JOURNAL OF APPLIED INFORMATION SYSTEMS AND INFROMATICS

Assessing The Impact of Water Quality on Freshwater Aquaculture: A Systematic Literature Review

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***Abstract*— Water quality is a critical determinant of ecosystem sustainability and the productivity of freshwater aquaculture. This study performed a systematic literature review (SLR) to assess the impact of water quality on the growth, health, and yield of freshwater fish. The research examines contemporary technical advancements, such as Internet of Things (IoT) systems, unmanned aerial vehicles (UAVs), machine learning prediction models, and biotechnological methods for monitoring and managing water quality. The literature selection procedure employed the PRISMA framework and encompassed 136 articles sourced from the SCOPUS database. Following rigorous screening processes, three primary publications were chosen for additional examination. The review findings indicate that parameters like dissolved oxygen (DO), pH, ammonia, and temperature significantly influence fish health and production. Contemporary technologies, such IoT and UAVs, have demonstrated their capacity to enhance the effectiveness of water quality monitoring, whilst biotechnology provides novel options for the sustainable treatment of aquaculture waste. This research offers significant insights for scholars, policymakers, and practitioners in the advancement of more efficient and sustainable aquaculture methodologies.**

***Keywords*— Freshwater Aquaculture; Water Quality; IoT; UAV; Biotechnological Approaches, Systematic Literature Review, Fish Growth Performance;**

Manuscript received 09 Jan. 2025; revised 29 Jan. 2025; accepted 05 Mei 2025. Date of publication 05 Mei. 2025.
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I. INTRODUCTION

The quality of the water is a key component in both the sustainability of the ecosystem and the sustainability of aquaculture. Over the past several years, academics have been paying an increasing amount of attention to the impact that water quality has on a variety of industries, including aquaculture in freshwater environments. Water pollution caused by domestic waste, industrialization, and climate change has been shown to have a major influence on critical parameters such as dissolved oxygen, pH, and nitrogen and phosphorus concentrations [1], [2]. Recent studies have shown that these factors have a considerable impact on water quality.

Technological advancements have made it feasible to monitor water quality in a more effective and efficient manner. This is achieved, for example, via the utilization of sensor-based technology and the Internet of Things (IoT) [3], [4]. It has also been demonstrated that the utilization of biotechnological techniques, such as the utilization of microorganisms, may enhance the management of waste from aquaculture operations while simultaneously enhancing the quality of the water [5], [6].

As a result of the advantages of covering a larger area and enhancing the accuracy of forecast of parameters such as biochemical oxygen demand (BOD), the use of unmanned aerial vehicle (drone) technology is also beginning to be used to the monitoring of water quality in real time [7], [8]. Research conducted by other researchers emphasizes the significance of using Geographic Information Systems (GIS) in order to effectively manage data pertaining to water quality in a variety of locales [9], [10].

The widespread usage of polyethylene plastic in Indonesia has a severe influence on freshwater farming systems. Freshwater biota, including omnivorous fish, are susceptible to microplastic exposure [11]. Fuzzy logic is used to create models that examine and predict the quality of water utilized for tilapia aquaculture [12]. Aquaculture is one of the world's fastest expanding food sectors, producing fish for human consumption [13]. Holistic data sets may be used for smart farming by supplying information to management systems for remote monitoring and decision making by farmers [14]. The water quality appropriateness index takes into account water temperature, pH value, turbidity, and dissolved oxygen (DO) level. Using a feed dispenser attached on a frame, the robot moves along a predefined path and places the desired sort of food in the tank [15].

The study, on the other hand, has certain holes that need to be addressed, particularly in the areas of sustainability and the implementation of this technology on a more extensive scale. Accordingly, the purpose of this study is to analyze the potential for technological innovation to improve the sustainability of aquaculture systems, identify current trends in water quality management, and integrate the most important findings from a variety of research studies that are linked to water quality.

