Water Quality Monitoring and Controlling Systems for Aquaculture

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Abstract Due to large increases in demand for fish and seafood around the world, aquaculture has been a rapidly expanding sector. Shrimp, fish, and other aquatic crops are grown in aquaculture, where the water's qualities determine the crop. Dissolved oxygen, salinity, temperature, alkalinity, turbidity, hardness, pH, ammonia, water level, and nutrient levels are a few water quality factors that should be kept at ideal levels to enhance yield. Depending on the circumstances, these characteristics might change drastically throughout the day. In order to fully exploit their potential, these factors must be regulated at high frequencies. This paper affords an in-depth assessment of the diverse strategies utilized in aquaculture to Detect and manage water quality. This survey highlights the research gap on this area and presents higher scope for superior work. Keywords: Aquaculture, Water quality index, Water quality monitoring, Wireless Sensor Net-works.

Keywords AI (Artificial Intelligence) · IoT (Internet of Things) · Sensors · MCU · Wireless sensor networks

1 Introduction

Water is one of the major sources for human beings for drinking and other maintenance, agriculture, fisheries, industrial applications etc. In India and other countries in the world, the water resources like lakes, rivers, and ocean are polluted because of the increase of population, and industrialization, cor- responding wastages are

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dissolved in the soil and water resources. They can pollute the ground and surface water.

In India, fisheries and aquaculture play a significant role in food produc- tion, ensuring the food basket's nutritional security, boosting agricultural exports, and employing over 14 million people in various occupations. The water of a high standard has to be kept in aquatic ponds to enhance production. The quality of water refers to its condition in respect to the requirements of one or more biotic species or any agricultural necessity or purpose. Water's quality is determined by its physical, chemical, and biological characteristics. Manual and automated devices are now used to measure the water quality for aquaculture. Farmers that use the manual approach must take water samples from the ponds and evaluate the water's properties in a lab. This strategy is tiresome. Aqua farms are monitored by wireless sensor networks in automated systems employing the unreliable GSM and Zigbee protocols, which are only effective for small distances and pond.

2 Literature Review

Different kinds of water quality monitoring techniques have been researched in the section of the literature review. The following is a discussion of some of those that are being used in aquaculture farms.

2.1 Water Quality Monitoring Using Wireless Sensor Networks

Wireless sensor networks are used to continuously monitor water quality parameters using GSM / Zigbee protocols, which are not reliable and limited to short distances and ponds [1], developed an inexpensive, open-source hardware system for tracking and recording water-quality indicators for aquaculture production. It has the ability to take records and transmit data using the ZigBee wireless protocol to a graphical user interface, which can show data graphically and save the data in a database [2], have tested a prototype smart system for monitoring the pH, DO, and temperature in an Eel fish aquarium. The system is designed by a single Raspberry-Pi3 system. They anticipated that the Raspberry Pi 3 system will use integrated Wi-Fi to connect data to the internet network. Additionally, cell phones may be used to remotely regulate an automated system that maintains water quality at the appropriate sensor value [3], developed an Arduino-based low-cost water quality monitoring system, in order to effectively monitor water quality parameters in distribution networks using the ZigBee protocol. According to [4], the focus is on using Wireless Sensor Networks (WSN) for real-time water quality monitoring in order to avoid the delay caused by using GPRS to handle the situation. In order to regulate the changes in water parameters like temperature, conductivity, turbidity, and the presence of an oil layer over the water as well as fish behavior during the feeding process using the fish swimming depth sensor and velocity sensor, optimized a low-cost WSN for aquaculture monitoring [5].

[6], established a fully autonomous system for water quality monitoring employing an improved Kalman filtering algorithm and route tracking algorithm to monitor the water quality parameters in a broad region of cultivation areas. The Android mobile app obtains the water quality characteristics of any place using GPS for decision making [7], designed online PH and DO monitoring system in Shrimp Aquaculture. The main aim of the system is to reduce the energy consumption and optimal usage of water. The PH and DO sensors continuously measure and send the master station and corresponding necessary action will be taken by the corresponding system. This system has a smaller number of sensors. Therefore, the complexity of the system is less, simple in operation and maintenance. [8], illustrated a wireless sensor network based on virtual instruments for aquaculture monitoring and management as shown in Figure 1. They also detailed the physical design of smart nodes that enable real-time alterations in water properties like as pH, humidity, and temperature.

