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EMERGING INTERNET OF THINGS (IoT), ARTIFICIAL INTELLIGENCE AND ICT APPLICATIONS IN FISHERIES AND AQUACULTURE: A REVIEW

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ABSTRACT
The accelerating global demand for aquatic products is transforming fisheries and aquaculture, prompting a shift from traditional practices to technology-driven systems. This desk study investigates the integration of emerging information technologies such as artificial intelligence (AI), Internet of Things (IoT), blockchain, geographic information systems (GIS), and big data into aquaculture operations, with a focus on sustainability, productivity, and traceability. Drawing on case studies from both developed and developing regions, it examines how these tools support real-time environmental monitoring, optimise feeding regimes, strengthen disease surveillance, and improve supply chain transparency. GIS is highlighted for its role in site selection and biodiversity conservation, while blockchain demonstrates potential in ensuring product authenticity and regulatory compliance. These innovations offer substantial opportunities for enhancing operational efficiency, reducing environmental impacts, and improving market competitiveness. However, their adoption is hindered by high capital costs, limited digital literacy, and infrastructural constraints, particularly in resource-limited contexts. To address these barriers, the paper proposes strategic measures combining policy incentives, capacity-building programs, and public-private partnerships to promote inclusive and equitable digital transformation in aquaculture. Ultimately, the fusion of advanced information technologies with aquaculture practices is essential not only for meeting future global food security targets but also for creating resilient, transparent, and environmentally responsible aquatic food systems.

KEYWORDS*:* Technology-driven Systems, Artificial Intelligence (AI), Internet of Things (IoT), Geographic Information Systems (GIS), Operational Efficiency.

INTRODUCTION

Global drivers and the digital pivot in aquaculture

Growing global demand for fish and other aquatic products driven by population growth, urban diets, and nutrition imperatives is colliding with limits on wild fisheries and the environmental costs of intensification. As a result, producers and policymakers increasingly turn to digital solutions to raise productivity while reducing ecological pressure. Over the last twenty years, information and communication technologies (ICTs) have evolved from pilot projects into operational tools that support everything from remote environmental sensing to automated feeding and market traceability. Technologies such as the Internet of Things (IoT), artificial intelligence (AI), geographic information systems (GIS), blockchain, and cloud analytics now underpin precision aquaculture practices that replace guesswork with data-driven management. Several recent reviews and applied studies show how these tools enable faster responses to water-quality shifts, better feed conversion, and improved oversight of disease risk. (Rather et al., 2024; Li & Liu, 2020; Mandal & Ghosh, 2024). At the farm scale, Internet of Things (IoT) networks paired with low-cost sensors and mobile dashboards permit continuous monitoring of dissolved oxygen, temperature, pH and nitrogenous wastes, triggering automated aeration or feed adjustments when thresholds are crossed (Assaf et al., 2024). AI and machine learning add predictive layers: models trained on historical growth and environmental data can forecast mortality risk or optimise feeding schedules, improving feed conversion ratios and lowering waste (Mandal & Ghosh, 2024; Li & Liu, 2020). Geographic information systems (GIS) and remote sensing broaden the lens: spatial analysis aids site selection, carrying-capacity assessment and habitat conservation planning, as shown in case studies from sensitive regions (Baruah et al., 2020; Ganie et al., 2024). On the market side, blockchain and immutable ledgers are being trialed to record provenance, certify handling practices, and reduce fraud, increasing buyer confidence and easing access to export markets (Ferreira et al., 2021). Yet these gains coexist with non-technical hurdles: high upfront costs, patchy rural electrification and connectivity, and limited digital literacy among smallholder producers remain serious adoption barriers (Bhusan et al., 2025; Effiong et al., 2025).

Regional disparities, policy needs and the research agenda

In Nigeria, the adoption of advanced digital systems in aquaculture is gaining momentum, though still at an early stage. Effiong et al. (2025) highlight that agricultural science educators in Cross River State have begun incorporating digital aquaculture tools into training programs, signaling a growing awareness of technology's role in the sector. Nonetheless, infrastructure deficits limited internet penetration in rural areas, and varying levels of digital literacy remain significant barriers to widespread uptake. Bridging these gaps demands targeted policy interventions, capacity-building initiatives, and investment in affordable, scalable technologies tailored to local contexts. Low-cost IoT devices, mobile-based extension platforms, and community-driven GIS mapping projects could enhance accessibility for small-scale farmers, enabling them to participate fully in the digital transition. Aligning such efforts with national blue economy strategies, climate adaptation policies, and food

security frameworks would amplify their impact, ensuring that technological transformation contributes not only to productivity gains but also to long-term environmental stewardship. Figure 1 shows the global map that illustrates the varying levels of digital technology adoption in aquaculture across different regions, highlighting distinct disparities. Regions such as East and Southeast Asia, including China, Vietnam, and Indonesia, demonstrate very high adoption levels, reflecting their leadership in aquaculture innovation. Similarly, countries in Northern and Western Europe, like Norway and the UK, as well as Australia and New Zealand, show advanced digital integration. In contrast, Sub-Saharan Africa, including Nigeria, along with parts of Central Asia and Latin America, display low to moderate adoption due to infrastructural and technological constraints. These patterns underscore the uneven global progress in adopting technologies such as IoT, GIS, AI, and block chain in fisheries and aquaculture (Assaf *et al*., 2024; Bhusan *et al.*, 2025; Ganie *et al*., 2024).

