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Digital Innovation for Sustainable Shrimp Aquaculture in Indonesia: Addressing Disease Outbreaks, Socioeconomic, and Environmental Challenges

A M A Khan[1*], R Andoyo[2], G Wibisono[3], S Widianto[4], H Ritchi[4], R P Sari[4], S M Seshadrinath[5], M Cooray[5], and H Y Siry[6]

[1] Tropical Marine Fisheries Undergraduate Programme for Pangandaran Campus of Universitas Padjadjaran, Kabupaten Pangandaran, Indonesia
[2] Department of Food Technology, Faculty of Agro-Industrial Technology, Universitas Padjadjaran, Kabupaten Sumedang, Indonesia
[3] Department of Fisheries, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran, Kabupaten Sumedang, Indonesia
[4] Faculty of Economics and Business, Universitas Padjadjaran, Kabupaten Sumedang, Indonesia
[5] School of Information Systems and Technology Management, UNSW Business School, University of New South Wales, Sydney, Australia
[6] Ministry of Marine Affairs and Fisheries (MMAF) Republic of Indonesia, Jakarta, Indonesia

[*]E-mail: alexander.khan@unpad.ac.id

Abstract. Shrimp aquaculture is a vital component of Indonesia's coastal economy and food security, yet its long-term viability is significantly challenged by a complex interplay of factors. This manuscript critically examines the primary obstacles hindering sustainable shrimp farming in Indonesia, including the escalating frequency of disease outbreaks, pervasive environmental degradation, issues of insecure land ownership, the scarcity and inconsistent quality of essential agro-inputs, and persistent socio-economic disparities such as worker exploitation and entrenched gender inequality. Through a comprehensive literature review, meticulously conducted following modified PRISMA guidelines and drawing from Scopus, Google Scholar, and pertinent literatures, this study illuminates how deficiencies in disease management, restricted access to land, and the systemic marginalization of women in decision-making processes collectively undermine the sector's sustainability. In response, this study proposes the conceptualization and development of a Gender-Inclusive Disease Reporting and Monitoring System (DRMS). This innovative, participatory, and data-driven digital platform aims to facilitate real-time information exchange, significantly enhance disease surveillance capabilities, and empower shrimp farmers, particularly women, by integrating their indigenous knowledge with advanced technological solutions. By addressing both technical biosecurity needs and long-standing structural imbalances, the DRMS seeks to foster more resilient, equitable, and environmentally sound aquaculture practices across Indonesia.

1. Introduction

Aquaculture is one of the activities that significantly enhances the well-being of coastal communities [1]. Aquaculture improves coastal community welfare by creating jobs, supporting livelihoods, and ensuring food, nutrition, health, and income for fish farmers [1][2][3]. Aquaculture even at the traditional scale contributes to poverty reduction in several regions of the world, including China, Indonesia and Vietnam [4]. One of the aquaculture activities commonly in Indonesia is brackish water shrimp culture. The brackish water shrimp culture traditionally known as tambak in Indonesia [5]. The brackish water shrimp culture in Indonesia mostly located in regions like Aceh, South Sulawesi, and Java. Historically, shrimp were secondary products of milkfish farming in Indonesia [5], but since the 1970s, species such as *Penaeus monodon* (tiger shrimp) and *Penaeus vannamei* (white shrimp) have become primary targets for aquaculture, driven by export demands. As of 1990, brackish water ponds produced approximately 272,000 tons of shrimp, contributing significantly to Indonesia's fisheries exports [6]. Brackish water

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shrimp aquaculture in Indonesia facing significant challenges from both environmental and disease that hampered both ecologically and local coastal communities' source of income [7]. One of the primary concerns is the deforestation of mangrove ecosystems for the establishment of shrimp ponds, resulting in massive habitat loss, a decline in coastal biodiversity, and intensified coastal erosion [8][9]. Moreover, shrimp farming practices contribute to water pollution through the release of nutrient-rich effluents that lead to the proliferation of algae, depleting oxygen levels in the surrounding waters, harming aquatic species and disrupting local fisheries [10].

