Marine Pollution Risk Management in Marine Resources Governance and Implications for the Blue Economy

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Abstract

This study aims to analyze marine pollution risk management within ocean resource governance and its implications for the blue economy. Using a qualitative literature review approach, this research explores various risk management strategies, including risk identification, assessment, mitigation, and monitoring, and their role in supporting the sustainability of blue economy sectors, such as fisheries, marine tourism, and renewable marine energy. The findings indicate that effective marine pollution risk management reduces negative impacts on marine ecosystems, enhances the quality of marine resources, and supports sustainable economic growth. However, challenges such as limited resources, lack of stakeholder coordination, and weak law enforcement binder optimal risk management implementation. This study recommends strengthening policies, utilizing advanced monitoring technologies, and increasing public awareness to support effective marine pollution risk management within ocean governance contributes to the sustainable growth of the blue economy.

Keywords: Risk Management, Marine Pollution, Ocean Resource Governance, Blue Economy, Sustainability.

Introduction

In efforts to sustainably manage marine resources, one of the significant problems is marine pollution caused by industrial activities and economic activities in the waters. Threats posed by marine pollution can include a decline in the quality of marine ecosystems, disruption to human health, and threats to the sustainability of marine resources. There are various types of pollutants that pollute them, including plastic waste that does not decompose easily, oil spills from ships at sea or oil drilling, various kinds of industrial waste, dangerous chemicals and so on.

Based on data from the Ministry of Environment and Forestry (KLHK) contained in the 2022 Indonesian Environmental Status report, throughout 2020 there was approximately 521,275.06 tons of plastic waste polluting Indonesia's seas (KLHK, 2022). Plastic waste in the sea comes from leaks of land waste into the waters and waste leaks from activities in the ocean. In Indonesia, as an archipelagic country with a vast sea area, the challenge of dealing with marine pollution can become increasingly complex due to the high economic activity in the waters, where the sea is subject to heavy trade traffic but this will also increase the potential for pollution.

In order to support the sustainability of the blue economy, an effective marine resource management system is needed to handle the risk of marine pollution as described above. In this journal the author wants to explain how risk management in the context of marine pollution is an approach to reducing the negative impacts arising from various marine pollutants. Through appropriate identification and mitigation measures, it is hoped that marine resource management can run effectively and maintain the sustainability of the blue economy.

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Brief Literature Review

Several studies have examined risk management in the context of marine pollution and its implications for the blue economy. According to Dwivedi (2022), risk management in marine pollution is critical to the blue economy, as it involves implementing strategies to reduce non-point source pollution and protect ocean health. Based on the study, legislation, environmental programming and continuous monitoring are essential to assess and address the impacts of pollution on marine ecosystems (Dwivedi, 2022). By enhancing marine environmental protection, these measures support sustainable economic growth, improve livelihoods and ensure the resilience of coastal communities, ultimately contributing to the overall health and sustainability of marine resources (Dwivedi, 2022).

Emma et al (2019) examined the importance of integrated risk assessment in managing marine pollution in the blue economy. According to Emma et al (2019) along with the increasing industrialization of the ocean, new risks related to ecosystems have emerged that require an interdisciplinary framework that combines ecological, social and economic factors. Effective risk management must therefore consider the perspectives of diverse stakeholders and the subjective nature of risk, ensuring transparent decision-making (Emma et al, 2019). By addressing the diverse impacts of marine pollution, integrated assessment can help balance ecological sustainability with economic development in the blue economy.

In line with the research of Emma et al (2019) above, Steffen et al (2023) argue in their research that risk management in overcoming marine pollution, and risk management is an important part of a sustainable blue economy. Risk management emphasizes the interdependence of ecological, economic, political, and social factors, indicating that effective strategies must consider these relationships to reduce pollution risks. By implementing sustainable practices, the blue economy can increase resilience and protect marine ecosystems, ultimately contributing to economic growth while addressing pressing environmental challenges related to marine pollution.

Edward (2023), emphasizes the need for effective risk management in marine pollution to support a sustainable blue economy. The research conducted by Edward highlights the low price of marine capital and the funding gap for marine conservation, which exacerbates pollution risks. To reduce this pollution risk problem, Edward (2023) recommends eliminating harmful subsidies, implementing market-based incentives, and increasing private sector participation in marine conservation.