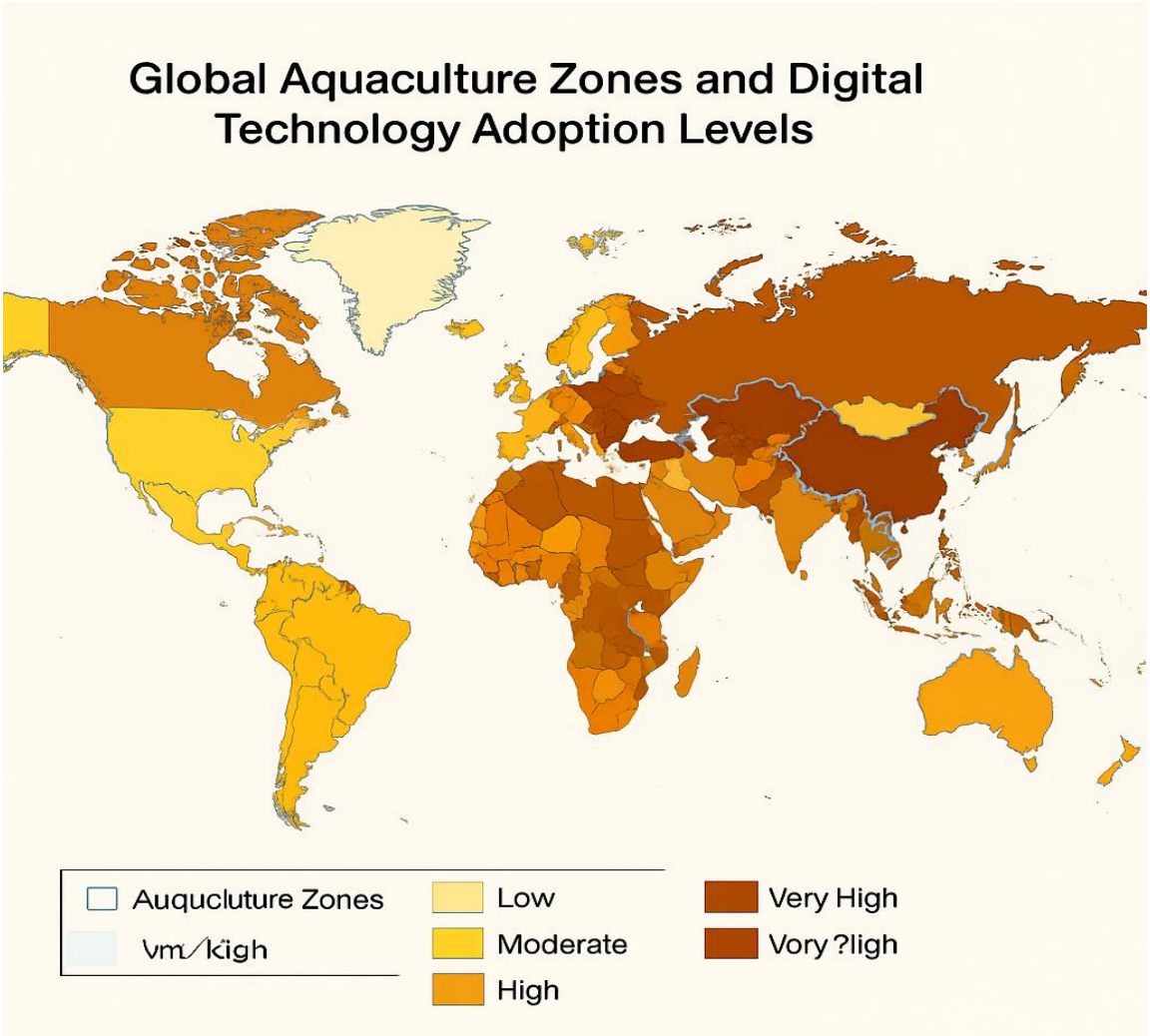


Figure 1*: Map showing global aquaculture zones and digital technology adoption levels (Rather et al., 2024; Li & Liu, 2020).*

Conceptual and Theoretical Framework

The integration of Information Technology (IT) into fisheries and aquaculture has transformed these traditionally manual and locally governed sectors into data-driven and technology-enhanced domains. Historically, fisheries relied heavily on indigenous knowledge, seasonal patterns, and labour-intensive methods, often leading to inefficiencies and unsustainable practices. However, with the advent of digital innovation, there has been a paradigm shift from reactive to predictive management approaches. Understanding this shift requires a thorough conceptual clarification of the terminologies involved and the theoretical underpinnings that explain how IT tools can be harnessed to drive efficiency, transparency, and sustainability in aquatic food systems. Theories such as Technological Determinism and the Socio-Technical Systems Approach provide useful lenses for analyzing how innovations are shaping aquaculture operations, organisational processes, and policy formulations. This section provides clarity on the key concepts and explores the synergistic framework that underlines the intersection of IT and aquaculture practices, ultimately contributing to global food security and blue economy goals.

Overview of Fisheries and Aquaculture

Fisheries and aquaculture are crucial sub-sectors of the global food system, collectively contributing to nutrition, livelihoods, and economic stability for millions of people worldwide. While capture fisheries involve the harvesting of naturally occurring fish stocks, aquaculture pertains to the farming of aquatic organisms under controlled or semi-controlled conditions. With rising pressure on wild fish stocks and environmental concerns, aquaculture has emerged as the fastest-growing food production sector globally. Despite its potential, the sector faces challenges such as disease prevalence, inadequate resource planning, habitat loss, and inefficient post-harvest handling (Islam et al., 2024). These challenges are exacerbated by climate change and human-induced stressors, prompting a growing need for system-wide innovations. Jayasankar (2023) asserts that the future of aquaculture lies in embracing smart farming methods that incorporate IT to monitor biophysical variables and enforce compliance with environmental standards. Mandal and Ghosh (2024) further emphasise that monitoring fish health and growth using AI tools significantly reduces mortality rates and enhances yield predictability. Thus, a sustainable aquaculture future necessitates leveraging digital innovations to overcome traditional barriers and scale up responsibly.

The Intersection of IT and Aquaculture Systems

The confluence of IT and aquaculture represents a transformative nexus that underpins the vision of smart, sustainable, and inclusive aquatic food production systems. At this intersection, technologies such as Geographic Information Systems (GIS) facilitate spatial analysis for selecting optimal farm sites, managing water bodies, and detecting environmental hazards (Baruah et al., 2020; Ganie et al., 2024). GIS mapping enhances data visualisation and improves planning efficiency for government agencies and private investors alike. Artificial Intelligence (AI), on the other hand, powers smart feeding systems and predictive analytics tools that assess fish growth trends and health anomalies in real-time, helping farmers respond proactively (Li & Liu, 2020; Rather et al., 2024). Blockchain and big data platforms ensure that supply chains are transparent, product quality is verifiabl, and certification protocols are maintained (Ferreira et al., 2021). These tools

collectively redefine aquaculture operations from traditional trial-and-error approaches to precision-based management systems. According to Føre et al. (2023), smart feeding algorithms reduce feed waste and contribute to environmental conservation, while Effiong et al. (2025) report increased acceptance of IT-driven fish farming practices among educators and stakeholders in developing regions. Ultimately, the integration of IT with aquaculture not only drives innovation but also embeds sustainability and accountability at the heart of modern fisheries development.