Brackish water shrimp aquaculture also faces significant challenges beyond environmental damage. Disease outbreaks, which have become more frequent since the rise of intensive farming methods in the 1990s, pose a serious threat [11]. These outbreaks can cause substantial economic losses for farmers, with numerous ponds abandoned due to viral infections [12]. The practice of keeping high densities of shrimp in ponds further increases the risk of disease transmission within the population, making disease management more difficult. Additionally, the introduction of non-native species like *Penaeus vannamei* raises concerns about potential ecological harm and the spread of diseases to native shrimp populations such as *Penaeus monodon* [1][2][7][9]. In addition to high operational costs, viral diseases such as White Spot Syndrome Virus (WSSV) and Taura Syndrome Virus (TSV) pose a serious threat [13]. Another example related to shrimp aquaculture disease in tropical country such as Indonesia is the Acute Hepatopancreatic Necrosis Disease (AHPND) which caused by *Vibrio parahaemolyticus* that leads to rapid death and severe hepatopancreatic damage among farmed *Litopenaeus vannamei* shrimp [14][15]. Moreover, the occurrence of regional disease outbreaks characterized by co-infections, specifically involving Acute Hepatopancreatic Necrosis Disease (AHPND) and Epizootic Hemorrhagic Pandemic Disease (EHP), underscores the intricate and multifaceted nature of shrimp disease epidemiology within Indonesian aquaculture systems [16][17].

Furthermore, apparent disparities also exist to women's involvement in aquaculture which can be found in land ownership, wage gap, and core shrimp farming activities, including technological adoption. Technological and societal ventures to grapple these challenges are therefore of necessity to help establish an inclusive participation in shrimp aquaculture. Amidst these challenges, the development of a gender-inclusive Disease Reporting and Monitoring Systems (DRMS) emerges as a potential solution. The DRMS will be an open collaborative platform, allowing shrimp farmers and stakeholders in the aquaculture ecosystem to share real-time data, report and monitor potential diseases in their farming environment.

2. Methods

This research was conducted using a literature review approach, adapting the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [18]. A thorough review of available literature was conducted through both the Scopus and Google Scholar databases to capture peer-reviewed articles, in addition to unindexed grey literature from entities like the Food and Agriculture Organization (FAO), the Asian Development Bank (ADB), and Indonesia's Ministry of Marine Affairs and Fisheries (MMAF). Next, further relevant sources were uncovered by a thorough review of citations found in lead publications to ensure a complete listing of relevant studies.

The keywords used in this review included: "shrimp aquaculture Indonesia," "disease outbreak," "gender inclusion aquaculture," "sustainability in aquaculture," and "disease reporting system." The parameters used in searching were restricted to keywords, titles, and English and Indonesian language abstracts. No specific time restrictions were set in an effort to include a wide range of literature that was relevant to the context of shrimp aquaculture in Indonesia; correspondences to editors, editorial content, and presentation materials like PowerPoint slides, however, were not included in this review. The articles were identified using clear criteria: (1)

relevance to the research goals, specifically in connection to managing illness, as well as incorporating gender factors in shrimp aquaculture, and (2) contribution to the understanding of socio-environmental management, land tenure, labour relations, input utilization, and productivity in pond environments. The articles selected were published between 1994 and 2024. The selected articles were organized by themes, critically examined, and assessed to provide information required for construction of a Gender-Inclusive Disease Reporting and Monitoring System (DRMS) for shrimp farming in Indonesia.

Ethical Statement. This study is not involve live animals or any form of animal experimentation. As no experimental procedures were conducted, ethical approval was not required.

3. Results and Discussion

Shrimp aquaculture in Indonesia presents both a significant economic opportunity and a series of persistent challenges that threaten its long-term viability. This discussion synthesizes key thematic insights from the literature to explore the current landscape of shrimp farming, including environmental degradation, disease outbreaks, socio-political constraints, and gender disparities. While the industry has shown considerable growth over the past decades, it remains vulnerable to systemic pressures exacerbated by climate change, inadequate biosecurity measures, and inequitable access to resources. This section is structured thematically to examine the multifaceted barriers hindering the sustainability of shrimp aquaculture. First, it highlights the intensifying impact of diseases in shrimp farming, which continue to cause substantial economic losses. It then explores structural issues related to land ownership and spatial planning that limit farmers' capacity to scale operations. Labor conditions and gender inequality are also addressed, emphasizing the need for inclusive participation in disease management and decision-making. Furthermore, the availability and quality of agro-inputs and shrimp seedlings are examined in terms of farm productivity and disease resilience.

Collectively, these findings underscore the urgent need for integrated solutions such as gender-inclusive Disease Reporting and Monitoring Systems (DRMS) to support sustainable aquaculture in Indonesia. The conceptual framework of the DRMS is illustrated in Figure 1.