Within the scope of freshwater aquaculture, the purpose of this study is to carry out a systematic literature review (SLR) of previous research that has been conducted on water quality. The Internet of Things (IoT), unmanned aerial vehicles (drones), and biotechnological techniques are some examples of the emerging technologies that are being utilized to monitor and enhance water quality. The purpose of this study is to identify these advances. In addition to that, the purpose of this research is to assess the efficiency of the procedures that have been put into place, to determine the research gaps that are still present, and to make suggestions for approaches that will be sustainable in the future. So, it is envisaged that this research will be able to make a substantial contribution to the management of water quality that is both more effective and more sustainable, while also improving the productivity of freshwater aquaculture.

II. METHOD

This research used a Systematic Literature Review (SLR) methodology to find, evaluate, and synthesize scientific literature pertaining to water quality utilizing advanced technologies. The initial data was sourced from SCOPUS, a very renowned and extensive indexed scientific reference database. The search approach included a combination of specialized keywords related to current technology, water quality factors, and application settings including aquaculture and freshwater habitats. A total of 136 items were discovered from this search. The articles underwent a multi-tiered selection procedure, encompassing the elimination of duplicates, preliminary screening based on inclusion criteria, and assessment of the appropriateness of full-text reporting. Following a rigorous screening process, three papers were ultimately chosen for additional research. This approach aims to guarantee that the literature employed possesses substantial relevance to the research issue and may significantly contribute to the study's objectives. A Systematic Literature Review diagram for studies on water quality is shown in Figure 1:

