ISSN: 2458-8989

Natural and Engineering Sciences

NESciences, 2024, 9 (2): 234-243 doi: 10.28978/nesciences.1575456

Effective Surveillance of Water Quality in Recirculating Aquaculture Systems through the Application of Intelligent Biosensors

Manish Nandy [1*], Ahilya Dubey [2]

[1*] Assistant Professor, Department of CS & IT, Kalinga University, Raipur, India.
E-mail: ku.manishnandy@kalingauniversity.ac.in

[2] Research Scholar, Department of CS & IT, Kalinga University, Raipur, India.
E-mail: ahilya.dubey@kalingauniversity.ac.in

Abstract

Water quality (WQ) is the paramount element influencing fish well-being and productivity in aquaculture farming systems. The survival of fish is mostly reliant on the aquatic environment that sustains them. Consequently, it is vital to possess a comprehensive awareness of the WQ prerequisites for the fish. Optimal WQ in Recirculating Aquaculture Systems (RAS) is essential for cultivating species' effective development and survival. Currently, no laws dictate the parameters to be monitored in RAS, leaving each farmer to choose which parameters to monitor. Historically, WQ measurements have been assessed at certain intervals using portable sensors and laboratory tests, which may be labor-intensive. This study proposes an Effective Surveillance of Water Quality (ESWQ) in RAS using Intelligent Biosensors (IBS). This study examines essential water characteristics (temperature, pH, calcium, magnesium, and Dissolved Oxygen (DO)) for RAS and evaluates the IBS for monitoring these factors. This research provides a potential solution for RAS using IBS, which would enhance ESWQ aspects, facilitate data-driven decision-making, and enable more rapid adaptation to evolving RAS situations.

Keywords:

Water quality, recirculating, aquaculture, intelligent biosensors, surveillance, dissolved oxygen.

Article history:

Received: 27/05/2024, Revised: 21/07/2024, Accepted: 30/08/2024, Available online: 30/10/2024

Introduction and Related Works on WQ, RAS, and IBS

Water pollution is a global issue, necessitating constant monitoring of contaminating ions to ensure water safety. Furthermore, freshwater and aquatic fishing substantially contribute to the economies of nations such as Australia, Japan, and the Philippines. Globally, it is acknowledged that high WQ is essential for sustaining successful aquaculture output and competing within the expanding aquaculture sector (Grilli et al., 2020).

Corresponding Author: Manish Nandy, E-mail: ku.manishnandy@kalingauniversity.ac.in

Subpar WQ leads to poorer goods, health hazards for people, and diminished profits. Water pollutants adversely affect farmed fish's maturation, development, reproduction, and death, significantly diminishing output levels (Jayapriya, 2021). Certain contaminants may persist in minimal amounts but risk human health (MacNeil et al., 2019).

Fish respire, expel waste, consume food, breed, and regulate their internal salt balance within their aquatic environment (Dhanaraju et al., 2022). Therefore, preserving WQ is crucial for the success or failure of an aquaculture operation. A set of recommendations for farmers about critical WQ factors and the safe levels of various indicators is required. Otherwise, ongoing deterioration of WQ due to human causes will diminish the farm's production and profitability (Akhter et al., 2021; Bolfe et al., 2020). Consequently, regulating and overseeing WQ in aquatic resources are essential for freshwater and maritime aquaculture (Bobir et al., 2024).

RAS are terrestrial-intensive aquaculture systems that recycle water, mostly via physical and biological methods, to minimize water use while ensuring sufficient WQ (Buljubašić, 2020). RAS employs contemporary insights from biology, ecological sciences, mechanical design, and computer science (Xiao et al., 2019). Circulating water is reused often, with just a minimal fraction replaced by fresh water. A diverse array of marine and freshwater organisms is cultivated in RAS from hatching to grow-out stages. RAS has been used for fish production for many decades, although only a limited number of extensive systems, producing over 10 million kg annually, are now operational (Aura et al., 2018; Giacomazzo et al., 2020).

