Jurnal Ilmiah Ilmu Administrasi
Volume 16 Nomor 1 Tahun 2026 : 14 – 30
http://ejournal.unis.ac.id/index.php/JIIA
DOI: 10.33592/jiia.v16i1.8517

p-ISSN 2477-5088
e-ISSN 2716-2621

Marine Waste Management Based on Smart Environment in ASEAN: A Comparative Analysis of the Philippines, Indonesia, and Malaysia

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(Accepted: 03-February-2026; Reviewed: 09-February 2026; Approved: 14-July-2026)

ABSTRACT

The issue of marine debris in the ASEAN region is becoming increasingly urgent due to population growth, urbanization, and high plastic consumption. This research compares the implementation of marine waste management policies in ASEAN, particularly in three countries: Indonesia, Malaysia, and the Philippines, using a Smart Environment approach. This research uses the systematic literature review method, examining national regulations. The research results show that although the three countries have supportive marine waste management policies, the implementation of these policies has not yet been fully effective. The main challenges include the lack of adequate infrastructure, low public awareness, and limited inter-sectoral cooperation. The application of technologies such as IoT and microplastic sensors can enhance the efficiency of marine waste management, but further collaboration between the government, the private sector, and the community is needed to achieve more integrated and sustainable results.

Keywords: *smart city; ASEAN marine waste management; smart environmen*

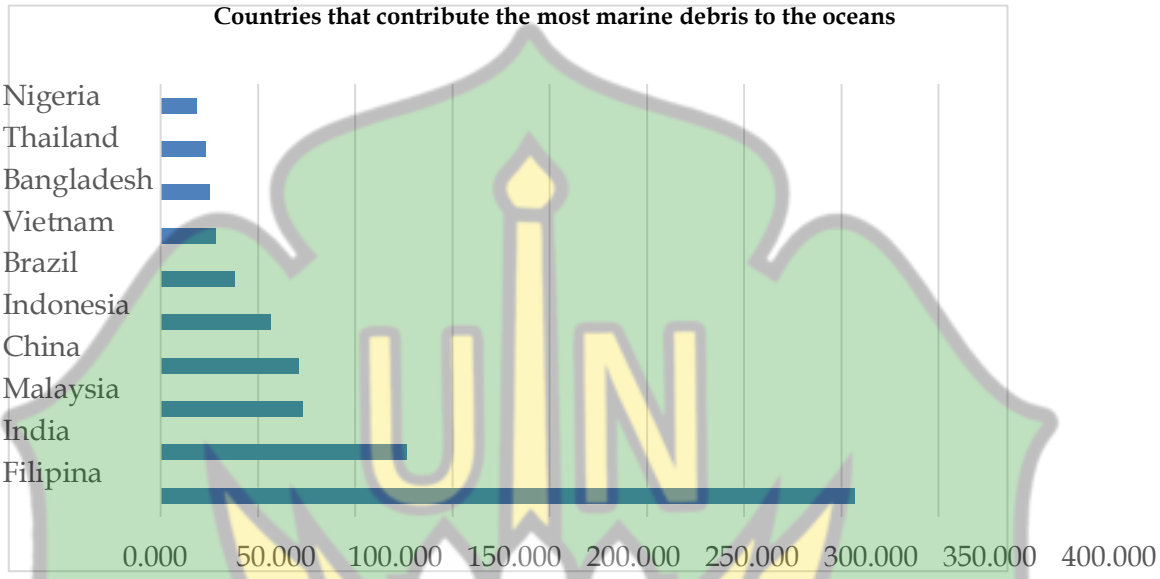
A. INTRODUCTION

Waste has become a global issue that urgently needs to be addressed thru comprehensive and integrated efforts from upstream to downstream. Proper handling not only has the potential to provide economic benefits but also to improve public health, maintain environmental security, and encourage changes in human behavior toward a more sustainable life (Farras & Pramudya, 2025). The main factors contributing to the increase in waste volume and the complexity of its management are economic growth, high urbanization rates, and population growth (Lasaiba & Lasaiba, 2024). The presence of Smart Environment becomes a solution to the increasingly complex waste management issues amid rapid population growth and urbanization. The increase in waste, especially plastic, which often ends up in the ocean, poses a serious threat to marine ecosystems and environmental quality. By integrating smart technology and sustainable approaches, Smart Environment can provide more effective and coordinated solutions,

enhancing efficiency in reducing waste and minimizing negative impacts on the marine environment.