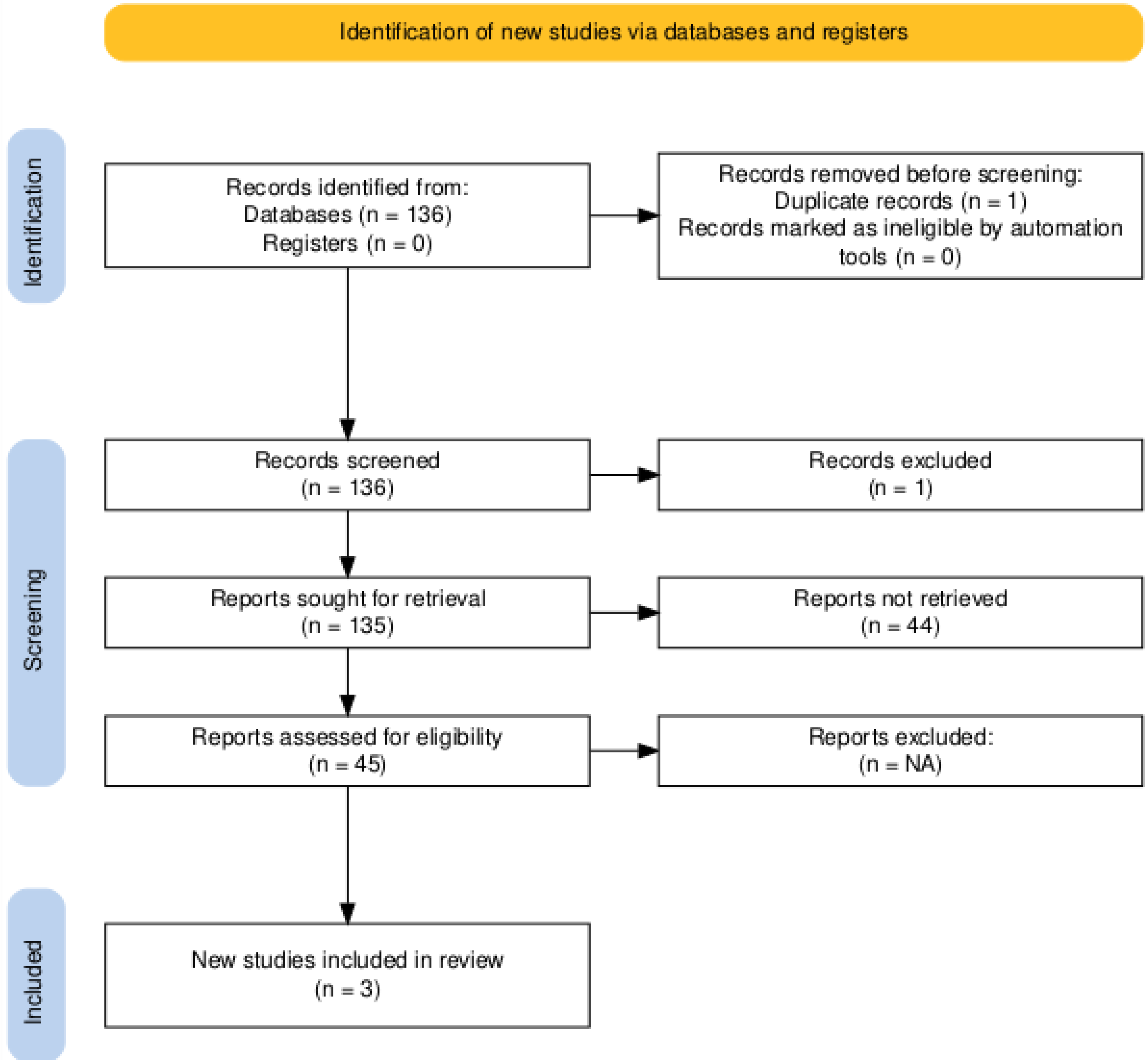

Fig. 1 Systematic literature review process flow in water quality research [16]

Figure 1 The PRISMA diagram above delineates the systematic methodology employed in the research to filter and select pertinent articles for the literature review. The procedure started with the identification phase, during which 136 articles were retrieved from the SCOPUS database. No items were acquired via registration (register = 0). At this juncture, one item was eliminated owing to redundancy, whilst 0 articles were omitted through automated screening. The remaining 135 items proceeded to the initial screening stage.

During the screening phase, all 135 papers were evaluated for eligibility according to the initial inclusion criteria. One item was eliminated from this total due to irrelevance, leaving 135 articles for the subsequent round of full-text retrieval. At this juncture, an effort was undertaken to obtain the whole text reports of the evaluated papers.

Out of the 135 articles advanced to the full report search stage, 44 items were inaccessible owing to either accessibility issues or lack of document availability. Consequently, 91 papers were successfully acquired with comprehensive reports and proceeded to the eligibility evaluation phase.

During the feasibility evaluation phase, 45 papers were meticulously analyzed to ascertain their relevance and alignment with the research goals. No expressly specified reports were disseminated at this juncture; hence, only those reports that fulfilled the requirements were incorporated into the final evaluation.

Ultimately, after the comprehensive process of identification, screening, and eligibility evaluation, three articles were determined to satisfy all criteria and were incorporated into the systematic literature review. This figure illustrates the significance of a meticulous and transparent selection procedure in SLR-based research to guarantee that only high-quality and pertinent studies are included for further analysis. This procedure embodies the methodical, structured, and comprehensive methodological framework key to the PRISMA methodology.

This PRISMA diagram depicts the methodical selection procedure employed to guarantee the inclusion of just the most pertinent and high-caliber articles in the literature review. Out of the 136 initially recognized articles, many selection phases excluded irrelevant or unavailable ones, resulting in just 3 articles that fulfilled the final criterion. This procedure illustrates the significance of transparency in documenting literature selection to uphold the validity and reliability of systematic literature reviews.

III. RESULTS

The activities during the individual study articles phase entail a comprehensive examination of the three articles selected from the final screening to investigate the principal results, methodologies, and significance of each study in relation to the research topic. Each article was meticulously analyzed to discern its distinct contributions, including the utilization of remote sensing technology for water quality monitoring [7], the implementation of microbes in aquaculture wastewater treatment [5], and the amalgamation of UAVs with machine learning for predicting water quality parameters [7]. This investigation reveals significant insights into the application of current technologies for enhancing efficiency, accuracy, and sustainability in water quality control. Table 1 presents the findings of specific research publications.