Although previous literature has discussed several aspects of marine pollution risk management and impacts, research that specifically links marine pollution risk management and the blue economy within the framework of marine resource governance is still very limited. Therefore, a more in-depth study that integrates aspects of risk management, marine resource governance, and its impact on the blue economy is expected to enrich understanding and provide significant contributions to marine management practices.

Research Objectives

This study aims to analyze how marine pollution risk management is applied in marine resource governance and its implications for the sustainability of the blue economy. With this approach, the study is expected to provide recommendations to improve the effectiveness of marine resource governance through risk mitigation strategies that support sustainable marine economic growth. In addition, this study aims to identify challenges and opportunities in the implementation of marine pollution risk management that involves various stakeholders in an effort to maintain the balance of the marine ecosystem.

Literature Review

Risk Management Theory in the Context of Maritime and Marine Pollution

In general, risk management can be defined as a systematic approach to identifying, analyzing, and controlling risks. In the maritime context, risk management can be defined differently. According to Reis et

al., (2014) maritime risk management refers to a systematic approach to identifying, assessing, and mitigating risks associated with maritime structures, such as breakwaters and ports, which are vulnerable to wave attacks. Meanwhile, Kambiz and Ren (2014) argue that maritime risk management refers to a systematic approach to identifying, assessing, and mitigating risks associated with maritime activities, including logistics and supply chain operations. Such risk management includes strategies to manage hazards that can cause property damage, environmental damage, or accidents resulting in injury or death (Kambiz and Ren, 2014). The risk management methodology according to Kamiz and Ren (2014) aims to integrate risk management into the decision-making process and business functions in the marine industry, promoting a holistic understanding and proactive risk management throughout the life cycle of marine applications. In writing this journal, the author uses the definition put forward by Gibbs and Browman (2015) which states that maritime risk management refers to the systematic process of identifying, assessing, and mitigating risks associated with marine activities, including fisheries, aquaculture, and coastal development. Risk management involves evaluating the likelihood and consequences of potential hazards, utilizing quantitative risk assessment methodologies, and incorporating stakeholder input to improve decision-making (Gibbs and Browman, 2015). The risk management approach aims to improve the management of marine resources and habitats, ensuring sustainable practices while addressing uncertainty, especially in the context of environmental change and human impacts on marine ecosystems (Gibbs and Browman, 2015).

In the context of marine pollution, according to Florin et al. (2023), marine risk management in pollution involves an integrated approach that characterizes exposure and effects of pollutants. Physico-chemical assessments, monitoring of biological effects, and biotests with ecologically relevant species such as algae, invertebrates, and fish are carried out in such risk management (Florin et al., 2023). By addressing uncertainties related to chemical pollutants and their impacts, environmental managers can make informed decisions. The assessment also considers various stressors and future global change scenarios, highlighting the importance of addressing legacy pollutants and emerging contaminants in marine systems (Florin et al., 2023).

Koboević et al. (2018) stated that risk management in marine pollution involves identifying threats, assessing vulnerabilities, and evaluating risks associated with pollutants, such as black water from ships. The model proposed by Koboević et al. (2018) uses a multiplicative matrix to combine several factors that influence risk, including ship type, regulations, and location sensitivity. The comprehensive approach taken by Koboević et al. (2018) allows for more accurate pollution risk assessments, facilitating informed decision-making to protect coastal seas, human health and economic activities from the adverse effects of marine pollution.

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In a recent study, Sarda et al. (2017) stated that in marine risk management, an ecosystem-based approach is used, where this approach is an effective strategy in marine risk management. In this approach, mitigation actions do not only focus on controlling direct pollution, but also consider the broad impacts of pollution on ecosystems and fish populations. Therefore, based on this approach, the theory of risk management in marine management is often associated with the protection of biodiversity and sustainable marine spatial planning (Sarda et al., 2017).

Marine Resource Governance

Literatures discuss the definition and scope of marine resource governance, where in general marine resource governance includes the process of regulating, monitoring, and supervising activities at sea to ensure sustainable use of marine resources. According to Elliot et al. (2023), marine resource governance

includes policies, politics, administration, and laws that ensure sustainable practices in the marine environment. This governance refers to the framework and processes that guide the management and use of marine resources across jurisdictions where effective governance requires connectivity, coherence, and equity in management approaches, addressing the ecological, social, and economic dimensions of marine activities (Elliot et al., 2023). This governance framework is essential to addressing barriers to sustainable management and ensuring that marine resources are used responsibly and equitably across transboundary areas (Elliot et al., 2023).