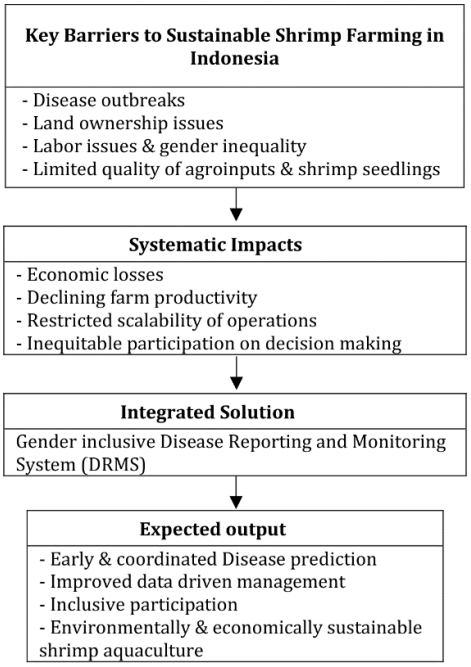


Figure 1. Conceptual framework of DRMS to addressing key barriers to sustainable shrimp aquaculture in Indonesia

3.1 Snapshot of global and Indonesia shrimp aquaculture

According to [19], the global farmed shrimp production in 2024 is anticipated to reach approximately 6 million tons, with the production is expected to recover from the minor decline in 2023, when output was approximately 5.6 million tons. This downturn can be attributed to a confluence of industry challenges, including environmental perturbations and market fluctuations [20]. The predicted expansion of shrimp production in 2024 is primarily attributed to substantial increases in output anticipated from major shrimp-producing nations, notably Ecuador, India, and Vietnam [20][21]. *Litopenaeus vannamei* remains the dominant species in global shrimp aquaculture where concurrent advancements in aquaculture practices, including novel farming techniques and enhanced biosecurity protocols, are being implemented to augment production yields and foster sustainable aquaculture systems rapidly [20][22]. The second largest production from *Penaeus monodon*, commonly known as tiger shrimp, occupies a niche market within the global seafood industry, characterized by a smaller volume but higher value. This distinction is primarily attributed to its unique flavor profile and larger size, which caters to premium consumer segments [20]. The Asian region remains a significant contributor to tiger shrimp production; however, production during the first half of 2024 exhibited a decline compared to the corresponding period in 2023 [19]. This downturn can be attributed to decreased stocking densities within aquaculture ponds, particularly impacting India and Southeast Asia. This phenomenon is largely a consequence of farmers encountering difficulties in procuring sufficient quantities of high-quality seed stock for shrimp aquaculture [20].

Sustained investments in enhancing broodstock quality and implementing sustainable aquaculture practices are crucial for optimizing production yields and maintaining a competitive edge within the global seafood market [23]. Globally the total shrimp value from aquaculture has increased for decades driven by rising demand and production. The total market's value surged from approximately USD 20 billion in 2014 to an estimated value exceeding USD 40 billion by 2023, reflecting a compound annual growth rate of about 6.3% during this period [25]. This forecast has been conformed by [24] as reports that the global shrimp aquaculture industry has seen substantial growth in recent years, while precise figures for total global shrimp value from aquaculture can fluctuate, the FAO tracks production volumes and market trends, indicating a significant economic contribution. The industry plays a crucial role in food security, employment, and economic development, particularly in many low- and lower-middle-income countries [26].

Demand for shrimps and prawns was high in China and the European Union in 2022, contrasting with a marginal decline in the United States of America. In 2022, global exports of shrimps and prawns reached USD 32.3 billion, an increase of 8.7 percent from 2021 – which had already seen a 22 percent growth from 2020 following three consecutive years of decline between 2018 and 2020. This downward trend reflected the diminished prices driven by large production volumes, particularly from aquaculture. Although prices saw a slight increase in 2022, they remained lower than historical levels. However, in 2023, international shrimp prices dropped by 16 percent compared with 2022, as reported by the FAO Fish Price Index. This, combined with rising production costs, had a negative impact on the profitability of the sector [19]. Reflected as of late 2023, global shrimp production is anticipated to stabilize around 5.6 million metric tons, slightly down from previous years but expected to grow again by approximately 4.8% in 2024 [19][20][27]. Furthermore, with the Organization for Economic Cooperation and Development (OECD) forecasting a decline in seafood prices over the next decade due to oversupply and changing consumer preferences, the shrimp market will need to consider and navigate these challenges carefully for facing future market's behavior changes [28][29].

