Advancing Sustainable Aquaculture through Water Quality Monitoring and Technological Innovations

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ABSTRACT

The escalating global demand for seafood, especially fish, spotlights aquaculture's rapid growth. Despite this, inadequate domestic production leads to significant fish imports. For instance, Ghana's fish supply falls short of half its demand. This scarcity underscores aquaculture's pivotal role in boosting the fisheries sector. This article emphasizes economic growth and food production via aquaculture practices. Monitoring pond water attributes anticipates adverse conditions, protecting both environment and processes. Tracking oxygen levels, temperature, water clarity, and pH sustains favorable conditions, preventing disruptions. Vigilant water quality management is essential for effective fisheries due to disease impact. Overfeeding and resulting pollution are common aquaculture challenges. Consistently monitoring tank parameters ensures fish health, growth, and disease prevention. Indian aquaculture supports millions through nutritional security and livelihoods. Ignoring water quality leads to issues like algal blooms and fish mortality. Maintaining consistent conditions is crucial for thriving fish species. Integrating technology offers cost-effective solutions. A neural network-based system holds potential for optimizing aquaculture management and outcomes. This article encapsulates aquaculture's multifaceted significance, water quality's centrality, and technology's transformative potential.

KEYWORDS : Water quality monitoring, Aquaculture, Technological Innovations, Sustainability

I INTRODUCTION

Aquaculture has emerged as a rapidly growing field due to the global surge in demand for seafood. Among various seafood options, fish stands out as a highly sought-after choice, largely owing to its recognized health advantages. The practice of fish farming holds substantial sway over the economies of nations, given the escalating desire for fish. However, a considerable number of countries find themselves compelled to import fish due to insufficient domestic production. To illustrate, in Ghana, the supply of fish from both aquaculture and capture sources falls short of meeting half of the country's demand. As a response to the shortfall in supply, aquaculture has gained paramount significance in the advancement of the fisheries sector across many nations. This shift is particularly crucial as the limitations on supply are projected to persist and potentially intensify in the future. Aquaculture encompasses a range of practices, knowledge, and methods used for cultivating aquatic plants and specific animal species. This endeavour holds significant importance in both economic advancement and the production of food resources. Consistently observing the physical, chemical, and biological attributes of pond water serves a dual purpose: not only does it enable the anticipation and management of adverse conditions in aquaculture, but it also prevents harm to the environment and potential disruptions to the production process. Regularly tracking key factors like oxygen levels, temperature, water clarity, and pH within the water body is essential for sustaining favourable conditions and preventing undesirable scenarios that could jeopardize the stability of aquaculture systems. Effective fisheries management hinges on the observation of water quality, given the prevalence of fish diseases that significantly influence the quantity of the harvest obtained [1].A common error committed by aqua culturists involves excessive feeding, leading to the accumulation of unconsumed food that can result in water pollution. To prevent unfavourable circumstances for cultivation, it is crucial to consistently monitor key factors within the tank, including pH levels, dissolved oxygen, water levels, ammonia concentration, and temperature [2]. The feeding pace, rate of growth, and general well-being of the fish are contingent on the quality of the water. The necessity to closely observe aquaculture indicators becomes essential in light of potential diseases and diminished output that could stem from suboptimal water conditions.

II SCOPE OF THE AQUACULTURE WATER QUALITY MONITORING

This chapter primarily centers on the potential of a water quality monitoring system within fish farming. The monitoring of water quality holds a pivotal role in influencing the survival and developmental progression of fish. Even a minor alteration in water conditions could exert stress on the fish, possibly resulting in fatality. In contemporary intensive fish farming, more sophisticated technological systems have emerged to ensure the maintenance of optimal water conditions. Broadly, a water quality monitoring system for aquaculture typically encompasses components like Wireless Sensor Networks (WSN), Artificial Intelligence (AI)-based programs, automated processes, alert mechanisms, data retention, interactive graphical user interfaces, data analysis, and real-time [3].