According to Haas et al. (2022), marine resource governance refers to the processes and structures through which decisions regarding the management and use of marine resources are made. Marine resource governance encompasses interactions between multiple actors, including states, civil society, local communities, and markets, aimed at ensuring sustainable management of marine ecosystems. Effective governance addresses risks such as overexploitation of resources, inequitable access to marine ecosystem services, and inadequate adaptation to changing ocean conditions, in line with frameworks such as the Sustainable Development Goals (SDGs) (Haas et al., 2022).

Marine resource governance refers to the frameworks and processes that govern the use, protection and conservation of marine resources (Grip, 2017). It encompasses a range of approaches, including ecosystembased management, which integrates ecological, socio-economic and institutional perspectives within a geographical framework (Grip, 2017). Effective marine resource governance aims to achieve sustainability by coordinating efforts across sectors, such as fisheries, conservation and shipping, while addressing competing interests and ensuring compliance with international laws and principles, as highlighted in the context of marine environmental governance (Grip, 2017).

Marine Pollution and Its Impact on the Blue Economy

Marine pollution is a significant threat to the sustainability of the implementation of the blue economy, which is a marine-based economy that focuses on the sustainability and preservation of marine resources. Pollution causes environmental challenges such as ocean acidification and habitat destruction, threatening biodiversity and economic activities that depend on marine resources (Gideon, 2024). Based on his research, Gideon (2024) emphasized the need for effective waste management, public awareness campaigns, and sustainable practices to reduce these impacts and promote the sustainability of the blue economy, ensuring a balance between economic growth and environmental preservation.

Youssef (2023) stated that marine pollution significantly threatens the blue economy by compromising the health and sustainability of marine ecosystems. Marine pollution causes biodiversity loss, which affects fisheries and tourism, two important sectors of the blue economy (Youssef, 2023). Marine pollution also has economic and social consequences, such as reduced livelihoods and cultural heritage (Youssef, 2023). Addressing marine pollution requires international cooperation, effective governance, and investment in sustainable practices and technologies to mitigate its impacts and ensure the long-term viability of marine resources (Youssef, 2023).

Nathan et al (2021) study that marine pollution poses significant risks to the blue economy, affecting fisheries, tourism and coastal livelihoods. Contaminants such as plastics and chemicals disrupt marine ecosystems, leading to biodiversity loss and economic decline. Proposed solutions include stricter regulations on waste management, promoting sustainable practices and raising public awareness. Addressing marine pollution is critical to ensuring the sustainability of marine resources and protecting livelihoods that depend on a healthy marine environment, thereby supporting blue growth and blue equity.

Marine pollution significantly threatens the blue economy, which relies on healthy marine ecosystems for resources and services (Andrea et al., 2021). Pollution can degrade marine habitats, reduce biodiversity, and harm fisheries, leading to economic losses for communities that depend on these resources. Andrea et al., (2021) emphasize the need for sustainable practices to balance resource exploitation with environmental conservation, ensuring that marine resources remain viable for future generations while addressing the challenges posed by pollution.

Marine pollution significantly impacts the Blue Economy by threatening marine ecosystems, which are critical for sustainable economic activities. (Khairunnisa, 2022) Issues such as overfishing and marine debris, which originate from land-based and marine activities, hamper the health of the marine environment. The Blue Economy concept aims to address these challenges by promoting sustainable practices that balance economic growth with ecosystem protection. Countries such as Indonesia can learn from China's successful regulation to boost their ocean-based economy while preserving marine ecosystems.

Method

Research Design

This research on marine pollution risk management in marine resource governance and its implications for the blue economy was conducted using a qualitative approach, where the research design uses a literature study. This literature design is designed to analyze various relevant literature sources on marine pollution risk management in marine resource governance and its implications for the blue economy. The choice of this literature design approach provides researchers with the freedom to explore concepts, theories, and empirical findings that have developed, allowing for a comprehensive understanding of the phenomena being studied (Lisa, 2008)

Systematically, literature study is applied to identify, filter, and review sources related to risk management, marine pollution, marine resource governance, and aspects of the blue economy. In this process, the research does not use primary data, but relies on secondary data including scientific articles, books, reports from international institutions, and related policies. According to Habeeb (2020), with a qualitative approach, this research is directed to interpret and synthesize existing theories and findings, so as to be able to dive into the research questions in depth.