Total shrimp pond area is a dilemma topic to be discussed due to the environmental impact issues and the significance of shrimp production globally. It is estimated that in 2018 shrimp farms occupied approximately 3.49 million hectares (Mha) globally, with around 2.426 Mha dedicated specifically to production ponds as lower figures in 2015, estimates for shrimp pond areas indicated that around 2.135 million hectares were utilized across 30 countries that reported their shrimp farming activities to the FAO [30]. By 2023, it is estimated that the global shrimp pond area has continued to grow, driven by increasing demand for shrimp products worldwide [30]. The FAO's data suggests that the total area could be between 1.75 million and 2.25 million hectares, incorporating both intensive and extensive farming practices. Extensive production alone accounted for about 983,100 hectares, which represented roughly 46% of the total pond area but produced only about 13.3% of global shrimp output [19][28][30]. Indonesia has a vast potential of aquaculture land which is 17.91 million ha, which includes freshwater aquaculture land at 2.8 million ha, brackish water aquaculture land at 2.96 million ha, and marine aquaculture land at 12.12 million ha, The utilization of fisheries land potential has only reached 6.7% [19][27][28][31][32]. A summary of the potential and current utilization of aquaculture land in Indonesia is shown in Table 1 below.

Table 1. Potential and utilization of aquaculture land in Indonesia

No	Aquaculture type	Potential area (million ha)	Utilized area (million ha)	Utilization
1	Freshwater aquaculture	2.8	0.316	11.29%
2	Brackish water aquaculture	2.96	0.606	20.47%
3	Marine aquaculture	12.12	0.279	2.3%
	Total	**17.91**	**1.201**	**6.7%**

Source: [19][27][28][31][32]

Indonesia has emerged as a prominent global actor in shrimp production, with aquaculture constituting a cornerstone of the nation's economic landscape [31]. Based on data showed in 2023 by [19], Indonesia ranks as the fourth-largest shrimp producer worldwide and contributing approximately 6.6% of total global shrimp exports in 2022 as the Ministry of Maritime Affairs and Fisheries (MMAF RI) has also outlined strategic interventions aimed at enhancing shrimp production, particularly through the revitalization of traditional ponds into semi-intensive systems [24][27][28][31][32]. Indonesia’s government through MMAF RI in 2023 issuing an initiative called Blue Economy Roadmap, which envisions substantial growth in aquaculture by 2045 [31][32], as in 2022, Indonesia's total shrimp production reached around 700,000 tons, with projections indicating further increases as the government implements new technologies and farming methods to boost productivity [19][27][28][31][32].

Recent reports indicate that shrimp exports account for 34.5% of Indonesia's total fisheries exports, with major export destinations including the United States and Japan [19][27][28][31][32]. For instance, from 2010 to 2020, shrimp production grew at an average annual rate of approximately 8%. For the period January - June 2024, shrimp is still the main commodity for Indonesian fishery product exports with an export value of USD 755.79 million. This value contributed 27.8% of total fishery exports [31][32]. However, when compared to the same period in 2023, there was a 13.6% decrease in shrimp commodity exports with records shows that the main market for shrimp exports is the United States with a value of USD 477.29

million, followed by Japan (USD 137.94 million), China (USD 42.30 million), the European Union (USD 21.82 million) and ASEAN (USD 20.07 million) [19][27][28][31][32]. The composition of Indonesia's shrimp export market is presented in Figure 2.

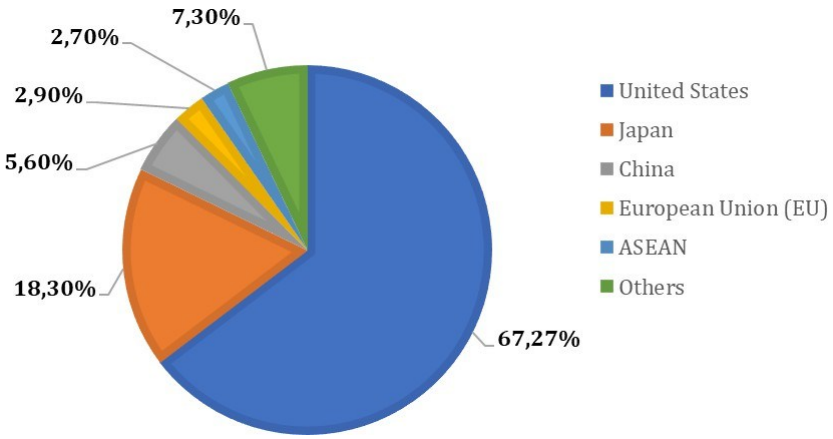


Figure 2. Composition of Indonesia's shrimp export market

The FAO has noted that aquaculture now contributes significantly to national food security and employment, providing livelihoods for millions of Indonesians involved in farming, processing, and distribution [19][27][28][31][32]. In terms of volume, East Java is the leading province, contributing 20,876,382 kg, followed by South Sulawesi with 17,798,195 kg, then Bali and Central Java [31][32]. From the data showed in export value, East Java was again the province with the largest contribution, as recording USD 1,869,123,374, followed by Central Java at USD 1,157,927,671, and South Sulawesi at USD 457,529,994. Other provinces such as Bali and North Sumatra also contributed significantly to the national export value [31][32].