METHODOLOGY

Literature regarding the study topic was found through an exhaustive search of database sources like Scopus, Web of Science, ScienceDirect, IEEE Xplore, SpringerLink, MDPI, Frontiers, and Google Scholar. The search identified relevant journal articles, review papers, conference proceedings, and other scholarly publications related to the application of artificial intelligence in fisheries, such as Fishes, Sustainability, Frontiers in Marine Science, Expert Systems with Applications, PLOS ONE, and SoftwareX, and in conferences such as IEEE International Joint Conference on Neural Networks (IJCNN), IEEE International Conference on Omni-layer Intelligent Systems (COINS), and Springer Lecture Notes in Computer Science (LNCS).

The literature searches employed combinations of predefined keywords, using the terms "AND" and "OR" to broaden and refine the search, thereby maximising the retrieval of relevant studies. Some of the key terms involved in the search are “artificial intelligence,” “machine learning,” “deep learning,” “computer vision,” “convolutional neural networks,” “neural networks,” “smart fisheries,” “internet of things,” “fisheries management,” “technological driven system,” “fish stock estimation,” “fish population monitoring,” “geographical information system,” “fish species identification,” “fish behaviour recognition,” “fishing vessel behaviour,” “smart fish farm,” “underwater imaging,” “electronic monitoring,” “real-time catch analysis,” “autonomous underwater vehicles,” “fish habitat monitoring,” "aquaculture management"

This paper was mainly concerned with literature from the years 2018 to 2025; however, other earlier literatures which contained a methodological contribution was considered. The criteria of inclusion involved journals and proceedings as well as review papers that looked at how artificial intelligence (machine learning, deep learning, computer vision, and intelligent monitoring systems) was applied to fisheries management, fishing craft, fishing gears, fish population estimation, fish behavior analysis, and sustainable fishing. Literature that was not relevant to fisheries, lacked an application of AI technologies, duplicated papers, literature not written in English, editorials, and opinions were excluded. From the literature found, critical analysis and synthesis were done using the major themes of the study, which involved the application of artificial intelligence in fishing craft, fishing gear, fish population monitoring and estimation, sustainable fisheries management, challenges in the implementation process, and future research directions, among others.

EMERGENT TRENDS IN INFORMATION TECHNOLOGY

Recent advances in digital technologies are transforming aquaculture and fisheries management, shifting operations from traditional, resource-intensive methods to intelligent, adaptive, and data-driven systems. Key innovations, Artificial Intelligence (AI), Internet of

Things (IoT), Blockchain, Geographic Information Systems (GIS), and Big Data are enhancing efficiency, sustainability, traceability, and resilience. Rather than functioning in isolation, these tools operate synergistically, enabling precise monitoring of aquatic environments, optimised resource use, and improved fish health management. Their integration is proving vital in addressing climate change impacts and meeting rising food demands, marking a significant step toward smarter and more sustainable aquaculture systems.

Artificial Intelligence (AI) and Machine Learning

Artificial Intelligence (AI) and Machine Learning are transforming aquaculture operations by enabling smart systems capable of learning from data and making informed decisions. One of the key applications is in smart feeding systems, where AI-powered algorithms calculate the optimal feed quantity based on fish biomass, activity levels, and environmental variables. This approach reduces feed waste, lowers operational costs, and enhances water quality. Føre *et al.* (2023) detailed how marine fish farms employ smart sensors and AI platforms to fine-tune feed dispersion, thereby achieving higher feed conversion ratios and supporting ecological sustainability. Furthermore, AI-driven cameras and biometric sensors can monitor fish behaviour in real-time, ensuring prompt intervention in case of anomalies.

Additionally, AI plays a crucial role in growth prediction models, where machine learning analyses historical growth patterns, genetic data, and habitat conditions to forecast future performance. Such predictive tools enable farmers to make proactive stocking, harvesting, and health management decisions. Mandal and Ghosh (2024) affirm that AI-based models significantly improve the reliability of fish growth and health assessments, particularly in intensive aquaculture systems. According to Rather et al. (2024), AI is also instrumental in addressing food security by ensuring consistent fish supply through predictive yield modelling. These technologies collectively reduce reliance on guesswork and empower data-driven aquaculture management. Figure 2 illustrates a multi-layer IoT-based architecture for smart aquaculture. The **physical layer** comprises sensors and controlled devices within the fish farm, collecting real-time environmental data via protocols such as Wi-Fi, Bluetooth, and 5G. The **monitoring layer** processes and analyses this data, enabling device control, predictive modelling, and decision support, which are visualised for operators. Finally, the **virtual layer** hosts a cloud server environment for data storage, remote access, and integration of intelligent management systems.