The concept of RAS originated from biological purifying techniques in the 1965s. Since the 1980s, biotic science, automated control, bottom release, and regulation of physical parameters have been used. The current emphasis of RAS development is on enhancing water treatment devices and technologies, long-term viability, and wastewater discharge levels (Becke et al., 2019). Nevertheless, given that RAS are power-consuming and cost-intensive, recommendations have been proposed to enhance their economic efficiency (Robles et al., 2015).

WQ may be classified as physical characteristics, organic pollutants, biological pollutants, and microorganisms (Su et al., 2020). Physical factors are contingent upon climate and environmental variables. WQ management is crucial in aquaculture, particularly in RAS, where water is continuously cycled inside the system. The primary metrics for quality monitoring encompass pH, temperature, oxidation-reduction potential (ORP/Redox), turbidity, salinity, and DO. Optimal WQ may promote fish development rates and reduce the incidence of fish illnesses (Tolentino et al., 2020). Technologies that provide quick, and computerized surveillance and information storage are thus in high demand.

The quality of water in RAS is influenced by food input and configuration. Dissolved chemicals and particle materials may be hard to eliminate from the structure and may serve as the substratum for bacterial proliferation. Certain bacterial species may generate off-flavors in the system (Lindholm-Lehto et al., 2019; Suurnäkki et al., 2020). A significant proliferation of microorganisms might adversely impact fish by functioning as pathogens or vying for oxygen resources.

In RAS, WQ parameters are maintained consistently to provide optimal circumstances for the fish (Rojas-Tirado et al., 2018). Consequently, it is essential to understand and regulate the variables that alter WQ. WQ must be meticulously controlled to provide optimum growing conditions in RAS (Naughton et al., 2020). In recirculating aquaculture systems, fish are often cultivated at elevated densities, accumulating organic matter and nutrients. These aspects must be regulated and observed, yet the existing instruments are often intricate or exhibit significant delays between the sample and outcomes. No rules exist on the factors to be measured, resulting in each farmer having their perspective and capabilities for assessing WQ. Furthermore, there are no established parameters for permissible ranges and variations.

A multitude of research has been undertaken to investigate and advance Wireless Sensor Networks (WSN) for use in RAS. Many of these knowledges enhance the capacity to assess critical physical characteristics in real-time and promptly notify relevant personnel at the site when issues occur, enabling swift remediation (Kang et al., 2019). Lindholm-Lehto, (2023) developed a WSN-based water surveillance system that sends collected data and saves it in a database. The device can continuously detect temperature, pressure, and dissolved oxygen throughout the day. Upon detection of an issue, an SMS or email was sent to notify the person accountable for the capability. Boonsong et al., (2020) suggested an alternative water monitoring system based on WSN that can assess pH, water temperature, depth of water, and DO. The acquired information was sent to a dataset that supplied the details to the program for real-time monitoring. The software used in their system effectively segregated the reasoning, presentation, and information layers to enhance scalability and functionality. Alerts may also be sent to consumers via SMS. Finally, Su et al., (2020) introduced a WSN-based scheme that collected physical characteristic data. It has a real-time dashboard that presents information both quantitatively and visually. Silva et al., (2022) recently presented an interactive remote surveillance system for monitoring WQ in RAS with solar cells and batteries for effective supply of power.

Effective Surveillance of Water Quality (ESWQ) in RAS Using Intelligent Biosensors (IBS)

Significant Physical Parameters and Effects

Key physical factors to monitor and regulate in an RAS include DO, temperature, pH level, saltiness, and turbidity. Variations in these factors will directly influence animal health, feed efficiency, rate of growth, and load capacity. The water temperature influences the eating behavior and development of fish. Aquatic organisms often endure pressure and disease outbursts when temperatures are consistently at their maximum tolerance or vary abruptly. Furthermore, heated water has a lower dissolved oxygen concentration than chilly water. The concentration of DO in water and the quantity of oxygen used are closely correlated with fish size, nursing rate, movement, and temperature. The DO content would decrease with rising temperature and increasing saltiness. The correct quantity of dissolved oxygen is crucial for fish breathing and is also vital for phytoplankton, which converts poisonous ammonia into benign forms. This creature thus contributes indirectly to regulating the water's pH level. The permissible pH range for aquaculture typically lies between 6 and 9.2. When the pH level exceeds 8.5, ammonium (NH_4^+) in the water is transformed into poisonous ammonia (NH_3), a fatal chemical to fish. Conversely, when the pH value falls below 5, alkaline water will extract metals from stones and silt. These metals would negatively impact fish metabolism and their capacity to absorb water, while leading to mortality.