[9], designed to monitor the various parameters of the water in large-scale fish farms like the potential of hydrogen, dissolved Oxygen, water level, temperature, dissolved ammonia and dissolved carbon dioxide. Because the fish development not only depends on food feeding but also depending on the water quality. In the proposed system the water sample is collected at the sampling and sensing chamber. The required parameters can be sensed by the sensors and they are displayed on the central display board. After each sample collection, the chamber is cleaned with fresh water. This cleaning is also monitored by the program-based central system. If the measured parameters are above or below the specified limits and the operator not taking any necessary action, then the alarm circuit will be activated and it will give the alarm. This system is more suitable for the large-scale fish forming unit. But this system installation cost is more. [10], developed an intelligent, networked aquaculture environment monitoring system with low cost, low power consumption, and high-reliability characteristics of the wireless sensor network based on the Zigbee

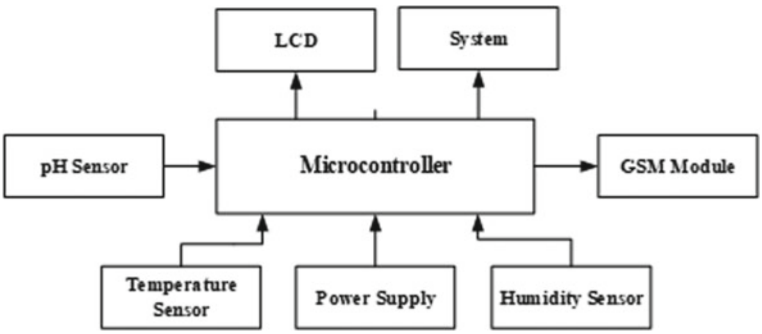

Fig.1 Block diagram of transmitter

protocol. [11], Present water recycling and reducing water waste with the assistance of a vertical aquatic system for energy management with electronic control. They also described the self-cleaning of organic waste in aquaculture. This design can easy to regulate water flow, and reduce labor costs. [12], reviewed various water quality parameters that are required to measure the water quality index during the summer and winter seasons of lake water and also offered strategies to enhance the lake water quality, such as a total ban on pollution-causing activities. [13], have designed a time-to- time fish feeding system to reduce labor cost and food wastage. This system can be designed by a microcontroller, DC motor, food storage system, and control circuit. The feeding time and food container opening time are adjusted as per the requirement. The program is stored in the microcontroller. Based in the program, the DC motor is operated through the PWM (Pulse Width Modulation) technique, and the food is fed to the fish through a food spreader. This device reduces the operation cost and as per the schedule, the food is spread in the fish container. But the productive efficiency is less be- cause some of the fishes will take more food than other fishes. In this method, food wastage is also more. [14], Since independence, the country has shown constant and sustained increases in fish output due to its diversified aquatic resources. In addition to producing about 6.3 percent of the world's fish, the sector contributes 1.1 percent to GDP and 5.15 percent to agricultural GDP. Currently, the inland sector contributes around 65 percent of the 10.07 mil- lion metric tonnes of overall fish production, with cultural fisheries making up roughly the same. However, disease recurrence has become a significant limitation to sustainable aquaculture output and product trade, hurting fishers' socioeconomic condition. Infection by opportunistic infections can be caused by a variety of stress conditions, including insufficient physicochemical and microbiological quality of culture water, low nutritional status, and excessive stocking density. [15], provide a survey on Wireless Sensor Network (WSN) applications in water quality monitoring. They also compare various sensor node topologies in terms of microcontroller units, wireless communication protocols used, data security implementation, and power supply topologies. The survey focuses on monitoring water quality metrics such as pH, electrical conductivity, oxidation-reduction potential (ORP), and turbidity, as well as the numerous obstacles connected with water quality assessment using WSN. They noted how the benefits of WSN stem from its low cost and capacity to execute measurements virtually and in real-time, as proposed by previous writers while taking into consideration their coverage, energy, and security is- sues. These networks, however, have resource constraints in terms of memory, processing power, energy/electricity, and communication bandwidth. [16], examined several approaches for analyzing lake water quality, such as water quality index, Hyperion, and hazard quotient. Analyzed the existence of contaminants in the lake that damage the aquatic ecosystem and proposed that pollution prevention and water re-use be implemented with nutrient re- cycling in regulated urban agriculture. [17], reviewed comprehensively and discussed the use of new techniques in the detection of critical water quality parameters, such as pH, effective chlorination, dissolved oxygen, turbidity, fluoride, and biochemical oxygen demand (B.O.D.) and summarized the benefits and limitations of optical sensors, MEMS and Biosensors for indication of different water parameters. [18], describes the Guidelines for