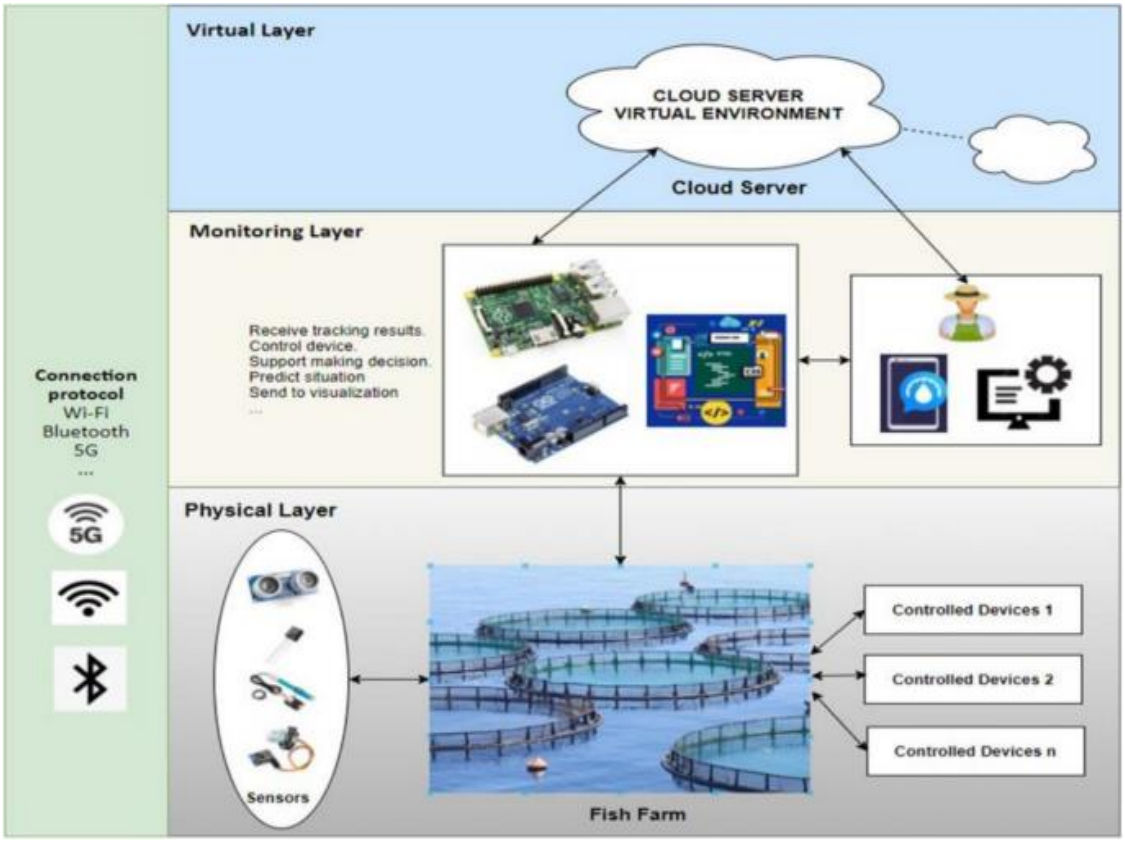


Figure 2: *AI in smart fish farming. (Akinsoroton, et al, 2024)*

Internet of Things (IoT)

The Internet of Things (IoT) is rapidly emerging as a game-changer in aquaculture, allowing seamless interconnection between devices and systems. Through smart sensors installed in ponds and tanks, IoT enables farmers to remotely monitor critical parameters such as dissolved oxygen, pH levels, ammonia concentration, and temperature. These sensors transmit real-time data to mobile dashboards, allowing operators to make instant adjustments that optimise fish health and water conditions. Assaf, *et al.* (2024) underscored the growing importance of IoT in facilitating automation and enhancing decision accuracy in aquaculture ecosystems. Their study shows that IoT helps reduce manpower needs while maintaining a consistent standard of farm management practices, Moreover, real-time water quality monitoring through IoT systems reduces the likelihood of mass fish mortality events caused by deteriorating water conditions. With threshold-triggered alerts and actuated responses, such as automated aeration or water exchange, IoT technologies ensure preventive action rather than reactive treatment. According to Bhusan *et al.* (2025), this capability is especially critical in regions vulnerable to extreme weather fluctuations and pollution. As these technologies continue to evolve, their integration into even small-scale farms is becoming increasingly affordable, democratising access to precision aquaculture and encouraging wider adoption among local and rural stakeholders. Figure 3 presents a range of Internet of Things (IoT) applications in fisheries, including smart buoys, drones, fish finders, GPS and satellite systems, and weather forecasting tools. Additional digital innovations such as electronic logbooks, automatic fish sorting devices, predictive analytics software, virtual reality training simulators, and smart fishing gears collectively enhance

operational efficiency, resource monitoring, and decision-making in modern fisheries.



a

Figure 3*: internet of a thing in smart fish farming (Bhusan et al. 2025)*

Blockchain for Traceability

Blockchain technology is increasingly being integrated into aquaculture supply chains to enhance transparency, traceability, and trust. By creating immutable digital records of each transaction and production stage, from hatchery to consumer, blockchain systems combat fraud and ensure product authenticity. Ferreira *et al*. (2021) explained how blockchain platforms are used to certify the origin, feed practices, and health history of fish products. This not only boosts consumer confidence but also facilitates export compliance and opens premium markets that demand traceable and ethically produced seafood.

In addition to supply chain transparency, blockchain enhances anti-fraud systems by recording information in a decentralised and tamper-proof format. This is particularly useful in curbing practices such as mislabeling, illegal harvesting, and substitution of species. Assaf *et al.* (2024) noted that integrating block chain with IoT and AI results in robust monitoring systems where data is securely logged and instantly available to all authorised stakeholders. As consumers and regulators demand more accountability, blockchain is emerging as a core digital tool in building trustworthy aquaculture brands and securing long-term market sustainability. Figure 4 illustrates the blockchain-enabled traceability framework within the fisheries value chain. From harvesting through transportation, warehousing, and retail distribution to final consumer purchase, each stage is secured via

smart contracts. This system stores data in a secure ledger, accessible through web or mobile interfaces, thereby ensuring transparency, authenticity, and compliance with trade regulations.