3.2 Challenges faced by the shrimp aquaculture in Indonesia

The shrimp aquaculture industry in Indonesia has emerged as a crucial component of the nation's economy, representing both an opportunity for growth and a series of complex challenges that require careful consideration and strategic management. Over the years, rapid expansion has led to detrimental practices, such as mangrove deforestation and water pollution, which threaten biodiversity and local ecosystems essential to sustaining marine life. Additionally, the industry is plagued by outbreaks of diseases that compromise shrimp health and yield, which are further exacerbated by inadequate biosecurity measures that fail to prevent the introduction and spread of pathogens. As this essay will explore in greater detail, addressing these multifaceted challenges is essential for ensuring the sustainability and long-term viability of shrimp aquaculture in Indonesia. It is imperative that stakeholders, ranging from government agencies to local farmers, collaborate to implement sustainable practices that conserve the environment while supporting the economic growth of this vital industry.

3.2.1 Disease

The shrimp aquaculture industry in Indonesia, while holding significant economic promise, faces critical challenges, notably in disease management. Viral, bacterial, and parasitic infections pose critical threats leading to disease outbreaks, and cause a substantial financial losses for farmers. The notable diseases is the AHPND, which has devastated shrimp populations across Southeast Asia. Additionally, WSSV remains a persistent challenge, severely impacting the survival rates of shrimp stocks. The rapid intensification of shrimp farming practices, often characterized by overcrowded ponds and inadequate biosecurity measures, has created an environment conducive to the spread of pathogenic organisms. This situation is exacerbated by a lack of awareness and

education among farmers regarding disease prevention and control strategies. A significant challenge confronting shrimp aquaculture in Indonesia is the prevalence of various types of diseases that affect shrimp health and productivity.

The optimal water parameters for shrimp culture have been established at 28-33°C temperatures, pH 7.5-8.5, 30-33 ppt salinity levels, dissolved oxygen greater than 4 mg/L, alkalinity of 100-150 mg/L, and total organic matter (TOM) less than 90 mg/L [33]. A research by [34], It was identified that ponds affected by White Feces Disease (WFD) exhibited suboptimal salinity (5–25 ppt) and temperatures exceeding 20 °C. These conditions facilitated a 6.68% increase in Vibrio populations. Diagnosis of shrimp disease is greatly reliant on water testing since environmental factors such as pH, water temperature, and salinity directly influence host-pathogen interaction, Vibrio bacteria have been incriminated as causative agents of significant diseases in shrimp, such as AHPND and Vibriosis. However, ensuring effective disease prevention requires not only environmental management but also systematic disease surveillance and rapid response mechanisms, underscoring the necessity of comprehensive Disease Reporting and Monitoring Systems (DRMS). Effective disease reporting and monitoring systems (DRMS) are essential for early detection and rapid response to mitigate these threats. Research indicates that integrating gender considerations into these systems can enhance community engagement, as women often play critical roles in shrimp farming and health management within households and communities [35].

3.2.2 Land ownership

In Indonesia, land ownership issues significantly impede the growth and sustainability of shrimp aquaculture, a sector that has immense economic potential. The fragmentation of land rights, often characterized by informal and unclear ownership structures, creates barriers for shrimp farmers seeking to expand their operations or secure investments. Furthermore, limited access to land often forces shrimp farmers into smaller, less productive plots, which hinders their ability to meet the rising global demand for shrimp. Addressing these challenges requires a concerted effort to clarify land rights, as noted in the literature surrounding rural aquaculture development.

According to [37], in Sumenep Regency, 101 ponds lack official permits, and only six hold legal licenses under ownership rights (HM/HGU). Licenced ponds are able to contribute Rp55.87 million (12.4%) to Regional Original Income (PAD) and unlicensed ponds can potentially contribute Rp166.08 million (36.9%). The results emphasize the wider issues of land ownership policy and its socio-economic impacts. One of the cases of land ownership issues is because the land stems from hereditary land use without formal documentation, creating conflicts with newer regulations. An example is the establishment of the Kuala Lupak Wildlife Reserve as a protected area, which generates legal uncertainty for pond farmers amid the presence of land certificates [38]. Another problem from unclear land tenure was the conversion of shrimp ponds into industrial zones, which offer clearer legal status. This uncertainty not only affects economic stability but also has broader implications for equitable participation in aquaculture.