Data Collection

Data collection was carried out using systematic literature search techniques through various scientific and reliable sources. The steps in systematic literature search for data collection include Habeeb (2020):

Data collection tools are carried out through systematic literature searches from various scientific and reliable sources. The data collection stage begins with the determination of inclusion and exclusion criteria to ensure the relevance of the literature to the research topic. Inclusion criteria include publications related to marine pollution risk management, marine resource governance, and the blue economy, with priority given to reputable scientific journals, international agency reports, and relevant policies. Literature that does not meet the relevance criteria or is less reliable will be excluded. Literature searches are conducted through scientific databases such as Google Scholar, Scopus, Web of Science, and ProQuest, using keywords that include "marine pollution risk management," "ocean governance," "blue economy," "marine spatial planning," and "sustainable marine resource management."

After the initial search, literature selection was carried out through abstract screening to ensure suitability to the research topic, where the literature that passed was further analyzed through thorough reading. The data extraction process was then applied to the selected literature, with information grouped according to the main research themes, such as the concept of risk management, marine governance approaches, the impact of marine pollution on the blue economy, and the role of stakeholders. The extracted data included the research methods used in each study, key findings, and recommendations or implications for sustainable marine resource governance.

Data Analysis

Data analysis in this study used the thematic qualitative analysis method, which includes several stages (Habeeb, 2020). First, the collected literature was categorized into main themes such as marine pollution risk management, marine resource governance, and blue economy, in order to organize and understand the relationships between the concepts and theories discussed. Once these themes were established, each literature was analyzed in depth through a thematic approach to identify patterns, trends, and information gaps related to marine pollution risks and mitigation strategies in marine governance.

Next, the researcher developed a narrative synthesis to combine findings from various sources, creating a comprehensive understanding of the topic by building a clear conceptual framework. Critical evaluation was applied to the literature to assess the quality of the methods, strengths and weaknesses of the studies analyzed, and to interpret various risk management approaches in the context of marine resource management and their implications for the blue economy. This approach not only describes existing theories but also assesses the effectiveness of the approaches applied in sustainable marine governance, offering deeper insights into the challenges in their implementation.

Result and Discussion

Results

The results of the literature review indicate that risk identification is a crucial initial step in marine pollution risk management. Marine pollution risks come from various sources, including industrial activities, offshore mining, maritime transportation, agriculture, and domestic waste. According to Thanigaivel et al (2024), the main sources of marine pollution include emerging pollutants such as natural and manufactured chemicals, insecticides, pesticides, surfactants, personal care products, cosmetics, pharmaceuticals, and industrial discharges.

According to He (2024), the main sources of marine pollution include agricultural pesticide runoff, industrial oil spills, tourism waste, and domestic wastewater. To reduce the problem of these main sources of marine pollution, governments can implement policies to reduce plastic use, promote sustainable tourism practices, and regulate industrial discharges. In addition, increasing environmental awareness among young people and involving them in conservation activities can foster a culture of marine protection. Scientific research can also lead to innovative solutions, such as microbial degradation of plastics and optimizing waste disposal systems.

Plastic waste and oil spills are two of the most significant forms of marine pollution (Ouyang, 2023). Plastic pollution causes marine animals, such as turtles and marine mammals, to ingest plastic or become entangled, causing damage or death. Oil spills are harmful to birds, marine animals, and plants, polluting their habitats and affecting their health. Both forms of pollution have a significant impact on marine ecosystems, leading to a decline in biodiversity and threatening the survival of many marine species.

In the context of marine resource governance, risk identification involves mapping areas vulnerable to pollution and identifying major pollution sources. According to Pan and Yu (2023), modern monitoring technologies, such as satellite imagery and ocean sensors, are essential for detecting and measuring pollution levels in the marine environment. These technologies provide a unique vantage point to observe large ocean areas with high precision and efficiency. They help identify pollution sources, assess impacts on marine ecosystems, and monitor the effectiveness of mitigation measures. By integrating biological methods with remote sensing, researchers can improve pollution detection and develop informed policies to prevent further marine pollution. Katerina et al (2024) emphasized the importance of utilizing modern monitoring technologies, such as satellite imagery, for automatic detection and tracking of marine pollutants. These technologies enable comprehensive data collection across a wide range of ocean surface features and pollutant types, overcoming the limitations of traditional methods.