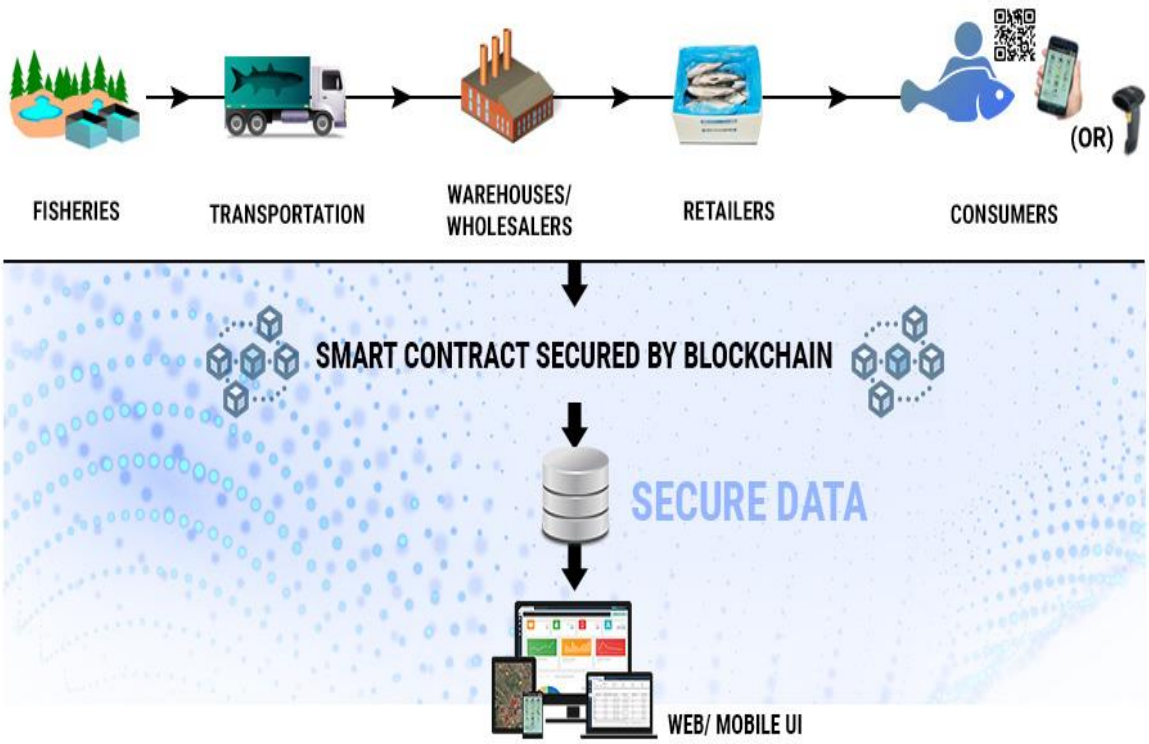


Figure: 4 *Smart Contract Secured by Block Chain (Ferreira et al. 2021)*

Geographic Information Systems (GIS) and Remote Sensing

Geographic Information Systems (GIS) and remote sensing technologies are essential tools for planning and managing aquaculture in spatially explicit environments. Habitat mapping using satellite imagery and GIS software enables stakeholders to visualise and evaluate suitable locations for aquaculture development based on criteria such as water availability, land use, and environmental sensitivity. Baruah *et al*. (2020) utilised GIS to map trout fisheries along the Yargyap Chu drainage, highlighting the technology's effectiveness in resource identification and biodiversity preservation. Ganie *et al.* (2024) further emphasise the role of GIS in cold water fisheries, where spatial analysis helps protect fragile ecosystems and ensures sustainable development. These technologies also support site selection by offering layered datasets that assess water depth, salinity gradients, pollution risk, and proximity to markets. This systematic approach reduces trial-and-error methods and optimises economic returns while mitigating ecological disruption. Bhusan *et al*. (2025) argued that combining GIS with socio-economic data enhances strategic decision-making and supports policies aimed at inclusive aquaculture growth. Remote sensing, when used alongside GIS, allows time-series analysis to monitor changes in aquaculture zones, detect illegal operations, and guide adaptive management strategies in response to environmental changes. Figure 5 integrates both IoT and blockchain concepts, showing how connected devices in fisheries supply chains feed real-time operational and transactional data into secure, decentralised networks. This fusion enables enhanced monitoring, quality assurance, and consumer

trust while streamlining logistics and reinforcing sustainability commitments.

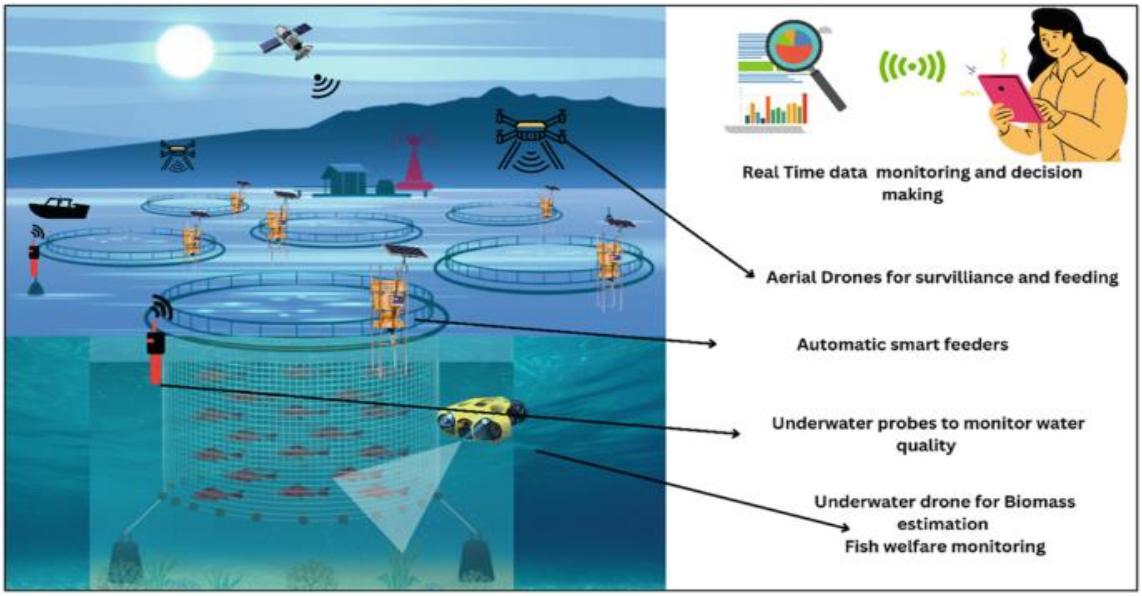


Figure 5: *Geographical information system in fisheries and aquaculture (Baruah et al. 2020)*