The equitable distribution of land rights can significantly influence the capacity of women farmers to engage in aquaculture. Furthermore, the integration of gender-responsive actions within agricultural initiatives, as elucidated in the Sourcebook for Gender in Agriculture, provides invaluable frameworks for practitioners to ensure women's voices are included in decision-making processes related to land and resources [39]. As the Rockefeller Foundation highlights, understanding the interplay between marine resource management and poverty alleviation is essential for effective disease prevention strategies in aquaculture [35].

3.2.3 Labour and gender issues

The shrimp aquaculture sector in Indonesia grapples with significant labor and gender issues that hinder its overall development. Despite the crucial role women play in aquaculture, they remain marginalized and often face discrimination. Such disparities are evident in various aquaculture

practices, where women typically perform labor intensive tasks, with low-paying positions, and lack access to resources, training, and decision-making roles. The need for inclusive policies that recognize the contributions of both genders in aquaculture cannot be overstated. The gender wage gap persists, with female workers earning significantly less than their male counterparts, reinforcing economic disparity in the sector [40].

The welfare of Indonesian shrimp farm workers remains a concern as most of them experience excessive working hours and unpaid overtime to keep the business profitable. A research by [41], found that labor and human rights violations persist in the shrimp supply chain, including a lack of contracts, withheld wages, poor working conditions, intimidation, child labor, and excessive overtime. This exploitation is driven by market-driven practices that continuously benefit global retailers, while shrimp farmers receive insufficient payments to cover production costs, disproportionately favoring processors, exporters, and distributors. Declining profit margins and increasing operational costs have pressured farms to minimize labor costs, often leading to overworked, underpaid employees. In such conditions, when shrimp prices in the market are unstable, farmers become the most vulnerable actors in the industry. One type of business that constitutes a significant portion of the industry is small-scale farms, which often rely on family labor, resulting in inconsistent labor availability and necessary skills to maintain optimal production levels.

In shrimp farming, labor and gender issues play a critical role in shaping the effectiveness of Disease Reporting and Monitoring Systems (DRMS). Research indicates that integrating gender-sensitive approaches into aquaculture can enhance participation among women and improve overall system resilience [42].

3.2.4 Agroinputs and seedlings source

In the context of shrimp farming in Indonesia, the sourcing of agroinputs and seedlings is critical for bolstering farm resilience and mitigating disease outbreaks. High-quality seedlings, sourced from reputable hatcheries, have been shown to possess greater disease resistance and growth potential. Moreover, the selection and application of agroinputs such as feed, fertilizers, and probiotics play a pivotal role in optimizing aquatic ecosystems, thus reducing susceptibility to pathogens. Enhancing the availability and dissemination of reliable information concerning agroinputs and seedlings not only empowers local farmers but also strengthens community capacities to pre-emptively address potential disease threats. Given the fundamental role of agroinputs in shrimp farming, understanding their cost structure and contribution to productivity is essential for improving farm management and sustainability. A research by [43] classify agroinputs as variable costs, with feed and seeds comprising the largest share, collectively contributing 61.39% to total production expenses. High-quality feed optimizes protein intake and improves the Feed Conversion Ratio (FCR), whereas high-quality seeds enhance survival rates and size uniformity at harvest. Shrimp seeding accounts for approximately 70% of cultivation success [44].

Shrimp seed procurement remains challenging. Local hatcheries often struggling to produce high-quality seeds [43]. The routine application of antibiotics in seed production has been linked to increased Vibrio resistance, which risks long-term sustainability [45]. The national demand for white leg shrimp seeds is projected to reach 148 billion to meet the 2024 production target of 2 million tons [44]. On the other hand, suppliers frequently have irregular access to quality seedlings due to supply chain breakdowns, which can slow down production and compromise the health of shrimp. To resolve these challenges, there is a necessity to create quality local hatcheries, provide additional farmer training in seed selection. Access and quality of agroinputs and seedlings are among the most important determinants of Indonesian shrimp aquaculture sustainability.