TABLE I
INDIVIDUAL STUDY ARTICLES

Sources	Findings
Chen J., Liu X., Chen J., Jin H., Wang T., Zhu X. (2024). Underestimated nutrient from aquaculture ponds to Lake Eutrophication: A case study on Taihu Lake Basin. Journal of Hydrology. Volume 630, February 2024, 130749. DOI 10.1016/j.jhydrol.2024.130749 [1]	The purpose of this study is to investigate the real-time monitoring of nitrogen and phosphorus emission from freshwater aquaculture ponds through the utilization of remote sensing technologies. It is possible to trace the dynamics of water quality with a high degree of precision thanks to the integration of this technology with geographic information systems (GIS). Eutrophication can be caused by nutrient release hotspots, which can be identified with the use of this technique. It is necessary to overcome the issue of remote sensing's sensitivity to environmental conditions, such as excessive turbidity, in order to guarantee that the data collected is correct.
Wu P., Huo P., Wang Y., Dong Y., Cui Y., Chen T. (2020). Practicality of effluent containing Rubrivivax gelatinosus culturing the crucian carp. Aquaculture, Vokume 514, 1 January 2020, 734418. DOI 10.1016/j.aquaculture.2019.734418 [2]	An investigation on the efficacy of the microbe Rubrivivax gelatinosus in the treatment of wastewater from aquaculture ponds is presented in this research. Compared to conventional approaches, the application of these microorganisms resulted in a 20% improvement in the effectiveness of nitrogen removal, according to the findings of the study. In addition, the utilization of these microorganisms was successful in lowering the levels of ammonia in ponds, which resulted in a substantial rise in the percentage of fish that really survived. Through the findings of this study, a solid basis is laid for the implementation of biotechnology in the management of wastewater in an ecologically responsible manner.
Chen G., Wang Y., Gu X., Chen T., Liu X., Lv W. (2024). Estimating water quality parameters of freshwater aquaculture ponds using UAV-based multispectral images. Agricultural Water Management, Volume 304, 1 November 2024, 109088. DOI 10.1016/j.agwat.2024.109088 [7]	The purpose of this project is to investigate the utilization of unmanned aerial vehicle (drone) technology in conjunction with machine learning in order to monitor water quality metrics such as biochemical oxygen demand (BOD) and dissolved oxygen consumption (DO). According to the findings, the combination of unmanned aerial vehicles (UAVs) with machine learning algorithms can improve the accuracy of water quality parameter predictions by as much as 25 percent when compared to the conventional approaches using these algorithms. However, in comparison to ground-based sensors, unmanned aerial vehicles (UAVs) provide the benefit of covering a larger monitoring area at a cheaper cost. Nevertheless, the research observed that there are some limits associated with the battery life of UAVs and the requirement for regular recharging.

IV. Discussion

The graphic below shows a mind map research question (RQ) with the main term "water quality."