Big Data and Cloud Computing

Big Data and Cloud Computing technologies are pivotal in transforming aquaculture into a data-intensive industry. Forecasting models powered by large datasets, ranging from sensor readings and climate data to historical production records, enable predictive insights that enhance productivity and risk management. Cloud platforms facilitate the aggregation of these datasets in real-time, breaking silos and ensuring collaborative decision-making among farm managers, researchers, and policymakers. According to Bhusan *et al*. (2025), predictive analytics using Big Data helps detect disease outbreaks before they escalate, thus significantly reducing losses and treatment costs. Furthermore, centralized data management in the cloud provides scalable infrastructure for smallholder and industrial farms alike to access and store high-resolution information securely. Effiong *et al.* (2025) found that integrating cloud-based systems with AI and IoT devices led to better educational outcomes among agricultural science teachers and greater acceptance of tech-driven aquaculture. The cloud supports remote diagnostics, virtual consultations, and farm performance benchmarking, all of which contribute to improved productivity, environmental stewardship, and knowledge dissemination. In the long term, these technologies hold the key to building smart aquaculture ecosystems that are resilient, transparent, and aligned with global food sustainability goals. **Figure 6** Shows smart aquaculture system with a fully connected fish farming setup with drones, underwater robots, smart feeding boats, and AI data centers working together for efficient and precise aquaculture management.

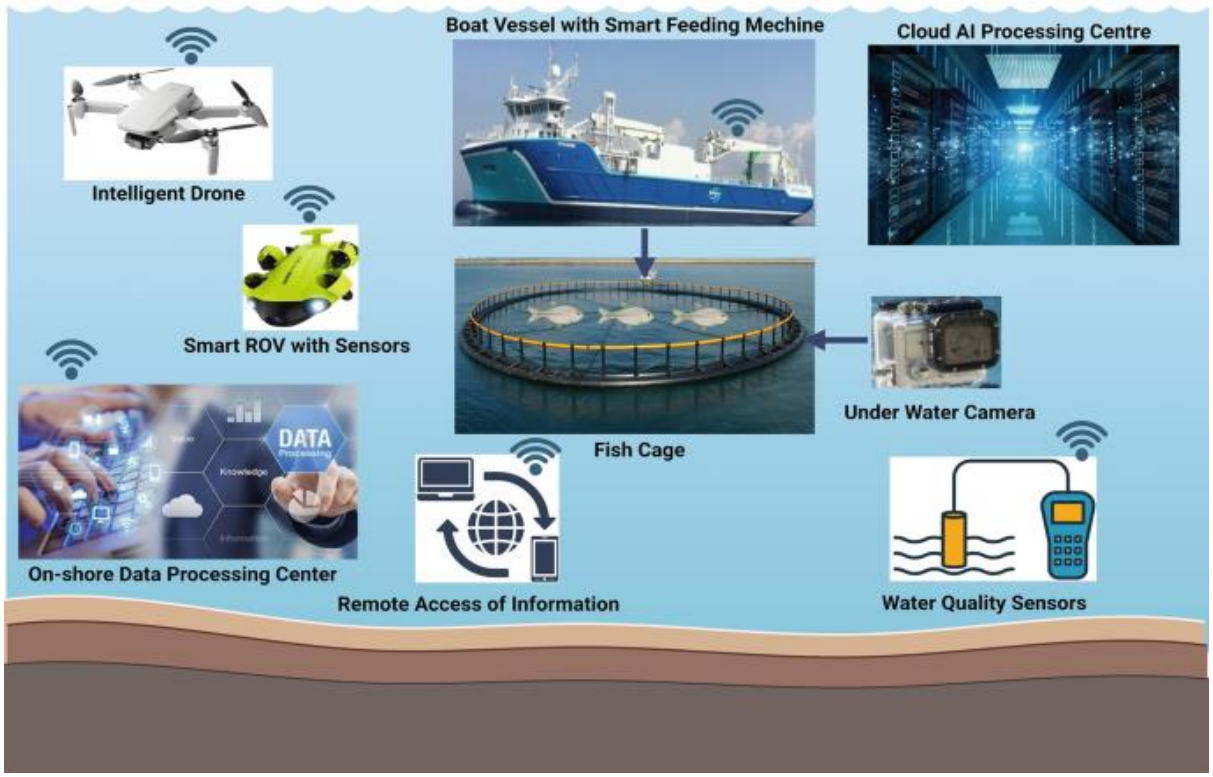


Figure 6: *Big data and cloud computing in fisheries and aquaculture (Effiong et al. 2025)*

PRACTICAL APPLICATIONS IN FISHERIES AND AQUACULTURE

Aquaculture Management Systems (e.g., AquaManager)

Modern aquaculture management systems such as AquaManager play a pivotal role in streamlining operations and enhancing productivity. These platforms integrate various digital tools including IoT sensors, real-time data analytics, and automation technologies to monitor fish health, water parameters, and feeding patterns. Through centralised dashboards, aquaculturists can track growth performance, oxygen levels, and biomass estimation, thereby making informed decisions that optimise both yield and resource utilisation (Assaf, *et al.*, 2024; Bhusan *et al.*, 2025).

Moreover, these systems facilitate record-keeping and compliance with environmental and regulatory standards. For instance, features such as traceability logs and performance history help in ensuring food safety and sustainability. With mobile-friendly interfaces and cloud integration, remote monitoring becomes possible, allowing farmers to act swiftly during anomalies such as disease outbreaks or equipment failure. These innovations collectively represent a shift from manual methods to intelligent, data-driven aquaculture (Effiong *et al.*, 2025; Jayasankar, 2023).

Smart Fish Farm

In Norway, smart marine fish farms have embraced technologies like underwater drones, AI-assisted feeding systems, and advanced image analysis tools to manage salmon farms efficiently. These innovations have significantly reduced feed waste and enhanced fish welfare by adapting to real-time behaviours (Føre *et al.*, 2023). India's adoption of smart aquaculture particularly in cold water fisheries has leveraged GIS and remote sensing for mapping suitable sites and managing trout populations sustainably (Baruah *et al.*, 2020; Ganie *et al.*, 2024).