III KEY PHYSICO-CHEMICAL PARAMETERS FOR AQUACULTURE WATER QUALITY

a) pH

pH serves as a gauge of the acidity or alkalinity of a solution. A pH value of 7 denotes neutrality, while values below or above 7 indicate acidity or alkalinity, respectively. In the context of aquaculture ponds, maintaining a pH within the range of 7.5 to 8.5 is typically advised.

b) Electrical Conductivity

Electrical conductivity gauges a solution's capacity to conduct electrical current. It is indicative of the presence of conductive ions, usually originating from dissolved salts and inorganic substances. A higher salt concentration corresponds to higher conductivity. Distilled water registers a low conductivity of 0.5 to 3μS/cm, while streams range from 50 to 1500μS/cm. In freshwater streams suitable for aquaculture, the recommended conductivity should fall within 150 to 500μS/cm.

c) Oxidation-Reduction Potential (ORP)

ORP quantifies the propensity of electrons to move between components within a solution, reflecting the water's ability to eliminate contaminants. Elevated ORP readings are indicative of healthy water conditions.

d) Turbidity

Turbidity assesses the quantity of suspended and colloidal materials within water and is measured in nephelometric turbidity units (NTU) or Jackson's Turbidity units. Drinking water should exhibit turbidity levels below 1 NTU. Aquatic organisms thrive within a turbidity range of 5 NTU to 50 NTU.

Table 1: Suggested water quality criteria for pond water fishery for getting high yield via applying minimum inputs

S. No.	Parameter	Acceptable range	Desirable range	Stress
1.	Temperature ($^{\circ}$C)	15-35	20-30	<12, >35
2.	Turbidity (cm)		30-80	<12,>80
3.	Water colour	Pale to light green	Light green to light brown	Clear water, Dark green &Brown
4.	Dissolved oxygen (mg L^{-1})	3-5	5	<5, >8
5.	BOD (mg L^{-1})	3-6	1-2	>10
6.	CO_2 (mg L^{-1})	0-10	<5, 5-8	>12
7.	pH	7-9.5	6.5-9	<4, >11
8.	Alkalinity (mg L^{-1})	50-200	25-100	<20, >300
9.	Hardness (mg L^{-1})	>20	75-150	<20,>300
10.	Calcium (mg L^{-1})	4-160	25-100	<10, >250
11.	Ammonia (mg L^{-1})	0-0.05	0- <0.025	>0.3
12.	Nitrite (mg L^{-1})	0.02-2	<0.02	>0.2
13.	Nitrate (mg L^{-1})	0-100	0.1-4.5	>100, <0.01
14.	Phosphorus (mg L^{-1})	0.03-2	0.01-3	>3
15.	H_2S (mg L^{-1})	0-0.02	0.002	Any detectable level
16.	Primary productivity (C $L^{-1} D^{-1}$)	1-15	1.6-9.14	<1.6, >20.3

Table 2: The water quality preferences for some commonly cultured species in India

Species	Temperature ºF	Dissolve oxygen mg/L	pH	Alkalinity mg/L	Ammonia %	Nitrite Mg/L
Baitfish	60-75	4-10	6-8	50-250	0-0.03	0-0.6
Catfish/Carp	65-80	3-10	6-8	50-250	0-0.03	0-0.6
Hybrid striped Bass	70-85	4-10	6-8	50-250	0-0.03	0-0.6
Perch/Walleye	50-65	5-10	6-8	50-250	0-0.03	0-0.6
Salmon/Trout	45-68	5-12	6-8	50-250	0-0.03	0-0.6
Tilapia	75-94	3-10	6-8	50-250	0-0.03	0-0.6
Tropical Ornamentals	68-84	4-10	6-8	50-250	0-0.03	0-0.5

IV APPLICATIONS OF WIRELESS SENSOR NETWORKS

The wireless sensor network (WSN) represents a significant and promising emerging technology, holding substantial promise for enhancing existing applications within the realm of intensive aquaculture [4]. WSNs are intricately linked to the immediate physical surroundings, enabling individual sensors to furnish comprehensive insights into materials' environments that would otherwise be challenging to acquire using conventional wired instruments [5].