Then, according to the World Population Review, it is estimated that around 4.8 to 12.7 million tons of plastic enter the oceans each year. One of the types of waste that has garnered global attention is marine debris (Maharani, 2023). This shows that there are still countries that fail in managing this waste, some of which include the Philippines, Indonesia, and Malaysia.

Table 1
Countries Contributing the Most Marine Debris



Source: World Population Review Marine Debris Emergency

Table 1. This is the result of a report from the World Population Review, which states that the largest contributors to plastic waste are the Philippines with 356,371 tons, followed by Malaysia with 73,098 tons, and Indonesia in fifth place with 56,333 tons.

Based on the data, the researchers decided to focus on three countries: Indonesia, the Philippines, and Malaysia. The selection of these three countries was not only because they are all ASEAN members but also because the Philippines, Indonesia, and Malaysia are the largest contributors of marine debris. These three countries are developing nations facing similar challenges in waste management and environmental protection, particularly concerning plastic waste that pollutes marine waters. The choice of the Philippines, Indonesia, and Malaysia as the focus of the research is based on the similarities in characteristics shared by these three countries, whether in terms of geography, demography, or their developing socio-economic status. This provides a strong basis for examining how these three countries can implement waste management solutions based on smart and sustainable technology. Here is a table that illustrates the similarities in characteristics of the three countries:

Table 2
Characteristics of the Three Countries

Country	Population (2024)	Number of Islands	Percentage of Coastal Population	System of Government	Form of State	State System	Other Similar Characteristics
Philippines	119.1 million	7,641	81%	Presidential	Unitary State (Republic)	Developing Country	Archipelagic State, Climate, Geographical Location, ASEAN Member
Indonesia	284.97 million	17,024	59%	Presidential	Unitary State (Republic)	Developing Country	Archipelagic State, Climate, Geographical Location, ASEAN Member
Malaysia	34.2 million	879	70%	Constitutional Monarchy	Federal State	Developing Country	Federal State, Climate, Geographical Location, ASEAN Member

Source: Based on data obtained from DetikEdu (Kristina, 2021)

Form The implementation of Smart Environment in the three countries that are the focus of the research shows significant benefits due to the similarities in the countries' characteristics relevant to environmental management challenges. Because the three countries are developing nations with geographical characteristics as archipelagic countries and a large percentage of the population living in coastal areas, this condition causes the impact of marine pollution and plastic waste to become equally important issues to be addressed effectively.

The similarity in status as developing countries helps clarify how limitations in infrastructure capacity, funding constraints, and the need for community involvement also affect the outcomes of the Smart Environment program. By comparing best practices and challenges in each country, the research can identify more effective and contextual strategies, as well as provide applicable policy recommendations for other countries with similar characteristics in the ASEAN region (Widyasari et al., 2024). The issues in these three countries are not limited to marine debris but also encompass maritime security aspects. For that reason, the Philippines, Indonesia, and Malaysia are forging cooperation. After conducting a series of intensive trilateral discussions since 2016, the three of them agreed in 2017 to establish a more concrete form of cooperation thru the Trilateral Cooperative Agreement (TCA). This agreement emphasizes joint patrol activities, both on land and at sea. Thus, the three countries are required to take collective security measures thru coordinated cooperation (Wiswayana, 2023).

The issue of marine debris in these three countries is not only addressed thru educational efforts but also by taking firm steps in the form of binding policy issuance. The Philippine government has enacted Republic Act No. 9003 on Waste Management since 2000, which mandates every village to establish recycling centers, sort waste, develop composting systems,

and regulate the collection of various types of waste, while the practice of open burning and uncontrolled waste disposal is legally prohibited (Tahar & Cordova, 2022).

Then the Indonesian government is committed to reducing marine debris by 70%. national by 2025. Presidential Regulation Number 83 of 2018 on Marine Debris Management in the 2018–2025 National Action Plan supports this goal. Large cities also have policies on the use of single-use plastics, but the success of the program still needs to be monitored and civilians must contribute to the common goal (Citaristi, 2022).

