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Review Article

Integrating One Health Approaches for the Prevention and Control of Zoonotic Diseases in Aquaculture and Fish Farming

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Abstract

Zoonotic diseases—that can spread from animals to people—are a serious public health concern, especially in aquaculture systems where there is a close relationship between people, animals, and the environment. The danger of zoonotic disease emergence and transmission in Ethiopia has increased due to the rapid expansion of aquaculture, weak biosecurity measures, and inadequate disease surveillance. For the Ethiopian aquaculture industry to effectively prevent and control zoonotic illnesses, this review emphasizes the significance of implementing a One Health approach. Early illness diagnosis, risk assessment, and coordinated responses to zoonotic hazards can all be improved by One Health programs that promote interdisciplinary collaboration among veterinary, medical, and environmental health specialists. Incorporating this strategy also benefits the livelihoods of people that depend on fish farming, advances sustainable aquaculture methods, and guarantees food safety. Along with highlighting important obstacles such as legislative gaps, low stakeholder awareness, and poor diagnostic infrastructure, the study offers specific suggestions for putting a One Health concept into practice in Ethiopia. A comprehensive approach to reducing zoonotic hazards and safeguarding the health of humans and animals is offered by the use of One Health principles, which place a strong emphasis on multisectoral collaboration, stakeholder education, and strategic investment in surveillance and research.

Keywords: Aquaculture; Fish; One Health; Zoonotic diseases; Ethiopia

Introduction

An important part of human nutrition and food security, aquaculture has a long and noteworthy history and contributes significantly to the world's supply of high-quality protein [1]. One of the many issues facing the aquaculture sector as the demand for aquatic food products rises globally is the rise and spread of zoonotic diseases, which is becoming a greater worry [2]. Zoonoses are contagious illnesses that can spread from animals to people and are brought on by a variety of pathogenic organisms, such as fungi, bacteria, viruses, and parasites [3]. The viability and profitability of aquaculture enterprises, as well as public health, are seriously threatened by these illnesses, which frequently cause significant financial losses [4].

The One Health concept acknowledges the interdependence of environmental, animal, and human health, providing a comprehensive framework to address such issues [5]. This integrated approach is especially pertinent to aquaculture because of the intimate relationships that exist between human populations, aquatic creatures under cultivation, and the surrounding ecosystems [6]. By adopting One Health principles, aquaculture systems can embrace more responsible and sustainable methods that protect public health, enhance aquatic animal welfare, and reduce negative environmental effects [7].

A significant issue in modern aquaculture systems is the rise of bacteria resistant to antibiotics, which is mostly caused by the abuse and overuse of antibiotics. In addition to making treating fish infections more difficult, the extensive prevalence of antimicrobial resistance (AMR) genes in aquatic ecosystems poses a growing concern to public health due to environmental dispersion and possible human exposure [8]. Aquaculture has yet to fully adopt the One Health paradigm, despite growing awareness of it in veterinary medicine and terrestrial agriculture [9]. This disparity emphasizes the necessity of focused studies and legislative measures especially designed to address aquatic systems' distinct epidemiological dynamics [10].

Global environmental stresses, including climate change, ocean acidification, habitat loss, biodiversity loss, and extreme weather events, also make aquaculture even more vulnerable by upsetting ecosystems and raising the risk of infectious disease outbreaks. Examining how One Health approaches can be incorporated into aquaculture and fish farming systems to prevent and manage zoonotic infections is the aim of this review. In particular, this study is intending to identify important issues, evaluate existing methods, and suggest long-term, scientifically supported solutions that lower the risks of zoonotic diseases, improve the health of aquatic animals, and safeguard public welfare in light of global environmental change.

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Objectives

✓ **Evaluate** the prevalence and types of zoonotic diseases affecting aquaculture, with a focus on their impact on both farmed aquatic species and human health.

✓ **Analyze** the implementation of the One Health approach in aquaculture, highlighting successful case studies and identifying gaps in its application.

✓ **Examine** the role of environmental factors—such as climate change, pollution, and biodiversity loss—in the emergence and spread of zoonotic diseases in aquatic ecosystems.

✓ **Propose** effective and sustainable disease management strategies that align with One Health principles to enhance fish health, ensure consumer safety, and promote environmental sustainability.

✓ **Recommend** appropriate diagnostic tools and surveillance systems for the early detection and monitoring of zoonotic diseases in aquaculture, improving health outcomes for both animals and humans.