[6] Introduced was an additional water monitoring system grounded in Wireless Sensor Networks (WSN). This system effectively gauged variables including pH, water temperature, water level, and dissolved oxygen. The collected data was transmitted to a centralized database, subsequently fed into software for real-time monitoring. The software's construction involved the utilization of Visual Studio 2005, with a distinct division of logic, display, and data layers to enhance adaptability and reusability. Ultimately, alerts were disseminated through SMS notifications or visual cues on devices.

[7] Introduced a WSN-driven water monitoring system which utilized ZigBee for transmitting data collected by sensors from the recirculating system. The data was subsequently stored within a MySql database. The system focused on measuring parameters such as temperature, pressure, and dissolved oxygen across the entire day. Whenever an issue was detected, an alert was dispatched via SMS or email to notify the designated personnel overseeing the facility.

[8] Developed an integrated wireless network and water quality measurement setup targeted at aquaculture. This endeavor involved the creation and application of a system tailored for monitoring water quality in ponds. This system involved floating modules, each equipped with sensors for capturing and transmitting pH, temperature, dissolved oxygen, and conductivity values. These readings were uploaded to the Internet and visualized through a desktop application designed using LabVIEW. Notably, this work did not explicitly reference the implementation of a database for data storage or the integration of a mobile application.

[9] Proposed a WSN-driven water quality monitoring system which effectively collected data encompassing pH, water temperature, and dissolved oxygen. This real-time interface facilitated both numerical and graphical data representation. The study furnished multiple test outcomes that illustrated fluctuations throughout the day. These findings revealed relative error percentages of 1.40% for pH, 0.27% for temperature, and 1.69% for dissolved oxygen.

This general flow illustrates how wireless sensor networks contribute to monitoring and maintaining water quality in fish farming environments, ensuring that the conditions are conducive to fish survival and productivity
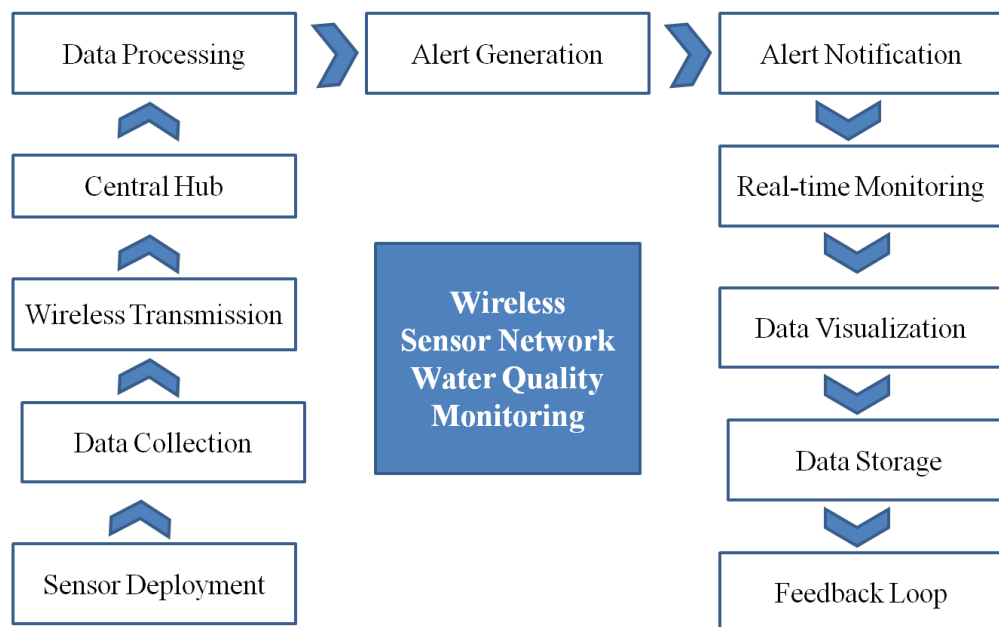

Figure 1 Wireless Sensor Network Water Quality Monitoring in Fish Farming: Process Flow

V EMBEDDED SYSTEMS IN AQUACULTURE

An embedded system refers to a programmed control and operating system designed for a specific purpose within a broader mechanical or electrical framework, frequently incorporating real-time computational limitations. This system is integrated into a comprehensive device, typically encompassing both hardware and mechanical components. Embedded systems govern numerous devices widely utilized in modern times. Nearly all microprocessors, constituting about 98% of the total, are integral constituents of embedded systems.