Once the risks have been identified, the next step is risk assessment and analysis to determine the probability of pollution occurring and its potential impacts. According to Ezinne et al (2023), risk analysis should

include an evaluation of economic, social and environmental impacts. Such environmental risk assessment involves assessing the likelihood of business activities causing environmental damage, including human health and ecological impacts. For example, pollution affecting marine tourism areas not only damages the ecosystem but also results in economic losses for local communities that depend on the sector. Therefore, a comprehensive risk assessment is an important basis for planning marine resource governance. This comprehensive approach ensures that potential hazards and impacts are explained before implementing countermeasures to reduce associated risks, thus forming an important part of the overall risk management plan (Ezinne et al., 2023).

Effective marine pollution risk mitigation strategies are an integral part of marine resource governance. Effective marine pollution risk mitigation strategies are essential for marine resource governance, as highlighted in the marine pollution technology review. A study by Anthony et al (2023) emphasized the need for interdisciplinary engagement and strengthening of scientific disciplines to prevent future marine disasters. Mitigation strategies include physical, chemical, and biological methods, while emerging technologies such as artificial intelligence and machine learning can enhance their effectiveness. Addressing marine pollution comprehensively is essential for sustainable management and protection of marine resources.

Research conducted by Li and Jiang (2023) emphasized the need for cooperation between the central government, local governments, and marine user companies to address marine ecological environmental pollution. By implementing strict governance policies, such as performance assessment and ecological damage compensation, stakeholders can overcome the prisoner's dilemma and improve compliance. This collaborative approach ultimately supports sustainable development and improves governance efficiency in protecting marine resources.

Strict regulations, such as restrictions on industrial waste discharge and bans on the use of hazardous chemicals, have been implemented in various countries to reduce sources of pollution (Stefania et al., 2023). In addition, the adoption of environmentally friendly technologies in the maritime and fisheries industries also contributes to reduce missions (Stefania et al., 2023). Effective monitoring and law enforcement are also important in risk mitigation. The use of satellite-based monitoring systems and marine drones allows early detection of oil spills or illegal activities that have the potential to pollute the sea (Stefania et al., 2023). Strict law enforcement against violators of regulations is a deterrent for parties who have the potential to pollute (Stefania et al., 2023).

Continuous monitoring and periodic evaluation are needed to ensure the effectiveness of the mitigation strategies that have been implemented. According to Kennish (2022), the monitoring system must involve various stakeholders, including government, industry, academics, and local communities. Community participation in monitoring can increase awareness and concern for marine pollution issues. Periodic evaluations allow for adjustments to strategies if necessary. For example, if pollution levels do not show a significant decrease, then a revision of the policy or increased law enforcement efforts are needed (Kennish, 2022).

Discussions

Risk Management and Blue Economy

The results of the literature review indicate that marine pollution risk management is an important component in sustainable marine resource governance. The implementation of effective risk management not only protects marine ecosystems but also supports the growth of the blue economy.

However, challenges in implementation, such as limited resources, lack of coordination, and weak law enforcement, need to be addressed through comprehensive policies and collaboration between stakeholders. Active community participation and the use of advanced technology are also key factors in increasing the effectiveness of risk management. This study confirms that in order to achieve a sustainable blue economy, marine pollution control efforts must be a priority in marine resource governance. The policy implications resulting from this study can be a reference for the government and other stakeholders in formulating concrete strategies and actions.

Effective management of marine pollution risks has direct implications for the sustainability of the fisheries sector, which is an essential component of the blue economy. By reducing pollution levels, fish habitats and marine biodiversity can be maintained, thereby ensuring the long-term availability of fish resources (Elliot et al 2022). Cohen et al (2021) also emphasize that good marine environmental quality increases fisheries productivity and fishermen's welfare.

With the implementation of effective marine pollution risk management, marine resource governance can support the growth of a sustainable blue economy. The expected benefits include the sustainability of natural resources by maintaining quality and quantity for long-term use, increasing economic competitiveness through sustainable blue economy sectors in the global market, environmental protection that reduces negative impacts on marine ecosystems and biodiversity, and improved social welfare with the quality of life of coastal communities through a clean and healthy environment (Evans et al, 2023).

Marine tourism is highly dependent on the quality of marine ecosystems, such as clean beaches and healthy coral reefs. Marine pollution can reduce the attractiveness of tourist destinations and reduce tourism revenues (Aishwarya and David, 2023). With effective pollution risk management, marine tourism destinations can maintain or even increase tourist visits, which has a positive impact on the blue economy (Aishwarya and David, 2023).