WSN for Physical Variables

Traditionally, the WQ in fish farms is frequently assessed on-site using portable sensors. The aforementioned physical criteria are generally necessary to sustain adequate levels of fish development, irrespective of the species. Although portable tools or sensors enable personnel to make on-site measurements during office hours, fluctuations in a critical water parameter over a safe threshold may transpire outside these hours, unnoticed by the staff. A sustained adverse condition may result in detrimental impacts, including stunted development, undiagnosed illness signs, or aberrant behavior in fish.

Recent improvements in various technologies related to communication and information and the emergence of affordable tiny sensors have enhanced the viability of simultaneously monitoring several parameters using WSN. The potential uses of WSN include surveillance of the three energy sources: greenhouses for cultivation, citrus crops, the condition of livestock (goats or cows), and aquaculture. A WSN consists of several self-organizing sensors installed within a surveillance area that measure, gather, communicate, and analyze data. The collected data is shown on a computer or sent as an alert to farmers for immediate updates. This remote surveillance system optimizes the data collection process, potentially reducing human errors and time interruptions while enhancing the volume and eminence of data across chronological and geographical dimensions.

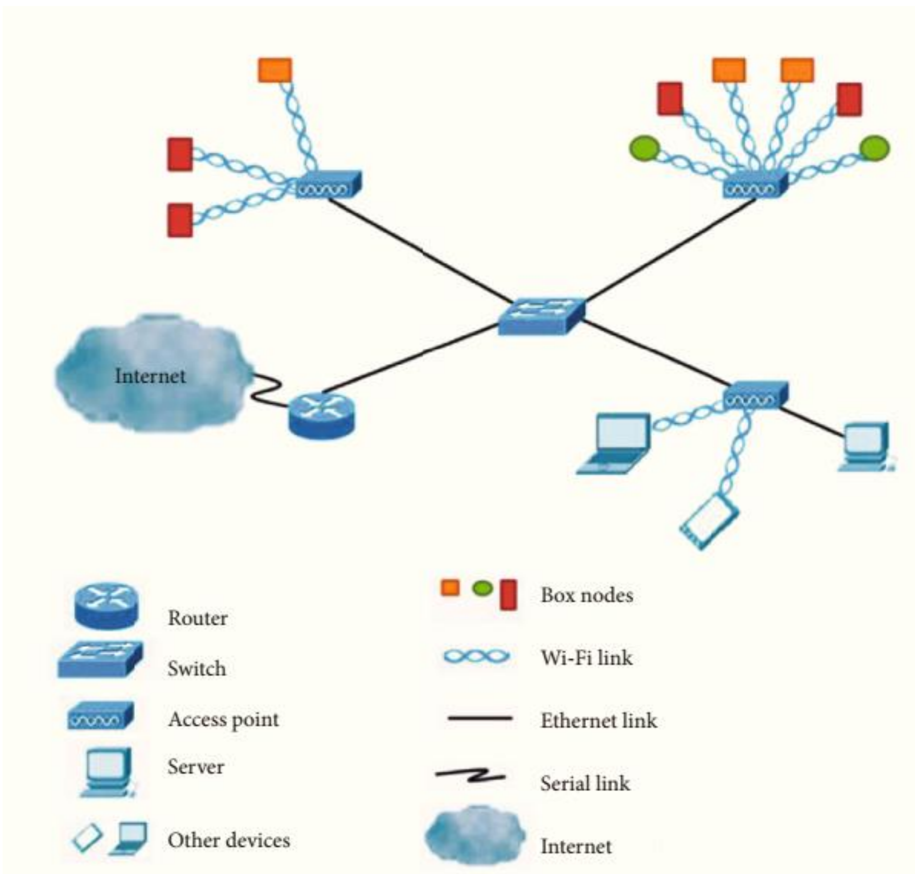

Figure 1. Intelligent Sensor Networks for ESWQ in RAS

Figure 1 depicts the Effective Surveillance of Water Quality (ESWQ) in RAS using Intelligent Sensor Networks. Figure 1 shows a wireless sensor network (WSN) to monitor WQ and fish conduct in RAS chambers during nursing activities. The system consists of sensor nodes in each container that transmit data over the local area network (LAN) to an Internet-based database. The system incorporates an intelligent algorithm that identifies anomalous values and triggers alerts upon occurrence. The system is economically priced at less than 90€, including sensors and terminals.

Biosensors

Biosensors are tiny analytical instruments primarily designed to measure toxins and germs. They may be more attractive for practical and real-time assessment. Visual and electrochemical biosensors are mostly designed to investigate aquatic environments among different biosensor types. Cunha et al. documented a light sensor using DNA aptamers and quantum dots (QDs) for the instantaneous on-site determination of underwater poisons generated by sea and river microbes, including cyanobacteria, and diatoms. This sensor utilizes fluorescence resonance energy transfer (FRET) among a DNA aptamer and QD in the presence of the intended toxin.

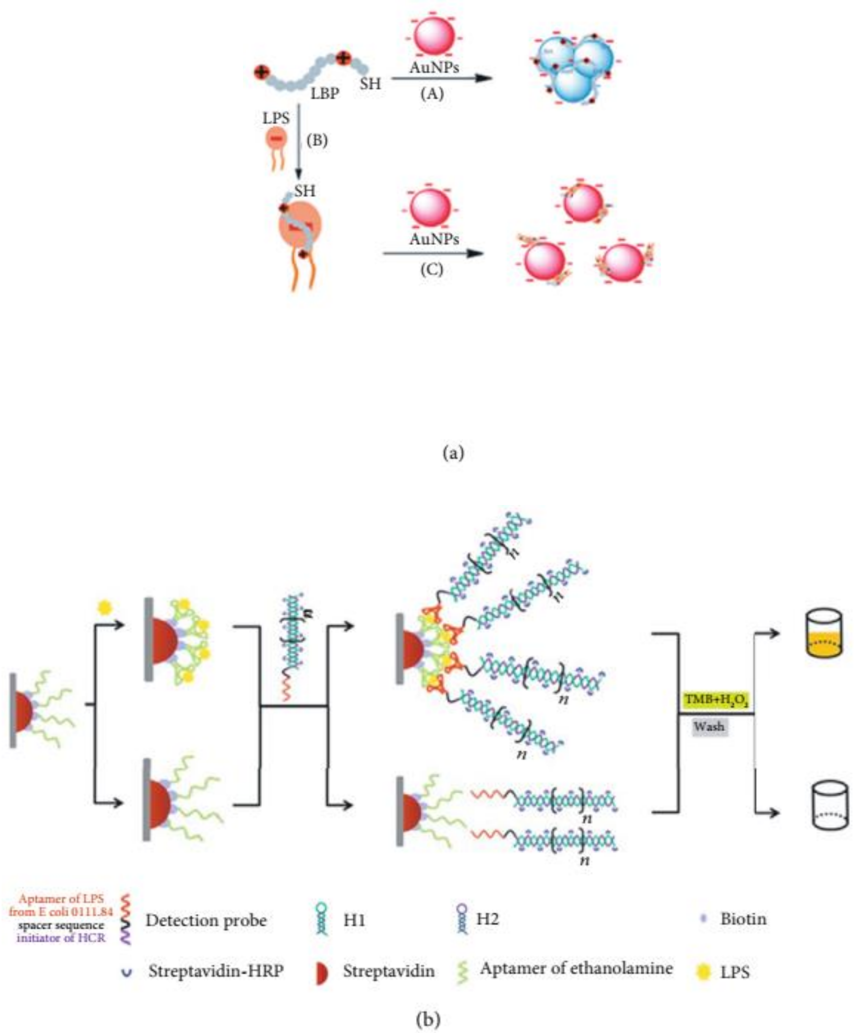

Figure 2. (a) Lipopolysaccharide (LS) sensor using Au-NP composite. (b) Biosensor based on HCR