[10] Introduced a water quality monitoring system that encompassed the measurement of pH, water level, water temperature, and dissolved oxygen. ZigBee technology was employed to transmit the gathered data. Displaying the acquired information was facilitated through the utilization of LabView software by National Instruments Corporation. The team conducted an array of experiments spanning communication performance, battery efficiency, and sensor readings over a span of six months. The results effectively illustrated the dynamic variations of these parameters across the course of a day.

[11] Embarked on a venture involving the development of an Automated Monitoring and Control System for Shrimp Farms. Their approach was both low-cost and versatile, leading to a prototype system that had the potential to evolve into a commercially viable product. The distributed architecture was constructed through the integration of technologies such as ZigBee, GSM, Cloud, MSP430, and Lab View. This system specifically monitored three critical variables—pH, oxygen levels, and temperature—in two shrimp farms. The team concluded that their implemented system was characterized by scalability, user-friendliness, and affordability, making it a promising solution for aquaculture operations.

[12] Conducted experiment within farm environments employing IoT systems, contrasting the expenses and resources with those farms without such systems. The outcomes indicated a reduction in costs ranging from 19.34% to 6.03%, with an average of 3.98%, in farms implementing these systems. In essence, the research concluded that the integration of IoT-based systems in aquaculture leads to tangible economic advantages within this domain.

VI OTHER AUTOMATIC MONITORING SYSTEMS

Automatic monitoring systems empower aquaculture farmers to efficiently manage their facilities, promoting the well-being of aquatic organisms and the sustainability of their operations.

[13] Introduced an innovative aquaculture environment monitoring system that harnessed RF (Radio Frequency) and GSM (Global System for Mobile communications) technology to measure temperature and dissolved oxygen levels. Their approach involved the creation of two algorithms, one for assessing the performance of the monitoring center and another for evaluating different substations. These substations carried out continuous 24-hour data collection and relayed the information in real-time to the central system.

[14] Took a different approach, utilizing GPS tracking devices to monitor sunfish mola. The tracking system achieved an approximate positional accuracy of 70 meters. This technology was tested on sunfish of varying sizes, ranging from 0.6 to 1 meter. The trajectory of the fish was visualized on a map, and the system also acquired speed data, which was depicted on a graph alongside the route.

[15] Devised a comprehensive water quality monitoring system tailored for fish farms. They employed artificial neural networks (ANN) to predict water quality trends, thereby mitigating potential losses. The data collection node integrated diverse sensors to measure parameters such as water and room temperature, dissolved oxygen saturation percentage, dissolved oxygen concentration, pH, electrical conductivity, and salinity. This data was then transmitted to a remote server for accessibility.

[16] Embarked on a fish behaviour monitoring initiative utilizing computer vision technology. Their system effectively monitored nine fish tanks concurrently, evaluating stock density as a stress factor. Remote control capabilities were integrated into the system, offering real-time visual insights into fish behaviour. Their findings unveiled noteworthy statistical differences, particularly in the experiment conducted with an undamaged mesh.

[17] Contributed a mobile sensor platform tailored for monitoring ponds in aquaculture settings. This architecture comprises sensing nodes within each pond, connected to a central sink. The sink then transmits the collected data to a mobile application, allowing real-time data visualization. Via GSM/3G connectivity, the information is sent to the Internet, enabling remote monitoring, and data storage in a database.