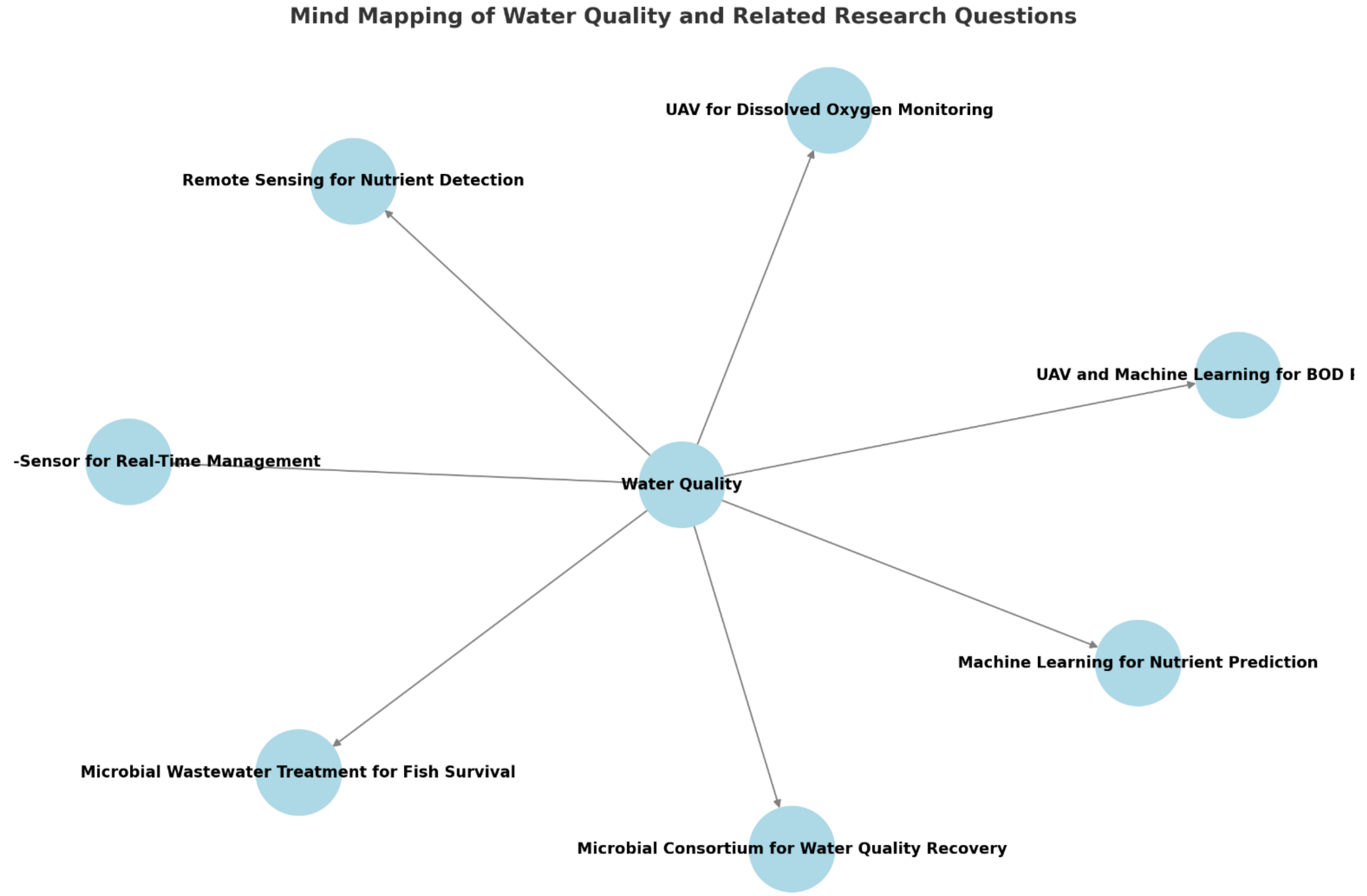

Fig. 2 Mind Map RQ

Figure 2 depicts a mind map (RQ) for water quality (Water Quality), which maps many current technical and biological techniques to understanding, monitoring, and improving water quality, particularly in the context of aquaculture and environmental management.

The mind map's central theme is Water Quality, which comprises seven major branches. First, Remote Sensing for Nutrient Detection looks at how remote sensing technology may be utilized to detect nitrogen and phosphorus discharges in freshwater aquaculture ponds. This remote sensing allows for real-time and quicker monitoring than traditional approaches, with GIS integration to easily track changes in water quality.

Second, Machine Learning for Nutrient Prediction compares the accuracy of machine learning models in forecasting nutrient levels to traditional modeling approaches. Support vector regression (SVR) technologies can enhance accuracy by up to 15%, making them ideal for processing vast and diverse datasets.

Third, the Microbial Consortium for Water Quality Recovery investigates the potential use of engineered microbial consortia to promote water quality recovery. Studies reveal that microorganisms like Rubrivivax gelatinosus may boost nitrogen removal efficiency by up to 20% compared to wild bacteria, demonstrating the efficacy of biotechnology-based techniques.

