonesia
(N. Ahmed Kabbashi et al, 2024)	Arduino	Real-time water quality monitoring system.	Sungai Pusu, Malaysia
(A. Roy and J. J. Kizhakkethottam, 2024)	Main controller not disclosed	Real-time water quality monitoring system that also considers Coliform and E-Coli levels.	Pamba River, India

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5.0 CONCLUSION

The findings of this scoping review provide an overview of the most common IoT settings used for river water quality monitoring. Most of the analyzed studies concern themselves with real-time water quality data acquisition. Hardware wise, it can be noted that Arduino devices prevail as most used for IoT applications in the domain of water quality monitoring and management.

Although some of the results about the water level quality from various studies may be considered alarming, the primary focus of this scoping review was on the IoT devices and systems used to gather such data, and not necessarily on the issue of the level of water quality itself. The need of precise and accurate water quality measurement systems is very important today and will be even more important in the future as greater levels of pollution might be expected. This review can help researchers quickly review current common practices applied in water quality monitoring. Such starting point could most likely lead to improvements in the system designs and approaches.

In that context, further advancements in the field of IoT technology could also be expected, leading to improved systems that will gather water samples, analyze and store data. Leveraging the recent advancements in AI in almost all fields of our living beginning from medicine [37], through education [38] till agriculture [39], as well as the advancements in the communication protocols [40] and quantum computing [41], smart management strategies could also be developed based on the analyzed water quality sensor data and set strategic goals.

This scoping review took consideration of only open access articles. However, some potential limitations might arise due to that approach. Of course, more data could be gathered and more studies could be reviewed had the scoping review not focused only on open access articles. The relatively small number of considered studies compared to some other much larger scoping reviews could perhaps be thought of as a limiting factor for this scoping review. However, to some extent, due to the observed trends in the reviewed studies, it can be expected that similar approaches should be observed even in other studies not in scope of this review.

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