Regulating Coastal Aquaculture for improving the production efficiency in various aqua- culture forms. [19], concentrated on identifying the most significant biological species necessary for certain processes, such as nitrification or fertilization of a specific algal species for nitrogen removal or oxygen replenishment for sustainable fish production. An autonomous system was developed to monitor water quality based on aquaculture size and temperature [20, 21].

2.2 Water Quality Monitoring Using IoT

[22], Presents an intelligent web-based control system to improve aquaculture. They designed an aquaponic cycle for recycling water between aquariums and plants. This cycle will convert fish wastage into fertilizers for plants to grow and maintain the water clean. [23], built an NB-IoT-based monitoring system to keep an eye on aquaculture ponds' water quality. It enables distributed monitoring and centrally managed management of aquaculture environment water quality parameters. It involves collecting data, distant transmission, data recovery, remote access, and advanced control functions. [24], have de- signed and implemented an online water monitoring system in a botanical garden for the measurement of pH, EC, ORP, and water Temperature using four sensors. The system consists of a microcontroller and all the sensors connected to the controller. The electrical power supply is given to the controller through the solar PV panel with a battery. The measuring data was continuously measured by the sensors and it sends to the data monitoring system through LoRa transmission. This system construction cost is low, real-time data will be collected and simple in data visualization. [25], has developed a smart IoT-based mini aquarium monitoring system. This system was designed by various sensors like Dissolved Oxygen (DO), temperature sensor, water level sensor, PH sensor, Electric Conductivity (EC) sensor, and total dissolved solids (TDS) sensors. This system can be used to closely monitor the fish behavior and sufficient food feeding of the system. This system's accuracy is more, but the installation cost is high. [26], developed a water level and quality monitoring system to monitor and report the parameters to mobile applications using MQTT protocol. A method suggested for real-time monitoring of water quality indicators uses wireless sensor networks, which monitor several water quality parameters remotely through distributed IoT [27–29].

[30], Present the findings of various European initiatives that use IoT to monitor water quality in aquaculture. The usage of PROTEUS novel sensors, which are based on cutting-edge carbon nanotube technology, was also discussed. to install high-performance, low-cost sensors to decrease maintenance costs. [31], showed the viability of a multi-parameter water quality monitoring system for floating harbors by gathering real-time high-frequency water quality data and displaying it online using wireless sensor networks and IoT. [32], have designed an IoT-based water level, salinity and pH in the water measurement device using the beat sensor. This system's power consumption is less and the device is suitable for agriculture and aquaculture. [33], have designed air and water quality monitoring system with the help of sensor

and IoT-based technology. It is portable and easy to install as per the requirements. It is used to measure temperature, humidity, volatile organic compounds in the air and temperature and pH level in the water. However, in this system power consumption is more and ethernet cable cables are required. [34], created an event-based Internet robotic system that was used to organize aquaculture chores. The robotic system is a dependable instrument for performing feeding and water quality measurement chores in an experimental shade house to aid aquaculture research and increase intense cultivation efficiency. It offers a closed loop event-referenced control system that may be expanded to a bilateral teleoperation system to deliver sensory input and improve user remote perception over the ponds. [35], have proposed a seawater quality monitoring system in the country of Fiji. This system is used to measure or sense the various parameters in the water and that data will send to the monitoring system using IoT and remote sensing technology. In the research work, 4 samples were tested under various conditions. The results were match the expected results. The system operation is depending on the GSM and cloud technology.