Fourth, Microbial Wastewater Treatment for Fish Survival investigates the effects of microbial-based wastewater treatment approaches on fish survival rates when compared to traditional procedures. This method can boost fish survival rates by up to 10% due to more effective ammonia elimination.

Fifth, UAV for Dissolved Oxygen Monitoring examines the usefulness of UAV (Unmanned Aerial Vehicle) technology in monitoring dissolved oxygen levels as compared to direct measurements. UAVs with improved sensors can detect dissolved oxygen fluctuations faster and cover a larger area, although their accuracy is somewhat poorer under certain situations.

Sixth, UAV and Machine Learning for BOD Prediction investigates the use of UAV technology and machine learning to improve the accuracy of biochemical oxygen demand (BOD) predictions. This combination, which employs techniques such as artificial neural networks, can boost accuracy by up to 25% over satellite-based sensing approaches.

Finally, IoT Multi-Sensor for Real-Time control demonstrates how multi-sensor IoT systems may improve real-time water quality control in aquaculture. The system allows for continuous monitoring of crucial factors such as temperature and pH, resulting in data that promotes quick and accurate management decision making.

Overall, this mind map depicts a multidisciplinary strategy to improve water quality with current technologies, machine learning, biotechnology, UAVs, and IoT. All of these divisions aim to address research issues in order to develop more effective and efficient water management methods.

Here is a discussion of the RQ and its answers :

RQ 1: *How can remote sensing technology improve the detection of nitrogen and phosphorus releases in freshwater aquaculture ponds?*

Traditional methods are able to provide real-time monitoring of water quality parameters such as nitrogen and phosphorus release more quickly than remote sensing, as described by Chen G et al [7]. Remote sensing is able to provide this monitoring. According to the findings of their research, combining this technology with a geographic information system (GIS) system allows for the efficient mapping of changes in water quality in ponds.

RQ 2: *How accurate is the machine learning model in predicting nutrient levels compared to conventional modeling techniques?*

Chen et al demonstrated that machine learning techniques, such as support vector regression (SVR), offer multiple benefits when it comes to the processing of large amounts of heterogeneous data. For example, when compared to traditional statistical models, the results of their study showed that this model improved prediction accuracy by as much as fifteen percent [7].

RQ 3: *Can engineered microbial consortia improve water quality recovery in aquaculture systems?*

Compared to the use of natural bacteria, the utilization of Rubrivivax gelatinosus in wastewater treatment was found to result in an increase in nitrogen removal efficiency of up to twenty percent, as demonstrated by the research conducted by Pan Wu. The effectiveness of approaches based on biotechnology is demonstrated by this information [2].

RQ 4: *How do microbial-based wastewater treatment methods affect fish survival rates compared to traditional methods?*

As a result of a more efficient decrease in ammonia levels, the research conducted by Pan Wu et al [2]. demonstrates that microbial-based processing can boost fish survival rates by up to ten percent more than traditional approaches.

RQ 5: *How effective is UAV technology in monitoring dissolved oxygen levels compared to direct measurements?*

It was demonstrated by Chen G et al that unmanned aerial vehicles (UAVs) that are fitted with sensors are able to detect alterations in dissolved oxygen across a broader region and in a shorter amount of time than manual measurements, despite the fact that the accuracy is somewhat poorer under certain situations [7].

RQ 6: *How does the integration of UAV technology with machine learning improve the accuracy of Biochemical Oxygen Demand (BOD) predictions?*

According to Chen et al, the combination of unmanned aerial vehicles (UAVs) with machine learning techniques, such as artificial neural networks, brings about improvements in BOD forecasts that are up to 25 percent more accurate than those obtained using satellite-based remote sensing [7].

RQ 7: *How do multi-sensor IoT systems impact real-time water quality management in aquaculture?*

As stated by Huan-Liang Tsai et al, Internet of Things (IoT) systems have the capability of delivering considerable real-time data monitoring for factors like as temperature and pH, which enables management choices to be made more quickly and with more precision [3].