3.2.5 Ponds productivity

Production systems applied in Indonesia range from extensive to semi-intensive, intensive, and super-intensive, distinguished by land area utilization, stocking density, and technological integration [46]. A research by [47] discovered Aceh Jaya's tiger prawn ponds to be less productive, because of the inefficient input allocation, especially in pond area and stocking with fry. The extensive farming produces smaller outputs than intensive systems, which are increasingly becoming widespread in Indonesia due to greater efficiency. One of the intensive system in PT. Sumbawa Sukses Lestari, West Nusa Tenggara, yielded 8.96 tons in 100 days with stocking density around 250 shrimp/m^2 [48]. Similarly, biofloc round pond systems have demonstrated superior efficiency, with stocking density up to 700 shrimp/m^3, primarily due to probiotic applications that enhance shrimp health [49]. High productivity levels are directly associated with effective management practices that create optimal growing conditions, thereby supporting local economies and enhancing food security by providing a consistent source of protein. However, challenges such as poor water quality, disease outbreaks, and inadequate management practices significantly hinder optimal productivity in shrimp farming. Effective fertilization strategies and the application of proper soil and water quality management in small-scale ponds are essential to mitigate these issues and enhance yield. As highlighted in the Rockefeller Foundations investigation, addressing the declining health of marine ecosystems through integrated approaches can bolster aquaculture productivity and contribute to food security for vulnerable populations [39]. Additionally, the responsible use of antibiotics and improved waste management techniques are vital for enhancing pond productivity while ensuring environmental sustainability [36].

3.3 Measures taken to address these challenges

Central to this strategy is the implementation of Gender-Inclusive Disease Reporting and Monitoring Systems (DRMS) which ensures that both male and female farmers contribute to disease surveillance efforts, thereby enhancing data accuracy and responsiveness to outbreaks. Such systems leverage mobile technology for real-time data collection and feedback, enabling rapid responses to emerging threats [36]. Furthermore, educational programs aimed at improving farmers' understanding of sustainable aquaculture practices are essential, as they empower local communities to engage in proactive health management, gain a clearer understanding of government policies, adopt gender-inclusive practices, and promote the responsible use of antibiotics.

3.3.1 Development of a disease reporting and monitoring systems (DRMS): Highlight the role of effective disease reporting systems in preventing outbreaks and enhancing sustainability in aquaculture

The establishment of robust Disease Reporting and Monitoring Systems (DRMS) is pivotal for mitigating outbreaks and promoting sustainability in aquaculture, particularly within shrimp farming in Indonesia. Effective disease reporting mechanisms not only facilitate timely detection of health threats but also enhance the overall management of aquatic resources. The DRMS (Disease Reporting and Monitoring System) is designed as a collaborative platform for tracking shrimp disease outbreaks, enabling early mitigation efforts and providing farmers with real-time disease occurrence data to improve awareness. The platform will ensure widespread access to disease occurrence information, allowing users to anticipate and respond to transmission risks. Disease reporting systems play a critical role in aquaculture disease management. One of the world's largest shrimp exporter, India, has implemented the Report Fish Disease (RFD) platform as part of its e-governance strategy. The RFD platform is a GPS-enabled mobile application that automatically transmitting data on disease symptoms and pond conditions to a centralized system, this system also enables precise location tracking [50].

The Ministry of Maritime Affairs and Fisheries of the Republic of Indonesia (MMAF RI) has implemented systematic shrimp disease data collection through the *Sicekatan* platform, which contains shrimp disease information & data in Indonesia. The proactive sharing of information fosters collaboration among stakeholders, enhancing collective responses to outbreaks and reinforcing sustainable practice [51].

3.3.2 Government regulation and policy related to land ownership for the shrimp aquauculture
Effective government regulation concerning land ownership plays a critical role in shaping the shrimp aquaculture sector in Indonesia. In Sumbersari Village, Central Java, pond ownership remains concentrated among a small group of village elites, who, in some cases, obscure ownership through family members or workers to circumvent tax and agrarian regulations. At the same time, there have been significant land-use changes where shrimp ponds were turned into plywood production facilities. Elites who had legalized possession received decent compensation [52]. The lack of understanding of the regulatory framework can benefit a certain group of people, and this can result in sentiments of jealousy and societal conflict. For instance, Government Regulation No. 5 of 2021 concerning the Implementation of Risk-Based Business Licensing mandates that shrimp farming businesses exceeding 10 hectares must obtain environmental approval as part of their licensing requirements [53]. By implementing inclusive land ownership policies that prioritize marginalized groups, such as women in aquaculture, the government can enhance community resilience. This approach aligns with findings that highlight the link between equitable resource distribution and food security [54][55].