2.3 Water Quality Monitoring Using Artificial Intelligence

[36], employing wireless technologies, created a prototype water quality monitoring system The prototype system may be separated into two sections for implementation. The sensors in the hardware implementation may be used to test water quality in terms of PH, Oxidization-Reduction Potential (ORP), Dissolved Oxygen (DO), and Electrical Conductivity (EC). The self-healing method can be used to restore data if it is interrupted for an extended length of time. The data that is continually captured will be sent to the cloud. Continuous data monitoring is feasible in this system under all situations. In addition to a deep learning prediction model of water quality parameter content distribution based on multi-source feature fusion of spectral image and convolutional neural network, a technique for acquiring water quality parameters suitable for freshwater aquaculture was also created [37]. [38], have developed a drinking water quality measurement device using IoT, Machine Learning, and Cloud Computing. This device is helpful for the measurement of water quality in any area (like rural and urban areas). This measurement including required actions will reduce the number of people from various dis- eases and deaths. This system's operation and maintenance cost is less. [39], created an early warning system for recirculating aquaculture water quality monitoring. It assesses the interaction hazardous behavior of a combination of un-ionized ammonia, nitrite, zinc copper, and aluminum to Aliivibrio fischeri using linear independent action models and linear concentration addition models. [40], have proposed a fish behavior-based smart fish feeding system. In this system, the fish container is divided into two unequal parts. The larger part contained sand and plants. This chamber is comfortable for the fish to spend more time in. The smaller chamber is used for food feeding and when they want the food, then only they will enter the chamber. In this system, a webcam, interface circuit, and automatic dispenser with a stepper motor are used for food feeding. When food

is required, the fish entered the food feeding chamber. It is captured or recorded by the webcam. Based on the fish behavior, the stepper motor is operated by the interface circuit to open the nozzle of the automatic dispenser to release the food into the smaller chamber. This method reduces food wastage, decrease maintenance cost and increase productivity. But in this system, continuous monitoring is required because if there is any fault in any part of the smart system, detecting de- vices are not inserted. [41], created a prediction model for an online water quality monitoring system for intensive fish farming in China, which was integrated with a web server and mobile communications technologies. Based on past data saved on the server, it is intended to anticipate water quality using artificial neural networks (ANNs) and adjust water quality in real-time to minimize catastrophic losses. [42], implemented a wireless sensor network for collecting seawater temperatures with sensor nodes and uploading the data to a server platform using a LoRa and MQTT combination network, the results of which can be obtained instantly by logging in to the WEB. [43], introduced a new smart sensor system for water quality monitoring that employs spectroscopic techniques in conjunction with the measurement of physicochemical variables to estimate global pollution parameters in water samples, specifically the Chemical Oxygen Demand (COD). An artificial neural network technique is used to generate this estimation, which is based on a multisensor fusion approach. A machine learning model was developed to estimate the Water Quality Index Class (WQI) based on the parameters like temperature, dissolved oxygen, pH value etc [44–47]. [48], a machine learning method was developed to predict the Water Quality Class (WQC) based on characteristics such as temperature, dissolved oxygen, pH value, turbidity, and nitrates.

3 Discussion

The summary of various kinds of water quality monitoring techniques for aquaculture are shown in Table 1.

Which includes the various water quality parameter for aquatic crops growth and the communication of those parameters through wireless net- works, Internet of Things and artificial intelligence.

4 Conclusion

Aquaculture in India is a growing business with diverse aquatic resources and potential, employing millions at the primary level and many further up the value chain. The crop (shrimp, fish, etc.) in aquaculture is determined by the parameters of the water. Water quality is a measure of the state of water in relation to the needs or purposes of one or more biotic organisms. To increase production, water's physical, chemical, and biological characteristics should be kept at ideal levels. Climate