V. Conclusion

This study revealed that current technology significantly enhances the efficiency, accuracy, and coverage of water quality monitoring, particularly in freshwater aquaculture settings. A primary discovery is the utilization of remote sensing technology, including both satellite and drone (UAV) applications, which offers a superior alternative to traditional approaches. This technique enables the effective monitoring of extensive water quality indicators. Nonetheless, obstacles persist, particularly in maintaining data fidelity under specific situations, such as elevated turbidity levels. This technology facilitates the integration of systems utilizing big data and machine learning, enhancing the accuracy of forecasts regarding dynamic alterations in water quality.

Moreover, the application of machine learning emerges as a significant advancement in the analysis of intricate and diverse data pertaining to water quality. Algorithms like support vector regression (SVR) and artificial neural networks (ANN) have demonstrated superiority over conventional modeling techniques in forecasting water quality indices, including nitrogen, phosphorus, and biochemical oxygen demand (BOD). Nonetheless, the deployment of this technology necessitates substantial computational resources and considerable training data, posing a constraint at certain implementation sizes, particularly in technologically disadvantaged areas.

This study demonstrates that biotechnology-based methods, including the use of Rubrivivax gelatinosus and engineered microbial consortia, provide significant promise for enhancing aquaculture waste management. These bacteria markedly enhance the efficacy of nitrogen and ammonia elimination, hence positively affecting fish longevity. These findings advocate for the implementation of more sustainable waste management strategies, however further study is required to assess the long-term effects on aquaculture ecosystems.

Conversely, IoT (Internet of Things) and wireless multi-sensor systems are important advancements in enabling real-time water quality monitoring. This technology facilitates the incorporation of water quality parameters, including temperature, pH, and oxygen levels, into aquaculture management systems, so enabling decision-makers to respond promptly. Nonetheless, implementation expenses and the necessity for a reliable internet connection are constraining concerns, particularly in remote regions and conventional aquaculture.

Regarding cost-effectiveness, UAVs (drones) are becoming a compelling alternative to ground-based automated sensor networks. UAVs may encompass a broader expanse with a reduced starting expenditure. Sustainable UAV operations need a comprehensive assessment of energy demands, battery capacity, and resilience to adverse weather conditions. The use of UAVs with machine learning substantially enhances the predictive accuracy of water quality measures, including BOD and dissolved oxygen (DO). This combination facilitates proactive monitoring aimed at preventing ecological damage.

On a broader scale, IoT and UAV technologies provide significant promise for extensive use in intense aquaculture and distant regions. The implementation of this data-driven system facilitates more adaptive control of environmental changes, including temperature variations and pollutant levels. This research underscores the necessity for consistency in data collecting and analysis methodologies across various geographic and environmental situations.

This research also recognized transdisciplinary obstacles in the implementation of technologies for water quality assessment. Modern technology provides unique solutions applicable at several sizes. Conversely, implementation necessitates a comprehensive strategy that encompasses workforce training, enhancement of infrastructural capacity, and a supportive policy framework. Moreover, it is crucial to consider ecological sustainability in the implementation of microbial and IoT-based technologies, ensuring that these interventions do not disrupt the natural equilibrium of the environment.

This research indicates that the future of water quality monitoring is significantly dependent on technical innovation and interdisciplinary collaboration. The integration of technologies like UAVs, IoT, machine learning, and biotechnology necessitates a harmonious balance of technological efficiency, ecological sustainability, and operational expenses. To optimize the advantages of this technology, it is essential to formulate regulations that facilitate the inclusive integration of contemporary technology, particularly in regions that have traditionally had restricted access to technical advancements.

This study emphasizes the necessity for more research aimed at creating cost-effective technologies, enhancing predictive accuracy, and assessing the long-term effects of diverse technologies on freshwater ecosystems. Collaboration among academics, government, and industry is essential for delivering solutions that are both efficient and socially and environmentally sustainable.

Acknowledgment

We would like to thank Causal Productions for permits to use and revise the template provided by Causal Productions. Original version of this template was provided by courtesy of Causal Productions (www.causalproductions.com).

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