In Nigeria, pilot programmes have introduced IoT-enabled tanks and smart aeration systems in urban aquaculture units. These systems automatically adjust water temperature and oxygen levels based on real-time data, reducing manual labour and mortality rates (Effiong *et al.*, 2025). The implementation of such technologies has also supported capacity building among fish farmers, demonstrating the potential for scalable smart farming practices across sub-Saharan Africa. Figure 7 shows depicts modern salmon farming in Norwegian fjords using large sea cages, automated feeding, and real-time monitoring in clean, deep waters. It also shows inland pond cage farming where multiple small cages are managed for freshwater fish production, combining traditional practices with simple monitoring tools.



Smart Farm in Salmon-Norway



Smart Farm in India

Figure 7: *Smart Fish Farming in Norway and India (Baruah et al., 2020; Ganie et al., 2024)*

Disease Surveillance and Health Monitoring

Cutting-edge technologies now enable real-time disease surveillance and early detection in aquaculture. Using sensors, underwater cameras, and machine learning models, health parameters such as erratic swimming, changes in pigmentation, and feeding anomalies can be quickly identified (Islam, *et al.*, 2024). AI algorithms are also employed to differentiate between benign and pathogenic changes, allowing for prompt interventions that reduce losses due to disease outbreaks. Additionally, the integration of digital pathology and biosensors assists in tracking parasitic infestations and bacterial infections. Blockchain technology is being explored to maintain health logs and medication histories, improving traceability and regulatory compliance (Ferreira *et al.*, 2021). This convergence of IT and biosciences in aquaculture promotes sustainable practices and enhances consumer trust in seafood quality and safety.

Automated Feeding and Harvesting Systems

Automated feeding systems employ AI to analyse consumption rates and fish size before dispensing optimal feed quantities. This practice not only minimises feed waste but also improves growth rates and feed conversion ratios (Føre *et al.*, 2023;

Mandal & Ghosh, 2024). With underwater cameras and sensors, the system continuously adjusts the feeding schedule based on real-time activity, ensuring that all fish receive adequate nourishment.

Likewise, automated harvesting technologies, including robotic arms and hydraulic lifting systems, enhance efficiency during harvest without stressing the fish. These tools ensure uniformity, speed, and hygiene, especially in large-scale commercial farms. Data from these systems also feeds into cloud-based platforms, enabling precise scheduling and logistics planning for downstream processing and distribution (Zhang & Gui, 2023). Figure 8 shows an automated feeding machine that feeds fish at a particular time set for each day.



Figure 8*: Automated Feeding and Harvesting Systems in fisheries and aquaculture (Føre et al., 2023; Mandal & Ghosh, 2024).*

Environmental Monitoring and Regulation Compliance

Environmental sustainability is a critical concern in aquaculture, and IT plays a central role in monitoring ecosystem impact. Through GIS and IoT networks, parameters like pH levels, turbidity, nitrate concentrations, and temperature are constantly tracked. This real-time environmental data supports both day-to-day operations and long-term ecological assessments (Baruah *et al.,* 2020; Assaf *et al.,* 2024).

Moreover, automated alerts and compliance tools ensure that farmers adhere to local and international environmental regulations. Platforms like AquaManager generate compliance reports, helping stakeholders avoid fines and promote sustainable practices. Satellite data and remote sensing also aid in assessing the carrying capacity of farming sites, supporting responsible expansion and conservation efforts (Ganie *et al.,* 2024).

BENEFITS AND CHALLENGES

Benefits

The application of information technology (IT) in fisheries and aquaculture presents numerous benefits, primarily centred on enhancing operational efficiency, improving productivity, and enabling smarter decision-making. Smart aquaculture systems powered by artificial intelligence (AI), the Internet of Things (IoT), and big data analytics facilitate continuous monitoring of water quality, feeding schedules, and fish health, leading to increased yields and reduced mortality (Mandal & Ghosh, 2024; Assaf *et al.,* 2024). Automation of feeding and environmental controls reduces labour intensity and optimises feed conversion ratios, which cuts operational costs significantly (Føre *et al.,* 2023). In addition, smart systems generate real-time data that managers can use to make informed decisions about stock management, resource use, and harvesting cycles, resulting in more sustainable practices (Bhusan *et al.,* 2025).

Disease surveillance and health monitoring through biosensors, automated cameras, and cloud-integrated analysis platforms also significantly contribute to early disease detection and biosecurity (Islam *et al.,* 2024). These technologies allow for prompt responses to pathogen outbreaks and reduce the overuse of antibiotics, which is critical for maintaining healthy aquaculture ecosystems. Furthermore, blockchain applications in fisheries supply chains ensure traceability, which enhances consumer trust, regulatory compliance, and export potential (Ferreira *et al.,* 2021). As noted by Effiong *et al.* (2025), the adoption of ICTs has empowered local fish farmers and agricultural educators with tools for improved farm management, thereby enhancing food security and economic outcomes.

Challenges

Despite these advantages, several challenges hinder the seamless integration of information technology in aquaculture. Foremost among these is the high initial cost of procuring and maintaining digital infrastructure such as sensors, automated systems, and software platforms (Bhusan *et al.,* 2025). For many small- and medium-scale fish farmers, particularly in developing regions like Nigeria and parts of South Asia, such capital investments are often unaffordable without governmental or institutional support (Effiong *et al.,* 2025). Moreover, the effective use of these technologies requires digital literacy and technical training, which are often limited among rural populations involved in fish farming (Assaf *et al.,* 2024).

Infrastructure deficits also pose significant obstacles, many aquaculture zones suffer from inconsistent electricity supply and limited internet connectivity, which impedes real-time data transmission and cloud-based monitoring (Baruah *et al.,* 2020). Security is another growing concern; cyber threats, data breaches, and unauthorised access to farm management systems can disrupt operations and compromise sensitive data (Ferreira *et al.,* 2021). Furthermore, the rapid pace of technological advancement can render existing systems obsolete, placing continuous pressure on farmers to update their systems and skills. These issues highlight the need for inclusive digital policies, training programmes, and supportive regulatory frameworks to ensure the broad and equitable adoption of smart aquaculture technologies.