Table 1 Comparison of Water quality monitoring systems using WSN, IoT and ML

Item	Parameters	Control Board	Technology Used	Operating Frequency band (MHz)	Data rate (Kbps)	Range	Comparative Power consumption
[1]	Temp, pH, DO	Arduino MEGA2650	Wireless ZigBee Network	2400, 915, 868	250, 40, 20	100 m +	Low
[3]	Temp, pH, DO, EC, ERP	Arduino Uno, Raspberry Pi 3	ZigBee	2400, 915, 868	250, 40, 20	100 m +	Low
[4]	Turbidity, Temp	Raspberry Pi	GPRS	800, 900, 1800, 1900	56–114	Depends on Internet access	Low
[5]	Temp, conductivity, Turbidi-ty, fish presence	Arduino MEGA2650	Wi-Fi	2400	1000	46 m – 92 m	Low
[6]	Temp, pH, DO	STM32	GPRS, GPS	800, 900, 1800, 1900	56–114	Depends on Internet access	Low
[23]	Temp, pH, DO, Aerator	STM32	IoT	758–960	125–150	15 km	Low
[24]	Temp, pH, ORP, EC	Arduino Mega2560	Lora	865–867	0.3 - 50	5–15 km	Low
[25]	pH, EC, DO, TDS, Water level, Temp	ESP8266, IoT kit	IoT	758–960	125–150	15 km	Low
[31]	pH, DO, EC, turbidity, ORP	Microcontroller	Wi-Fi	2400	1000	46 m – 92 m	Low
[36]	pH, EC, Temp, DO, ORP	Microcontroller	GPRS, IoT, ML	800, 900, 1800, 1900	56–114	Depends on Internet access	Low

change consequences must be evaluated with strategies to reduce air pollution. Water purification procedures should exist in current systems from filtering operations that should be carried out be- fore introducing any foreign material into the water body. Existing systems simply monitor water parameters such as pH, dissolved oxygen, temperature, and turbidity and communicate data to remote locations via wireless sensor networks and the Internet of things. The majority of these systems do not monitor the chemical and biological properties of water, which impact yield output. These issues, however, may be overcome with considerable research, advancements, and the application of appropriate current approaches. The existing systems can be improved by taking into account a large set of physicochemical and bacteriological parameters of water, storing the database in servers, and developing risk assessment algorithms using internet of things and machine learning tools for integrating many sensors to evaluate the risk of water degradation and improving production. With more study, these approaches may be able to give a "One-Stop Solution" for monitoring and maintaining the entire water quality management system, allowing for a very bright and good future in the forthcoming science and technology period.

References

1. B´orquez L´opez RA, Martinez Cordova LR, Gil Nun˜ez JC, Gonzalez Galaviz JR, Ibarra Gamez JC,Casillas Hernandez R (2020) Im- plementation and evaluation of open-source hardware to monitor water quality in precision aquaculture. Sensors 20(21):6112
2. Salim TI, Haiyunnisa T, Alam HS (2016) Design and implementation of water quality monitoring for eel fish aquaculture. In: 2016 Interna- tional symposium on electronics and smart devices (ISESD), IEEE, pp 208–213
3. Khatri P, Gupta KK, Gupta RK (2019) Smart water quality moni- toring system for distribution networks. In: Proceedings of international conference on sustainable computing in science, technology and man- agement (SUSCOM), Amity University Rajasthan, Jaipur-India
4. Doshi S, Dube S (2019) Wireless sensor network to monitor river wa- ter impurity. In: International conference on computer networks and communication technologies, pp 809–817
5. Parra L, Sendra S, Garc´ıa L, Lloret J (2018) Design and deployment of low-cost sensors for monitoring the water quality and fish behavior in aquaculture tanks during the feeding process. Sensors 18(3):750
6. Zhu X, Liu H, Chen Tian X (2018) Automatic cruise system for water quality monitoring. Int J Agric Bi ol Eng 11(4):244–250
7. Wiranto G, Maulana YY, Hermida IDP, Syamsu I, Mah- mudin D (2015) Integrated online water quality monitoring. In: 2015 Interna- tional conference on smart sensors and application (ICSSA), IEEE, pp 111–115
8. Chandanapalli SB, Reddy ES, Lakshmi DR et al. (2014) Design and deployment of aqua monitoring system using wireless sensor networks and iar-kick. J Aquac Res Dev 5(7)
9. Kamisetti SNR, Shaligram AD, Sadistap S (2012) Smart electronic system for pond management in fresh water aquaculture. In: 2012 IEEE Symposium on industrial electronics and applications, IEEE, pp 173–175
10. Ding W, Ma Y (2011) The application of wireless sensor in aquaculture water quality monitoring. In: International conference on computer and computing technologies in agriculture, Springer, pp 502–507
11. Shin KJ, Angani AV, Akbar M (2017) Fully automatic fluid flow control system for smart vertical aquarium. In: 2017 International con- ference on applied system innovation (ICASI), IEEE, pp 424– 427
12. Gorde S, Jadhav M (2013) Assessment of water quality parameters: a review. J Eng Res Appl 3(6):2029–2035
13. Noor M, Hussian A, Saaid MF, Ali M, Zolkapli M (2012) The design and development of automatic fish feeder system using pic microcon- troller. In: 2012 IEEE control and system graduate research collo- quium, IEEE, pp 343–347
14. Mishra SS, Rakesh D, Dhiman M, Choudhary P, Debbarma J, Sa-hoo S, Mishra C (2017) Present status of fish disease management in fresh- water aquaculture in india: state-of-the-art-review. J Aquacul Fish 1(003):14
15. Pule M, Yahya A, Chuma J (2017) Wireless sensor networks: a survey on monitoring water quality. J Appl Res Technol 15(6):562–570