Review of One Health

The Role of Bio-security in One Health and Aquatic Systems

According to Hulme & P.E. [11], biosecurity is a broad and integrated strategy that includes legal, regulatory, and policy frameworks for evaluating and controlling hazards that affect the health of people, animals, plants, and the environment. Biosecurity in aquatic systems refers to national and international initiatives to safeguard natural aquatic ecosystems, capture fisheries, aquaculture operations, and biodiversity against biological threats such as infections, invading species, and developing diseases [12]. Due to the rise in global pandemics, the introduction of new infectious agents, and increased worries about bioterrorism, the significance of biosecurity in aquatic ecosystems has come to light more frequently in recent years [13]. These advancements in global health have highlighted the need for strong, preventive frameworks to protect ecological integrity, food production systems' resilience, and public health [14].

One of the main goals of biosecurity is to stop the entry and spread of infectious organisms into aquatic environments and local communities, especially those that are highly pathogenic, new, or resistant to antibiotics [15]. Proactive in nature, successful biosecurity policies seek to identify biological threats early on, put containment procedures into place, and launch prompt, coordinated reactions to lessen possible effects [16]. The One Health approach's integration of biosecurity principles into aquaculture and fisheries management greatly reduces the need for antibiotics, promotes environmental and economic sustainability, and helps avoid disease. In addition to promoting ecological stability by halting disease outbreaks and ecosystem degradation, this integrated strategy benefits the health of human communities and aquatic animals [12].

Physical Aquaculture Biosecurity Measures

The prevention and management of illness in aquaculture systems is largely dependent on physical biosecurity measures. According to MacKinnon *et al.* [17], these tactics are intended to reduce the risk of pathogen introduction and the spread of infectious diseases in order to maintain the health and welfare of aquatic creatures. According to Assefa and Abunna [18], physical measures are mostly based on mechanical barriers and infrastructure that limit external vectors and possible disease carriers from entering aquaculture operations. Physical biosecurity components that are frequently used include screening systems, netting, and fences. These systems are designed to keep predators and reservoir hosts, including birds, reptiles, mammals, and other wildlife, from invading [19]. Through direct interaction with fish populations or indirect contamination of water sources and feed supplies, these creatures can introduce infections as mechanical carriers or biological vectors [20]. Numerous aspects, such as the material selection, mesh size, environmental resilience, and the particular geographic and ecological characteristics of the aquaculture facility, influence how effective these barriers are [21]. For example, in tropical locations, tiny mesh screens might be more successful at keeping insect vectors away, whereas in areas where wildlife invasion is a problem, wider perimeter fences might be required. Physical measures are crucial in lowering the prevalence of infectious and zoonotic diseases, which supports both animal health and food safety. They are the first line of defense in biosecurity systems [22]. These physical treatments support the long-term sustainability and viability of aquaculture operations when they are carried out methodically and appropriately [23].

Biological Aquaculture Bio-security Measures

In aquaculture systems, biological biosecurity measures are essential to the comprehensive management of disease risks because they provide sustainable and eco-friendly methods of disease prevention and control [24]. These tactics focus on strengthening aquatic creatures' innate defenses and creating a supportive microbial environment that actively inhibits the growth of diseases [25]. The use of disease-resistant or disease-free aquatic organisms is one of the fundamental strategies under biological biosecurity. In particular, the implementation of stocks that are Specific Pathogen Free (SPF) and Specific Pathogen Resistant (SPR) has been successful in reducing disease outbreaks. The heightened immunity and decreased susceptibility to common infections that these carefully bred or certified species possess not only lower the frequency of illness occurrences but also increase production efficiency [26,27]. Probiotics are yet another effective biological treatment. They're live microorganisms that give the host organism health benefits when given in the right amounts. Through the synthesis of antimicrobial chemicals, competitive exclusion, and the stimulation of host immune responses, probiotics are employed in aquaculture to increase nutrition absorption, maintain gut microbiota, and outcompete pathogenic microorganisms [28,29]. By enhancing water quality and lowering the need for antibiotics, their frequent use supports the general health of the system.

Immunostimulants, a broad category of natural or artificial substances that can improve fish and shellfish innate and adaptive immune responses, are another crucial class of biological agents. These substances have the potential to greatly increase resistance to infections, especially in farming environments that cause stress [30]. After administering immunostimulants to commercial aquaculture operations, a number of studies have documented improvements in growth rates, survival, and general health indices [31,32]. Building robust aquaculture systems requires incorporating biological biosecurity measures into standard farm management procedures. By limiting negative effects on the environment and slowing the development of antibiotic resistance, these tactics not only promote the health and well-being of animals but also serve the goals of One Health.