In response to the extensive issue of bacterial contaminants, many LS biological sensors have been significantly constructed, including photonic fiber-based plasmonic sensors, colorimetric sensors, and nanomaterial sensors. Nanomaterial-based LS sensors use several sensing methods, with nanoparticles serving as direct signal transducers. This is exemplified by colorimetric sensing via agglomeration (shown in Fig. 2(a)) or as signal amplifiers in electrochemical sensors. Colorimetric sensors based on gold nanoparticle (Au-NP) composites are user-friendly, primarily requiring basic blending and visual assessment of the color shift or UV-vis spectroscopic analysis of the absorption spectrum. However, they are susceptible to producing false-positive findings due to their tendency to aggregate inside complicated sample matrices. Therefore, meticulous strategy of the sensor agglomeration approach to prevent error collection and a thorough examination of the model matrix impacts on collection is necessary.

A colorimetric aptasensor was created using a DNA hybridizing chain reaction (HCR) in microplates to attain ultrahigh responsiveness (Fig. 2(b)). In summary, two identical biotinylated DNA hairpins were present in the test solution. Hybridization will not occur until a detecting probe is introduced. The recognition probe has three regions: an LS-mixing aptamer, a separator, and an HCR activator. In the prevalence of LS, this identification inquiry initiated an HCR avalanche in the microplate, whereby the ethoxy aptamer caught the LS affixed to the outer layer of the interaction well. Under ideal circumstances, the elevation in LS concentration resulted in a rise in the light density value produced by the color response. The sensor exhibits a limit of detection (LOD) of 1.74 ng/ml and an average response of 2 to 12 ng/ml.

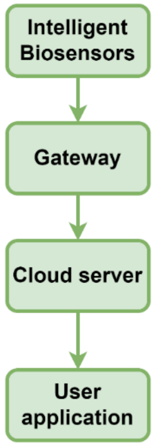

Figure 3. General architecture of the proposed system for ESWQ in RAS

Figure 3 illustrates the general architecture of the proposed system for ESWQ in RAS. The system comprises four primary components: Intelligent Biosensors, which track WQ parameters in real-time; a Gateway that aggregates sensor data and transmits it to a Cloud server for analysis and storage; and a User application that enables end users to access processed data and insights. This design enables ongoing, automated monitoring of WQ, guaranteeing ideal environmental conditions for aquaculture activities.

Results and Discussion

The impedance analyzer is employed to acquire data from each sensor and transform it into significant WQ characteristics by smearing an information processing algorithm. The performance of IBS declines with prolonged usage. Consequently, a self-calibration method will be formulated using the gathered information in the future, augmenting the suggested system's dependability. This study examines essential water characteristics (temperature, calcium, magnesium, nitrate, and DO) for RAS and evaluates the IBS to monitor these factors.

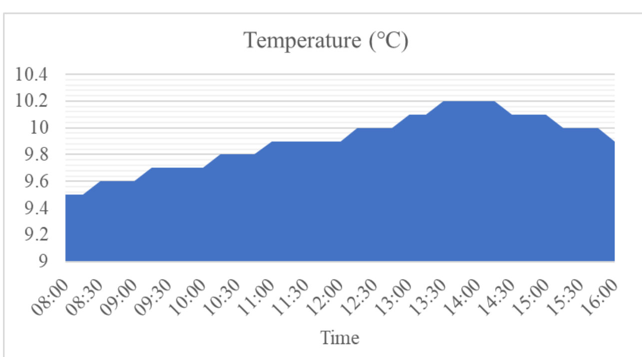

Figure 4. Temperature (in °C) data collected by IBS for ESWQ in RAS

Figure 4 shows the temperature (in °C) data collected by IBS for ESWQ in RAS. This table gives the temperature values at 15-minute intervals, following the figure's general pattern of temperature changes. The data shows a gradual warming trend in the morning and early afternoon, peaking at 10.2°C around 13:30, followed by a slight decline in temperature later in the day.