16. Bhateria R, Jain D (2016) Water quality assessment of lake water: a review. Sustain Water Res Manag 2(2):161–173
17. Bhardwaj J, Gupta KK, Gupta R (2015) A review of emerging trends on water quality measurement sensors. In: 2015 international confer- ence on technologies for sustainable development (ICTSD), IEEE, pp 1–6
18. Guidelines for regulating coastal aquaculture. caa.gov.in/uploaded/doc/Guidelines-Englishnew.pdf, accessed: 2022–08–24
19. Naughton S, Kavanagh S, Lynch M, Rowan NJ (2020) Synchronizing use of sophisticated wet-laboratory and in-field handheld technologies for real-time monitoring of key microalgae, bacteria and physicochemical parameters influencing efficacy of water quality in a freshwater aquaculture recirculation system: a case study from the republic of Ireland. Aquaculture 526:735377
20. Dolan A (2015) The effects of aquarium size and temperature on color vi- brancy size and physical activity in bettasplendens. Maryville College, Maryville, TN, USA, Tech. Rep 53309811
21. Chen J-H, Sung W-T, Lin G-Y (2015) Automated monitoring system for the fish farm aquaculture environment. In: 2015 IEEE international conference on systems, man, and cybernetics, IEEE, pp 1161– 1166
22. Elsokah MM, Sakah M (2019) Next generation of smart aquaponics with internet of things solutions. In: 2019 19th international confer- ence on sciences and techniques of automatic control and computer engineering (STA), IEEE, pp 106–111
23. Huan J, Li H, Wu F, Cao W (2020) Design of water quality monitoring system for aquaculture ponds based on nb-iot. Aquacul Eng 90:102088
24. Ngom B, Diallo M, Gueye B, Marilleau N (2019) Lora-based mea- surement station for water quality monitoring: case of botanical garden pool. In: 2019 IEEE sensors applications symposium (SAS), IEEE, pp 1–4
25. Lin Y-B, Tseng H-C (2019) Fishtalk: an iot-based mini aquarium sys- tem. IEEE Access 7:35457–35469
26. Sapkal R, Wattamwar P, Waghmode R, Tamboli U (2019) A review- water quality monitoring system
27. Encinas C, Ruiz E, Cortez J, Espinoza A (2017) Design and implemen- tation of a distributed iot system for the monitoring of water quality in aquaculture. In: 2017 wireless telecommunications symposium (WTS), IEEE, pp 1–7
28. Tseng S-P, Li Y-R, Wang M-C (2016) An application of internet of things on sustainable aquaculture system. In: 2016 International con- ference on orange technologies (ICOT), IEEE, pp 17–19
29. Raju KRSR, Varma GHK (2017) Knowledge based real time moni- toring system for aquaculture using Iot. In: 2017 IEEE 7th international advance computing conference (IACC), IEEE, pp 318–321
30. Dupont C, Cousin Y, Dupont S (2018) Iot for aquaculture 4.0 smart and easy-to-deploy real-time water monitoring with Iot. In: 2018 Global internet of things summit (GIoTS), IEEE, pp 1–5
31. Chen Y, Han D (2018) Water quality monitoring in smart city: A pilot project. Autom Constr 89:307–316
32. Manyvone D, Takitoge R, Ishibashi K (2018) Wireless and low-power water quality monitoring beat sensors for agri and acqua-culture Iot applications. In: 2018 15th international conference on electrical en- gineering/electronics, computer, telecommunications and information technology (ECTI-CON), IEEE, pp 122–125
33. Simi´c M, Stojanovi´c GM, Manjakkal L, Zaraska K (2016) Multi-sensor system for remote environmental (air and water) quality monitoring. In: 2016 24th telecommunications forum (TELFOR), IEEE, pp 1–4
34. Luna FDVB, de la Rosa AE, Naranjo JS, Jagu¨ey JG (2016) Robotic system for automation of water quality monitoring and feeding in aquaculture shadehouse. IEEE Transa Syst Man Cybern Syst 47(7):1575–1589