Operational Aquaculture Biosecurity Measures

In aquaculture, operational biosecurity measures are essential parts of all-encompassing disease prevention plans. According to Abraham *et al.* [33], these methods are intended to lower the danger of disease introduction, preserve the well-being and health of aquatic species kept in captivity, and promote sustainable agricultural productivity. Using high-quality, pathogen-free meals is a must for operational biosecurity. The safety of feed is a crucial control point since contaminated feed is the main vector for the spread of disease. High-quality diets enhanced with nutrients that boost the immune system can strengthen aquatic creatures' natural defenses, making them less vulnerable to diseases [34]. Appropriate feed handling procedures are equally crucial, and this includes regular checks for physical deterioration, microbiological contamination, and spoiling. To further reduce the risk of feed-borne illness, make sure that the storage conditions are suitable, such as cool, dry, and pest-free [35]. Another operational objective in aquaculture biosecurity is the maintenance of water quality. Because the aquatic environment is dynamic, even minor adjustments can have a big impact on host vulnerability and pathogen survival. Thus, it is crucial to continuously monitor variables such as temperature, pH, and levels of dissolved oxygen, ammonia, and nitrite in order to detect environmental stressors early [36]. According to Paredes-Trujillo *et al.* [37], proactive maintenance of ideal water conditions lowers animal stress, inhibits the growth of pathogens, and lessens the chance of disease outbreaks. Increasingly, the recirculating aquaculture system (RAS) is being used as a technique to improve operational biosecurity. RAS makes it possible to reuse water by using a closed-loop system that includes both biological and mechanical filtration elements. According to Gupta *et al.* [38], these systems minimize contact with natural, potentially polluted water sources, hence reducing exposure to external pathogens. By conserving water and precisely controlling rearing conditions, RAS also helps to maintain a sustainable ecosystem [39]. Methodically putting operational biosecurity procedures into practice can help lower the risk of disease, boost output, and further the One Health goal of safeguarding the health of people, animals, and the environment.

Future of Aquaculture Biosecurity

The combination of biotechnology and digital innovation is increasingly defining the future of aquaculture biosecurity, as they provide revolutionary prospects for rapid response, surveillance, and disease prevention. The incorporation of smart technologies is crucial for bolstering biosecurity systems and reducing zoonotic threats as aquaculture around the world grows in complexity and scale [4]. Among the most promising developments is the use of big data analytics. Large amounts of data are currently produced by aquaculture systems via operational logs, environmental sensors, automated feeding systems, and health monitoring equipment. By combining environmental, biological, and operational factors, machine learning algorithms enable the real-time analysis of this data to spot anomalous trends, forecast disease outbreaks, and evaluate biosecurity vulnerabilities [40,41]. By enabling evidence-based decision-making and early warning systems, these predictive tools lessen the need for reactive disease management strategies.

Aquaculture's spatial disease surveillance is being revolutionized at the same time by the integration of remote sensing technology and geographic information systems (GIS). These techniques make it possible to map and analyze important factors like climate, farm proximity, land-use change, and water quality—all of which are crucial for monitoring the spread of aquatic diseases and evaluating hazards at the ecosystem level [42]. Real-time insight into high-risk or inaccessible places is another benefit of remote sensing, which supports focused biosecurity measures and improves the ability to limit disease locally. Moreover, integrated digital platforms that bring together sensor networks, cloud-based data storage, and AI-driven diagnostics to provide smooth, automated biosecurity systems are probably going to be given more attention in the future. A comprehensive picture of aquaculture health status and biosecurity performance may be obtained from these platforms' centralized dashboards for farmers, veterinarians, and policymakers [43]. In conclusion, the effective incorporation of digital intelligence into farm operations, regulatory frameworks, and research projects will be critical to the ongoing development of aquaculture biosecurity. In addition to improving early detection and response capabilities, these technologies will bring aquaculture practices into line with the One Health paradigm, guaranteeing future aquatic food systems are safer and more robust.

Disease Surveillance and Management

Efficient disease surveillance and control is a crucial component of aquaculture's One Health concept, safeguarding not only the health of aquatic animals but also the general public and the integrity of the ecosystem [44]. Aquaculture settings, especially those with high stocking densities, intense production systems, and monoculture techniques, provide the perfect habitat for infectious agents to spread quickly. These conditions increase the risk of bacterial, viral, and parasitic illnesses in cultured species [45].