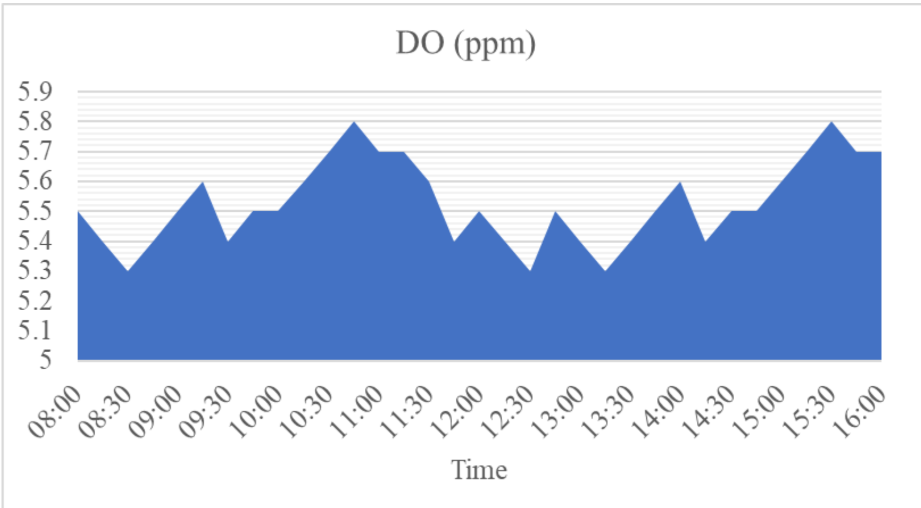

Figure 5. DO (in ppm) data collected by IBS for ESWQ in RAS

Figure 5 depicts the DO (in ppm) data collected by IBS for ESWQ in RAS. Commencing at 5.5 ppm at 08:00, dissolved oxygen levels decrease a little to 5.3 ppm by 08:30, after that, ascending to a maximum of 5.8 ppm by 10:45. Subsequently, DO levels exhibit considerable stability with slight variations between 5.5 and 5.7 ppm till 16:00. These oscillations signify dynamic changes in water conditions, perhaps affected by elements such as biological activity, water temperature, and circulation within the RAS. Maintaining dissolved oxygen levels within an appropriate range is essential for aquatic organisms, making these findings crucial for efficient aquaculture management.

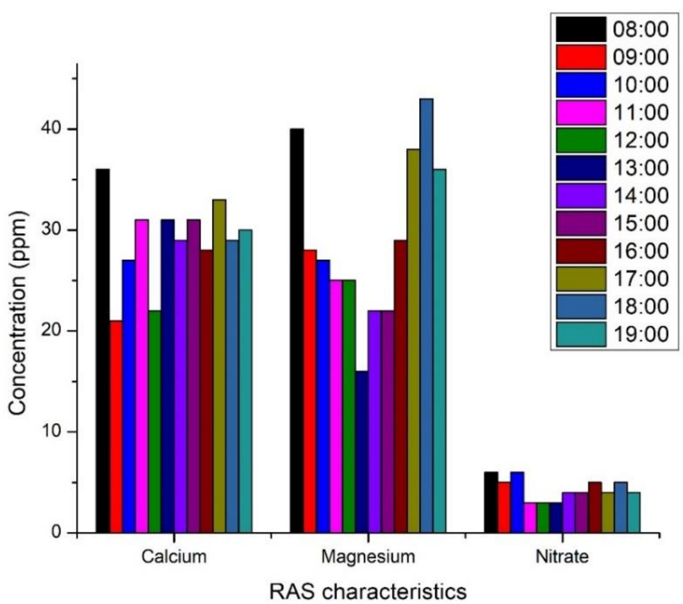

Figure 6. Calcium, magnesium, and nitrate concentration (in ppm) collected by IBS for ESWQ in RAS