35. Prasad A, Mamun KA, Islam F, Haqva H (2015) Smart water qual- ity monitoring system. In: 2015 2nd Asia-pacific world congress on computer science and engineering (APWC on CSE), IEEE, pp 1–6
36. Ariffin SH, Baharuddin MA, Fauzi MHM, Latiff NM, Syed- Yusof SK, Latiff NA (2017) Wireless water quality cloud monitoring system with self-healing algorithm. In: 2017 IEEE 13th Malaysia international conference on communications (MICC), IEEE, pp 218–223
37. Wang L, Yue X, Wang H, Ling K, Liu Y, Wang J, Hong J, Pen W, Song H (2020) Dynamic inversion of inland aquaculture water quality based on uavs-wsn spectral analysis. Remote Sensing 12(3):402
38. Koditala NK, Pandey PS (2018) Water quality monitoring system using iot and machine learning. In: 2018 International Conference on Research in Intelligent and Computing in Engineering (RICE), IEEE, pp 1–5
39. Da Silva LF, Yang Z, Pires NM, Dong T, Teien H-C, Store-bakken T, Salbu B (2018) Monitoring aquaculture water quality: design of an early warning sensor with aliivibrio fischeri and predictive models. Sensors 18(9):2848
40. AlZubi HS, Al-Nuaimy W, Buckley J, Young I (2016) An intelligent behavior-based fish feeding system. In: 2016 13th international multi- conference on systems, signals & devices (SSD), IEEE, pp 22–29
41. Zhu X, Li D, He D, Wang J, Ma D, Li F (2010) A remote wireless system for water quality online monitoring in intensive fish culture. Comput Electron Agric 71:S3–S9
42. Huang A, Huang M, Shao Z, Zhang X, Wu D, Cao C (2019) A prac- tical marine wireless sensor network monitoring system based on lora and mqtt. In 2019 IEEE 2nd international conference on electronics technology (ICET), IEEE, pp 330–334
43. Charef A, Ghauch A, Baussand P, Martin-Bouyer M (2000) Water quality monitoring using a smart sensing system. Measurement 28(3):219–224
44. Veeramsetty V, Shadamaki N, Pinninti R, Guduri N, Ashish G (2022) Water quality index estimation using linear regression model. In: AIP conference proceedings, vol 2418, no 1. AIP Publishing LLC, p 040033
45. Rupal M, Tanushree B, Sukalyan C (2012) Quality characterization of groundwater using water quality index in Surat city, Gujarat. India. Int Res J Envir Sci 1(4):14–23
46. Ahmed U, Mumtaz R, Anwar H, Shah AA, Irfan R, Garc´ıa JN (2019) Efficient water quality prediction using supervised machine learn- ing. Water 11(11):2210
47. Smith DG (1990) A better water quality indexing system for rivers and streams. Water Res 24(10):1237–1244
48. Veeramsetty V, Shadamaki N, Pinninti R, Mohnot A, Ashish G (2022) Water quality classification using support vector machine. In: AIP Con- ference Proceedings, vol 2418, no 1, AIP Publishing LLC, p 040022