Both passive surveillance—such as farm-level illness reporting and community alerts—and active monitoring—such as routine sampling and laboratory diagnostics—are necessary for this [46]. To improve their ability to detect pathogens, modern surveillance systems are using next-generation sequencing (NGS) and molecular diagnostic methods like PCR and LAMP. More focused and timely responses are made possible by these techniques' ability to quickly identify both novel and known infections, even at low concentrations [47]. Furthermore, bioinformatics systems are becoming more and more important in disease tracking since they can visualize transmission patterns and aggregate data from different regions to help with risk forecasts.

Bio-security and resilience in aquaculture systems ultimately depend on the creation of well-coordinated and resourced surveillance systems, backed by environmental scientists, public health officials, and veterinary specialists. The aquaculture industry's long-term sustainability, productivity, and safety are ensured via surveillance, which is a proactive approach rather than just a reactive one.

Importance of Diagnostic Tests

In aquaculture systems, early disease detection, precise diagnosis, and efficient management depend heavily on diagnostic tests [48]. In addition to enabling prompt response to disease outbreaks, prompt diagnosis also guides focused treatment and bio-security measures that can stop the spread of the disease, protecting the health of aquatic animals and public safety. Because of their improved speed, sensitivity, and specificity over conventional techniques, molecular-based diagnostic technologies have become important developments in aquaculture health management in recent years [49]. A notable technological advancement among these is the use of DNA microarrays, which allow for the simultaneous detection and identification of several diseases in a single assay [50].

To improve the accuracy and thoroughness of pathogen identification, these microarrays use fluorescently labeled probes designed to capture a variety of target co to improve the accuracy and thoroughness of pathogen identification, these microarrays use fluorescently labeled probes designed to capture a variety of target compounds, including proteins, glycans, and nucleic acids [51]. Furthermore, lethal sampling techniques—which entail the direct analysis of tissue samples to isolate and identify the causal agents of disease—are frequently emphasized in contemporary diagnostic protocols [52].

Antibiotic Usage and Resistance in Aquaculture

There are many difficulties with using antibiotics in aquaculture, especially when it comes to the development and spread of antibiotic resistance [53]. In order to maintain the health and production of farmed aquatic animals, antibiotics are frequently used to prevent and cure bacterial infections. The emergence of antibiotic-resistant bacteria, which represent major risks to the health of humans and animals, is facilitated by the unchecked and excessive use of these antimicrobial medications [54]. The emergence of antibiotic-resistant bacteria limits options for treating infectious diseases and raises the possibility of treatment failures, endangering the effectiveness of vital therapies in both human and veterinary medicine [55].

Urgent and coordinated effort across several sectors is required to address this worldwide public health issue. The One Health strategy integrates human, animal, and environmental health to provide a holistic framework for addressing antibiotic resistance in aquaculture [56]. This strategy promotes responsible antimicrobial stewardship that lessens the selection pressure favoring resistant strains by emphasizing the responsible use of antibiotics in aquaculture techniques. To comprehend the scope and dynamics of resistance development, it is essential to conduct efficient monitoring and detection of antimicrobial resistance (AMR) in aquaculture systems [57]. Urgent and coordinated effort across several sectors is required to address this worldwide public health issue. The One Health strategy integrates human, animal, and environmental health to provide a holistic framework for addressing antibiotic resistance in aquaculture [56]. This strategy promotes responsible antimicrobial stewardship that lessens the selection pressure favoring resistant strains by emphasizing the responsible use of antibiotics in aquaculture techniques. To comprehend the scope and dynamics of resistance development, it is essential to conduct efficient monitoring and detection of antimicrobial resistance (AMR) in aquaculture systems [57].

Stakeholders can detect new resistance trends and apply evidence-based risk-reduction strategies by conducting ongoing surveillance. In addition, the One Health framework makes it easier to monitor the use of antibiotics in both human and veterinary treatment while taking into consideration the intricate ecological relationships that lead to the spread of resistance [58]. We can preserve the efficacy of antibiotics, maintain public health, and advance sustainable aquaculture production by tackling AMR in aquaculture from this integrated perspective.