[18] Introduced a water quality monitoring system designed for fish farms. Utilizing the SUNSET (Software Defined Communication Stack) for networking and Hydrolab Series 5 probes for data acquisition, the system measured various parameters, including temperature, pH, luminescent dissolved oxygen (LDO), salinity, oxidation-reduction potential (ORP), and specific conductance (SpCond). Additionally, energy efficiency was enhanced through innovative sleep and wake-up mechanisms

[19] Proposed an Internet of Things (IoT)-based water monitoring system for aquaculture. Their setup incorporated an Atlas pH Probe digital sensor, an analog temperature sensor, and an Atlas Dissolved Oxygen Probe. Data transmission to a MySQL database was facilitated through an Arduino node equipped with a ZigBee module. The system utilized rechargeable batteries and sustained operation for 8 hours, with data accessible through desktop and mobile applications.

[20] Conducted a comprehensive survey of vision-based systems. They delineated the primary applications of optical sensors into pre-harvesting, cultivation, and post-harvesting scenarios. Various technologies, including machine vision, hyperspectral imaging, thermal imaging, and x-rays, were discussed in relation to fish monitoring. The authors categorized the applications of optical sensors into five

types: fish sorting, fish quality assessment, physical attributes measurement, chemical attributes assessment, and food security enhancement].

[21] Artificial neural network was employed to construct a predictive model for the developmental status of aquaculture. The advancement of the aquaculture system significantly influences multiple water quality parameters. This model, devised through the utilization of artificial neural network technology, addresses the issue of congestion encountered in traditional expert systems. The effectiveness of this approach has been substantiated through experimental findings.

VII CONCLUSION

The concluding observations extracted from the literature assessment are as follows:

Indian aquaculture constitutes a pivotal segment within the food production landscape, catering to nutritional security, providing livelihood support, and creating employment for over 14 million individuals. The estimated fish production for 2017-18 stood at 12.60 million metric tonnes, with nearly 65% derived from the inland sector. Culture fisheries accounted for around 50% of the total production, contributing approximately 6.3% to the global fish production. Often, water quality receives inadequate attention in the management of ponds or lakes, leading to a cascade of issues. Neglected water quality can result in problems such as excessive algal blooms, uncontrolled plant growth, unpleasant odors, or even fish mortality. The paramount importance of water quality in aquaculture cannot be understated. It serves as the chief determinant influencing fish health and performance within aquaculture systems. Each fish species exhibits specific water quality requirements (temperature, pH, oxygen levels, salinity, hardness, etc.) within which they can thrive, develop, and reproduce. The preservation of consistent and favourable water quality conditions is imperative, as polluted water poses a threat to habitat suitability. Addressing these aspects involves diverse methodologies, with the integration of Internet and Wi-Fi technologies offering enhanced convenience and cost-effectiveness. The implementation of a neural network-based system has the potential to provide a robust solution for managing aquaculture organisms and optimizing production outcomes.

VII FUTURE PROSPECTS

The evolution of IoT technology holds immense potential for the detection of chemical parameters in water, allowing for real-time monitoring and control. Leveraging IoT and Wireless Sensor Networks (WSN) opens doors to innovative projects, including the establishment of Smart City initiatives encompassing energy-efficient street lighting and air quality monitoring. Furthermore, opportunities abound for purifying and filtering contaminated water sources, assessing soil quality, and deploying base stations to oversee water quality across multiple regions. Additionally, IoT capabilities could extend to fish farming by facilitating fish count estimation and health monitoring. By incorporating additional sensors, a comprehensive understanding of both physical and chemical water quality determinants can be attained. This knowledge is pivotal in ensuring water quality is maintained at optimal levels. A significant avenue for exploration lies in assessing the energy consumption of IoT devices. This insight is crucial for optimizing energy-efficient operations within IoT-based systems. Furthermore, by introducing automation into aquaculture practices, labor costs and energy consumption can be markedly reduced. This progress would signify a shift towards a more sustainable and resource-efficient aquaculture industry. The convergence of IoT and WSN technologies promises transformative developments in water quality management, environmental monitoring, and aquaculture practices. The potential to enhance efficiency, accuracy, and sustainability underscores the exciting prospects that lie ahead.

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