The marine renewable energy sector, such as offshore wind and wave energy, is also affected by marine environmental conditions. Pollution can damage energy equipment and infrastructure, and incur high maintenance costs (Campbell et al., 2021).

Proper management of marine pollution risks supports the development of this sector, which contributes to the diversification of the blue economy and the provision of clean energy. Marine pollution not only impacts the economy but also the health of coastal communities. Exposure to marine pollutants can cause disease and reduce quality of life (Landrigan et al., 2020). By controlling marine pollution, public health improves, which in turn increases productivity and participation in marine economic activities (Landrigan et al., 2020).

Challenges in Implementing Marine Pollution Risk Management

One of the main challenges is the lack of coordination and collaboration among stakeholders in marine resource governance. According to Osemeike et al (2024), differing interests between government, industry, and communities often hinder the implementation of effective risk management strategies. Better communication and coordination mechanisms are needed to align goals and actions. Developing countries often face limitations in terms of financial and technological resources to carry out effective monitoring and enforcement (Evans et al, 2023). Investment in advanced monitoring technology and human resource training are obstacles that must be overcome to improve marine pollution risk management.

Weak law enforcement and ineffective sanctions against violators of marine pollution regulations reduce the deterrent effect and encourage the continuation of polluting practices (Evans et al, 2023). Strengthening the legal system and increasing transparency in the law enforcement process are needed to ensure compliance with regulations. Public and industry awareness of the impacts of marine pollution is still low in some areas. According to Uniyal (2024), environmental education programs and awareness campaigns need to be improved to encourage active participation in pollution control efforts.

The use of information and communication technology is also an important component in marine pollution risk management strategies. Technologies such as real-time monitoring systems and big data analytics enable early detection and faster response to pollution incidents (Podda and Erika, 2023). Although the initial investment for this technology is quite high, the long-term benefits are significant in

terms of marine resource management and increasing the efficiency of pollution handling processes. Marine Spatial Planning (MSP) is an important instrument used to plan and regulate activities at sea, reduce conflicts between users, and minimize negative impacts on the ecosystem. Thus, an integrated governance approach creates a balance between marine resource utilization and environmental protection (Podda and Erika, 2023).

Empowering local communities is another equally important strategy. By involving communities in monitoring and reporting pollution incidents, mitigation efforts become more effective and sustainable. Active community participation can accelerate the response and handling of pollution incidents (Uniyal, 2024). In addition, education and training programs for coastal communities are needed to increase their awareness and skills, so that they can play an active role in maintaining the cleanliness and health of the surrounding marine environment.

Conclusion

This study highlights the importance of marine pollution risk management in marine resource governance to support the sustainability of the blue economy. Based on the literature review, effective risk management in marine pollution control involves identification, assessment, mitigation, and continuous monitoring of pollution sources. The results of the analysis show that marine pollution has a direct impact on economic sectors that depend on the health of marine ecosystems, such as fisheries, marine tourism, and renewable energy. By managing pollution risks effectively, marine resource governance can support the sustainability and growth of marine-based economies. The implementation of appropriate risk management provides protection for marine ecosystems and creates conditions that support sustainable investment in the blue economy sector. However, there are several major challenges that must be overcome, such as limited resources, lack of coordination between stakeholders, and suboptimal law enforcement. Therefore, adaptive and collaborative governance, involving various parties including government, industry, and communities, is very important to achieve success in marine pollution control.

Suggestions

This study suggests several steps that can be taken to strengthen marine pollution risk management. First, strengthening policies and regulations is essential, where the government needs to set stricter standards in waste and marine pollution management and increase sanctions for violators. Strong regulations will encourage environmentally friendly practices in the maritime sector. In addition, the development of monitoring technology also needs to be encouraged, with investments in marine sensors, satellite imagery, and big data analysis to improve pollution detection and response. These technologies support more timely and accurate decision-making.

In addition to policies and technology, public education and awareness must be improved through education programs and campaigns that encourage active community participation in maintaining marine cleanliness and reporting pollution. Further research is also needed to explore the effectiveness of risk management approaches in various regions and to assess the socio-economic impacts of marine pollution on coastal communities. These recommendations are expected to contribute to improving marine resource governance that supports the sustainability of the blue economy, as well as minimizing the risk of marine pollution that threatens the ecosystem and the welfare of coastal communities.

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