Future Directions

The integration of digital technologies into fisheries and aquaculture offers considerable promise for transforming production, sustainability, and market

competitiveness. Future efforts should focus on expanding technical capacity among local fish farmers, particularly in rural and semi-urban areas, where enthusiasm for adoption is often hindered by limited digital literacy (Assaf et al., 2024). Embedding aquaculture technology modules in agricultural and vocational curricula will ensure sustained skills development among future practitioners.

On a broader scale, the operationalisation of village-level "smart ponds" with mobile-based control systems could significantly enhance productivity, resilience, and environmental monitoring. Advances in artificial intelligence and IoT should be adapted to local realities, including climate conditions, endemic species, and market dynamics. Stronger collaboration between software developers and fisheries scientists will be essential for producing tailored platforms capable of predictive disease modelling, real-time analytics, and voice-assisted interfaces in local languages. Such innovations could accelerate the transition towards inclusive, adaptive, and climate-resilient aquaculture systems in regions like Nigeria and beyond.

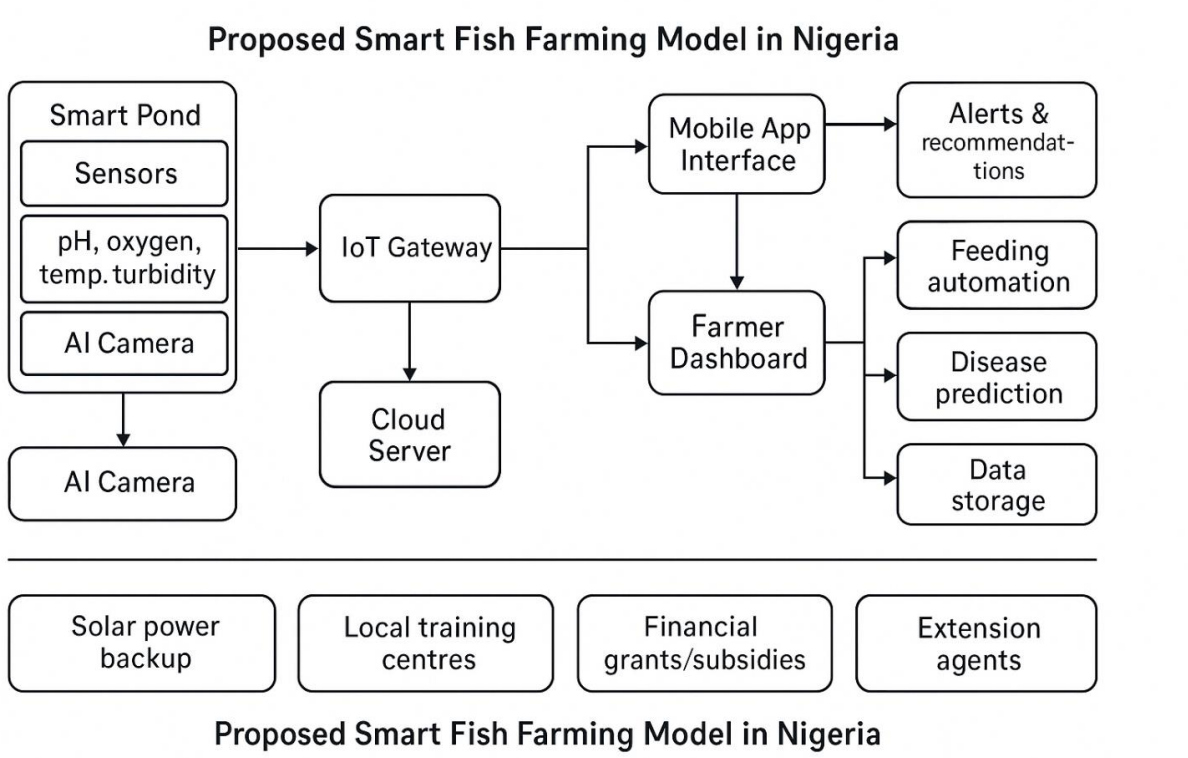


***Figure 9**: proposed smart fish farming model in Nigeria (Assaf et al., 2024).*

CONCLUSION

The integration of emergent information technologies in fisheries and aquaculture signifies a transformative shift in how aquatic resources are managed, monitored, and optimised. This paper has explored major technological trends such as artificial intelligence (AI), the Internet of Things (IoT), blockchain, geographic information systems (GIS), and big data analytics, all of which are reshaping the sector's operational landscape. These innovations offer a spectrum of capabilities from smart feeding and automated disease surveillance to blockchain-enabled traceability and satellite-based environmental monitoring making aquaculture systems more precise, adaptive, and sustainable. Importantly, these technologies are no longer confined to pilot

projects; they are actively deployed in diverse contexts such as Norway's offshore farms, India's cold water fisheries, and Nigeria's community-based aquaculture enterprises, with tangible outcomes in efficiency, resilience, and profitability (Føre et al., 2023; Assaf et al., 2024; Bhusan et al., 2025).

By enabling data-driven decision-making, minimising operational inefficiencies, and enhancing transparency across the value chain, digital tools support broader objectives of food security, climate adaptation, and economic diversification. When implemented alongside robust policy frameworks, targeted capacity-building initiatives, and affordable financing mechanisms, these technologies can accelerate the shift towards environmentally responsible and socially inclusive aquaculture. Nonetheless, persistent barriers such as high initial costs, inadequate infrastructure, and gaps in digital literacy must be addressed to ensure equitable adoption. Looking forward, a coordinated effort involving governments, industry stakeholders, research institutions, and local communities will be essential for unlocking the full potential of digital transformation in fisheries. Strategic investments in innovation, locally adapted solutions, and public–private partnerships will not only enhance productivity but also safeguard aquatic biodiversity and strengthen global supply chains. Ultimately, the digitalisation of aquaculture represents not just a technological evolution but a critical pathway towards building a resilient, competitive, and ecologically balanced aquatic food system for the future.

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