3.3.3 Government labour and gender inclusive protections
As the primary regulatory body in shrimp farming, the government is responsible for promoting gender inclusivity and labor welfare. Addressing these disparities requires a gender-responsive approach, as women remain underrepresented in key aspects of shrimp farming despite their significant roles in processing and marketing. As the Sourcebook highlights, integrating gender-responsive actions not only addresses disparities but also enhances the overall effectiveness of agricultural practices, including disease management. Data from MMAF RI shows that although women are more dominant in the processing and marketing of aquaculture products, their involvement in shrimp cultivation production is still limited, with only 13.9% of women hold a Maritime and Fisheries Business Card (KUSUKA), compared to 86.1% of men. These barriers demonstrate the need for more gender-responsive policies to increase women's involvement. Collaboration between the Ministry of Women's Empowerment and the MMAF RI has increased gender mainstreaming in fisheries and aquaculture programs, one example is women in Aceh who are involved in rehabilitating mangrove to reduce the impacts of abrasion [7]. Ultimately, robust gender-inclusive protections will empower women, leading to better health outcomes and more resilient farming communities capable of effectively responding to disease outbreaks.

3.3.4 Trusted agroinputs and specific pathogen free seedlings
In the context of shrimp farming, the use of trusted agroinputs and specific pathogen-free (SPF) seedlings plays a pivotal role in enhancing biosecurity and ensuring a sustainable aquaculture ecosystem. Good quality agroinputs, which consist of high-quality feed, probiotics, and other nutrients, enhance the health of shrimp and make them less vulnerable to pathogenic attacks. Furthermore, the procurement of Specific Pathogen Free (SPF) seedlings aids in developing a robust farm foundation capable of withstanding environmental stress and disease pressure. Good Aquaculture Practice (GAP) certification is crucial in ensuring safety and sustainability. Government and industry-led training programs are critical in fostering farmers' expertise and promoting responsible agroinput utilization. Specific Pathogen Free (SPF) seedlings of shrimp, which have been certified through rigorous biosecurity measures, should be procured from

government certified hatcheries or well-known international organizations, such as the World Organization for Animal Health (OIE), to ensure optimum disease avoidance and culture success.

3.3.5 Good aquaculture practices for shrimp aquaculture

Incorporating good aquaculture practices is essential for enhancing the sustainability and productivity of shrimp farming, particularly in Indonesia where disease outbreaks pose a significant threat to production. Effective management of shrimp aquaculture involves implementing rigorous biosecurity measures, optimizing pond conditions, and ensuring proper waste management. Research indicates that sustainable practices, such as rotational stocking and controlled feeding strategies, can significantly reduce stress on shrimp populations, thereby minimizing disease susceptibility [36]. GAP dissemination requires more government promotion, coordination with research institutions, and increased public and private sector investment for enhancing sustainability [56]. Vietnam's VietGAP program, particularly in the Mekong Delta, has led to significant reductions in disease outbreaks, stable production of 5.12 tons per cycle, improved profitability, and reduced antibiotic use through greater probiotic application [57]. Integrating GAP with the Disease Reporting and Monitoring System (DRMS) could further strengthen disease surveillance and provide substantial benefits for Indonesian shrimp farmers.

4. Conclusion

The development of a Gender-Inclusive Disease Reporting and Monitoring System (DRMS) is critical for mitigating disease outbreaks in Indonesia's shrimp farming industry. By actively involving diverse stakeholder groups, especially women who play pivotal roles in aquaculture, the system fosters an inclusive approach that enhances information sharing and community engagement. This participatory method not only addresses the specific health and economic needs of marginalized groups but also promotes sustainable farming practices that can lead to improved resilience against disease outbreaks. In summarizing the key findings from the research on designing disease reporting and monitoring systems (DRMS) in the context of shrimp farming in Indonesia, it becomes evident that gender inclusivity plays a crucial role in enhancing the effectiveness of disease prevention strategies. Furthermore, the findings underscore the necessity for ongoing training and capacity-building initiatives tailored to both male and female farmers to ensure equitable participation. Looking ahead, future research should focus on the long-term impact of these gender-inclusive practices on shrimp health outcomes and the socio-economic stability of farming communities.

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Credit authorship contribution statement

AMAK: Writing – review & editing, Writing – original draft, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **RA**: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **GW**: Writing – review & editing, Methodology. **SW**: Writing – review & editing, Writing – original draft, Formal analysis. **HR**: Project administration, Funding acquisition, Formal analysis, Validation, Supervision. **RPS**: Project administration, Funding acquisition, Formal analysis. **SMS**: Funding acquisition, Formal analysis. **MC**: Funding acquisition, Formal analysis. **HYS**: Formal analysis, Validation, Supervision

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will made available on request.

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