Figure 6 illustrates the calcium, magnesium, and nitrate concentration (in ppm) collected by IBS for ESWQ in RAS. The autonomous system may be implemented in any fishing vessel to monitor WQ indicators. The agriculturalists can operate the system with minimum learning and routinely monitor the water nutrient levels to control the farm's production effectively. They may get comments from professionals as needed, regardless of their location globally. This innovative prototype will profoundly influence agriculture by identifying abnormalities early and implementing essential interventions before the problem escalates.

Conclusion

This research introduces an Effective Surveillance of WQ in RAS using Intelligent Biosensors (IBS). This research analyzes critical water parameters for RAS and assesses the IBS to monitor these variables. This study proposes a viable solution for RAS via IBS, improving ESWQ dimensions, promoting data-driven decision-making, and allowing for quicker adaptability to changing RAS circumstances. A colorimetric aptasensor has been developed using a DNA hybridizing chain reaction (HCR) in microplates to achieve ultrahigh sensitivity. The efficacy of IBS diminishes with extended use. Thus, a self-calibration mechanism will be established using the gathered information in the future, thus improving the dependability of the proposed system. IBS data indicates a progressive rising trend in the morning and early afternoon, reaching a top of 10.2°C at around 13:30, followed by a little decrease in temperature later in the day. Also, DO levels demonstrate significant stability, with minor fluctuations between 5.5 and 5.7 ppm until 16:00. These oscillations indicate dynamic changes in water conditions, perhaps influenced by factors such as biological activity, water temperature, and circulation within the RAS. Maintaining dissolved oxygen levels within an optimal range is vital for aquatic species, making these results critical for effective aquaculture management.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

References

Akhter, F., Siddiquei, H. R., Alahi, M. E. E., & Mukhopadhyay, S. C. (2021). Recent advancement of the sensors for monitoring the water quality parameters in smart fisheries farming. *Computers*, 10(3), 26. https://doi.org/10.3390/computers10030026.

Aura, C. M., Musa, S., Yongo, E., Okechi, J. K., Njiru, J. M., Ogari, Z., & Oucho, J. A. (2018). Integration of mapping and socio-economic status of cage culture: Towards balancing lake-use and culture fisheries in Lake Victoria, Kenya. *Aquaculture Research*, 49(1), 532-545.

Becke, C., Schumann, M., Steinhagen, D., Rojas-Tirado, P., Geist, J., & Brinker, A. (2019). Effects of unionized ammonia and suspended solids on rainbow trout (Oncorhynchus mykiss) in recirculating aquaculture systems. *Aquaculture*, 499, 348-357.

Bobir, A.O., Askariy, M., Otabek, Y.Y., Nodir, R.K., Rakhima, A., Zukhra, Z.Y., Sherzod, A.A. (2024). Utilizing Deep Learning and the Internet of Things to Monitor the Health of Aquatic Ecosystems to Conserve Biodiversity. *Natural and Engineering Sciences*, 9(1), 72-83.

Bolfe, É. L., Jorge, L. A. D. C., Sanches, I. D. A., Luchiari Júnior, A., da Costa, C. C., Victoria, D. D. C., & Ramirez, A. R. (2020). Precision and digital agriculture: Adoption of technologies and perception of Brazilian farmers. *Agriculture*, 10(12), 653. https://doi.org/10.3390/agriculture10120653.

Boonsong, W. A. S. A. N. A., Ismail, W., Shinohara, N. A. O. K. I., Nameh, S. M. I. S., Alifah, S. U. R. Y. A. N. I., Hafiz, K. A. M. A. R. U. L., & Kamaludin, T. A. (2020). Real-time water quality monitoring of aquaculture pond using wireless sensor network and internet of things. *Journal of Theoretical and Applied Information Technology*, 98(22), 3573-3582.

Buljubašić, S. (2020). Application of New Technologies in the Water Supply System. *Archives for Technical Sciences*, 1(22), 27–34.

Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agriculture*, 12(10), 1745. https://doi.org/10.3390/agriculture12101745.

Giacomazzo, M., Bertolo, A., Brodeur, P., Massicotte, P., Goyette, J. O., & Magnan, P. (2020). Linking fisheries to land use: How anthropogenic inputs from the watershed shape fish habitat quality. *Science of The Total Environment*, 717, 135377. https://doi.org/10.1016/j.scitotenv.2019.135377

Grilli, G., Mukhopadhyay, S., Curtis, J., & Hynes, S. (2020). Recreational angling demand in a mixed resource fishery. *Fisheries Management and Ecology*, 27(6), 591-599.

Jayapriya, R. (2021). Scientometrics Analysis on Water Treatment During 2011 to 2020. *Indian Journal of Information Sources and Services*, 11(2), 58–63.

Kang, J., Kim, J., & Sohn, M. M. (2019). Supervised learning-based Lifetime Extension of Wireless Sensor Network Nodes. *Journal of Internet Services and Information Security*, 9(4), 59-67.

Lindholm-Lehto, P. (2023). Water quality monitoring in recirculating aquaculture systems. *Aquaculture, Fish and Fisheries*, 3(2), 113-131.

Lindholm-Lehto, P. C., Suurnäkki, S., Pulkkinen, J. T., Aalto, S. L., Tiirola, M., & Vielma, J. (2019). Effect of peracetic acid on levels of geosmin, 2-methylisoborneol, and their potential producers in a recirculating aquaculture system for rearing rainbow trout (Oncorhynchus mykiss). *Aquacultural Engineering*, 85, 56-64.

MacNeil, M. A., Mellin, C., Matthews, S., Wolff, N. H., McClanahan, T. R., Devlin, M., & Graham, N. A. (2019). Water quality mediates resilience on the Great Barrier Reef. *Nature Ecology & Evolution*, 3(4), 620-627.

Naughton, S., Kavanagh, S., Lynch, M., & Rowan, N. J. (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. https://doi.org/10.1016/j.aquaculture.2020.735377.

Robles, T., Alcarria, R., De Andrés, D.M., De la Cruz, M.N., Calero, R., Iglesias, S., & Lopez, M. (2015). An IoT based reference architecture for smart water management processes. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications*, 6(1), 4-23.

Rojas-Tirado, P., Pedersen, P. B., Vadstein, O., & Pedersen, L. F. (2018). Changes in microbial water quality in RAS following altered feed loading. *Aquacultural engineering*, 81, 80-88.

Silva, G. M. E., Campos, D. F., Brasil, J. A. T., Tremblay, M., Mendiondo, E. M., & Ghiglieno, F. (2022). Advances in technological research for online and in situ water quality monitoring—A review. *Sustainability*, 14(9), 5059. https://doi.org/10.3390/su14095059.

Su, X., Sutarlie, L., & Loh, X. J. (2020). Sensors, biosensors, and analytical technologies for aquaculture water quality. *Research*. https://doi.org/10.34133/2020/8272705

Suurnäkki, S., Pulkkinen, J. T., Lindholm-Lehto, P. C., Tiirola, M., & Aalto, S. L. (2020). The effect of peracetic acid on microbial community, water quality, nitrification and rainbow trout (Oncorhynchus mykiss) performance in recirculating aquaculture systems. *Aquaculture*, 516, 734534.

Tolentino, L. K. S., De Pedro, C. P., Icamina, J. D., Navarro, J. B. E., Salvacion, L. J. D., Sobrevilla, G. C. D., & Madrigal, G. A. M. (2020). Development of an IoT-based intensive aquaculture monitoring system with automatic water correction. *International Journal of Computing and Digital Systems*, 10, 1355-1365.

Xiao, R., Wei, Y., An, D., Li, D., Ta, X., Wu, Y., & Ren, Q. (2019). A review on the research status and development trend of equipment in water treatment processes of recirculating aquaculture systems. *Reviews in Aquaculture*, 11(3), 863-895.