Social Capital

Social capital, which includes trust, collaboration, common standards, and official and informal membership in groups, collectives, and networks, is an important component of farming communities [59]. These social resources greatly improve the efficacy and resilience of communities, especially when it comes to managing and monitoring illnesses in agricultural and aquaculture environments. Public health scholars have mostly studied the importance of social capital in epidemiology, concentrating on how social dynamics influence farmers' attitudes and reactions to disease risks [60]. By using social network analysis, one can gain a thorough grasp of the roles, sway, and embeddedness of individuals in these networks. According to Cvitanovic *et al.* [61], this analysis shows how community ties and individual interactions either help or impede the exchange of important information and group decision-making processes. Collective action is essential when it comes to managing diseases. It guarantees collaboration between people and institutions in pursuit of common goals, like the prevention or management of disease [62]. Coordination of reactions, prompt reporting of disease outbreaks, and adherence to biosecurity protocols are all improved by cooperative efforts based on high social capital.

Broadly speaking, national agencies and international organizations have formed cooperative networks to enhance cross-border coordination of animal and human disease surveillance [63]. These networks make it easier to share information effectively, coordinate policies, and coordinate efforts across industries and countries. They thus contribute to better management of zoonotic and other infectious illnesses in aquaculture and beyond by bolstering global disease surveillance and control.

The Role of Institutions

Particularly in the fields of public and animal health, institutions are the cornerstones of dependable frameworks for coordination and communication within and across organizations [64]. These organizations are essential to the efficient monitoring, management, and control of illnesses and operate on a local, national, and worldwide scale [65]. Their organized participation guarantees coordinated efforts across many industries and locations, regulatory monitoring, and policy coherence. Regional and sub-regional surveillance networks were created to handle the complexity of disease response and surveillance [66].

Multiple stakeholders' information sharing and disease notification are made more accurate, transparent, and timely by these cooperative networks. According to Hassan *et al.* [67], these networks are essential for improving disease surveillance and bolstering coordinated response systems in accordance with the One Health strategy because they promote trust and cooperation across national and institutional boundaries. Institutional support and multi-level cooperation make disease management is initiatives more methodical, effective, and adaptable, which eventually strengthens aquaculture biosecurity and public health systems.

Fish Vaccination in Aquaculture

In aquaculture, fish vaccination dates back to the time when cutthroat trout (Oncorhynchus clarkii) were vaccinated against the furunculosis-causing Aeromonas salmonicida infection [68]. Since this groundbreaking initiative, vaccination has emerged as a crucial part of managing fish health globally. The majority of vaccines used in aquaculture today are traditional inactivated or attenuated vaccines, mainly because our knowledge of the immune system of fish is still relatively new in comparison to that of terrestrial animals. Vaccination is still one of the most popular and successful methods for preventing and managing viral illnesses in aquaculture systems, despite these drawbacks [69].

Against certain diseases or antigens, vaccines elicit targeted protection and promote long-term immunity by stimulating both innate and adaptive immune responses [70]. Effective vaccination campaigns not only lower fish mortality and morbidity but also dramatically reduce antibiotic reliance, which helps to prevent the development of antibiotic resistance [71]. Immunization improves fish health and immunity in a sustainable manner, which supports biosecurity measures and improves animal welfare and production efficiency—goals that are strongly aligned with the One Health concept [4].

Good Husbandry Practices in Aquaculture

In aquaculture systems, good husbandry techniques are essential to fostering the resilience, health, and disease resistance of aquatic animals [72]. The foundation for better health outcomes throughout production is laid by proactive measures taken early in the production cycle, such as the implementation of targeted vaccination programs and the selection of disease-resistant stocks through genetic improvement or screening [33].

To reduce physiological stress and promote the stability of cultured species, it is essential to maintain ideal water quality parameters, such as temperature, dissolved oxygen, turbidity, pH, and ammonia concentrations [73]. Reducing environmental stresses and improving immunological function are two benefits of maintaining these parameters within species-specific tolerance ranges. In addition to maintaining aquatic animals' overall health, regular use of sound husbandry techniques fortifies their innate immune systems. The creation of biosecure and sustainable aquaculture systems is greatly aided by these initiatives [74].

Conclusion

In aquaculture and fisheries, the One Health concept is essential for the efficient management and avoidance of zoonotic illnesses [23]. Through highlighting the interdependence of human, animal, and environmental health, this integrated approach promotes coordinated cooperation amongst aquaculture stakeholders, environmental scientists, public health officials, and veterinarians [75]. Important elements of this strategy include encouraging responsible antibiotic use, improving disease outbreak monitoring, fortifying biosecurity protocols, and guaranteeing environmental sustainability [76]. The One Health framework has potential to safeguard public health, lower the risk of zoonotic disease transmission, and promote the aquaculture industry's long-term viability through enhanced cooperation, surveillance, and education [58].

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