Furthermore, waste management in Malaysia is regulated by law. Solid Waste Management and Public Cleansing Act 2007 (Act 672), which applies in all peninsular regions except Perak, Selangor, and Penang. This act requires waste management service operators to obtain permission from the Director General of the National Solid Waste Management Department and prior written approval before the construction, modification, or closure of waste management facilities. In this law, solid waste is divided into several categories, including household, commercial, industrial, and construction waste (Wardani, 2024).

This research will fill the gap left by previous studies such as in The first study conducted by (Trenggono et al., 2025) emphasizes the importance of national policies and local government participation. The second study by (Capriati et al., 2025) shows a gap between policy and field practice due to limitations in infrastructure and coordination among actors. The third study by (Voronkova et al., 2025) identifies the potential use of information technology, environmental monitoring, and data-based systems in waste management. The fourth study by (Annisa et al., 2025) shows that the success of waste management is greatly influenced by the synergy between the government, the private sector, and the community. The fifth study by (Suhardono et al., 2024) examines the issue of marine debris in the context of ASEAN regional cooperation and sustainable development. Previous research emphasized the importance of harmonizing inter-country policies and regional commitments, but did not deeply examine how the concept of a smart environment can become a strategic instrument in strengthening transnational marine waste management.

Therefore, the novelty of this research lies in a more in-depth exploration. toward a smart environment as an integrative analytical framework in examining marine waste management in the ASEAN region thru a comparative study of Malaysia, Indonesia, and the Philippines. The research is very interesting because it examines marine waste management, not only highlighting the technical aspects of marine waste management but also studying marine waste management with a Smart Environment approach, which includes data-based and digital technology management, and simultaneously linking it with the dimensions of policy, governance, and technological readiness in realizing a sustainable coastal environment.

At the ASEAN level, the ASEAN Smart Cities Network (ASCN) was launched in 2018 to accelerate smart city collaboration among member countries, including Indonesia, Malaysia, and the Philippines, with the aim of promoting digital transformation and sustainable development. The developments in each country are also different: in Indonesia, programs such as the Movement Toward 1000 Smart Cities introduced this concept since 2017–2018 in various pilot cities like Jakarta and Makassar as part of the ASEAN Smart Cities strategy (Diana et al., 2024). Meanwhile, in the Philippines, the Philippine Smart City Development Project was launched by DICT in 2016 and evolved into the Digital Cities 2025 program, targeting the digital transformation of cities in the 2020s according to the national plan (Antos et al., 2024). In Malaysia, smart cities have become part of sustainable urban planning that began in the 2000s

and continues to develop thru the National Smart City Framework, which integrates ICT and sustainability initiatives in major cities like Kuala Lumpur and Cyberjaya (Leong et al., 2023).

The analysis in this research will adopt indicators from the Smart Environment, namely: the first indicator, waste and garbage management, identified as a crucial element for urban sustainability, where technology is used to monitor, optimize, and minimize waste generated by the urban population, thereby significantly reducing environmental impact (Kumar, 2024). Second, energy management and pollution become a focus in smart cities thru the development of smart grids, integration of renewable energy sources, and energy-efficient consumption control systems, which not only reduce emissions but also enhance energy use efficiency (Ali et al., 2023). Third, sustainable environmental governance includes the management of water, air, and green space resources thru policies, technology-based infrastructure, and the measurement of environmental indicators that support the SDGs. The aspect of environmental sustainability must be a core part of the smart city strategy, encompassing air and water quality as well as resource conservation. Thus, the aim of this research is to thoroughly examine the differences in the level of implementation, challenges, and development opportunities of Smart Environment in marine waste management in ASEAN countries.

B. METHOD

This research uses qualitative analysis methods with a Systematic Literature Review (SLR) approach. The study was conducted by reviewing research related to marine waste management in Indonesia, Malaysia, and the Philippines, using scientific publications. The data used are secondary data sourced from leading academic databases and scientific articles, as well as supporting data from various news sources.

Literature collection was conducted thru the Google Scholar and Semantic Scholar databases. ScienceDirect and Sage Publications, with the help of the Publish or Perish tool to ensure data quality and integrity. The main keywords used include "Marine Waste Management," "Smart Environment," "ASEAN Countries," "Malaysia," "Philippines," and "Indonesia." Data analysis was conducted using Mendeley, Convidence, VosViewer, and Microsoft Excel.

Table 3
Criteria for article eligibility used'

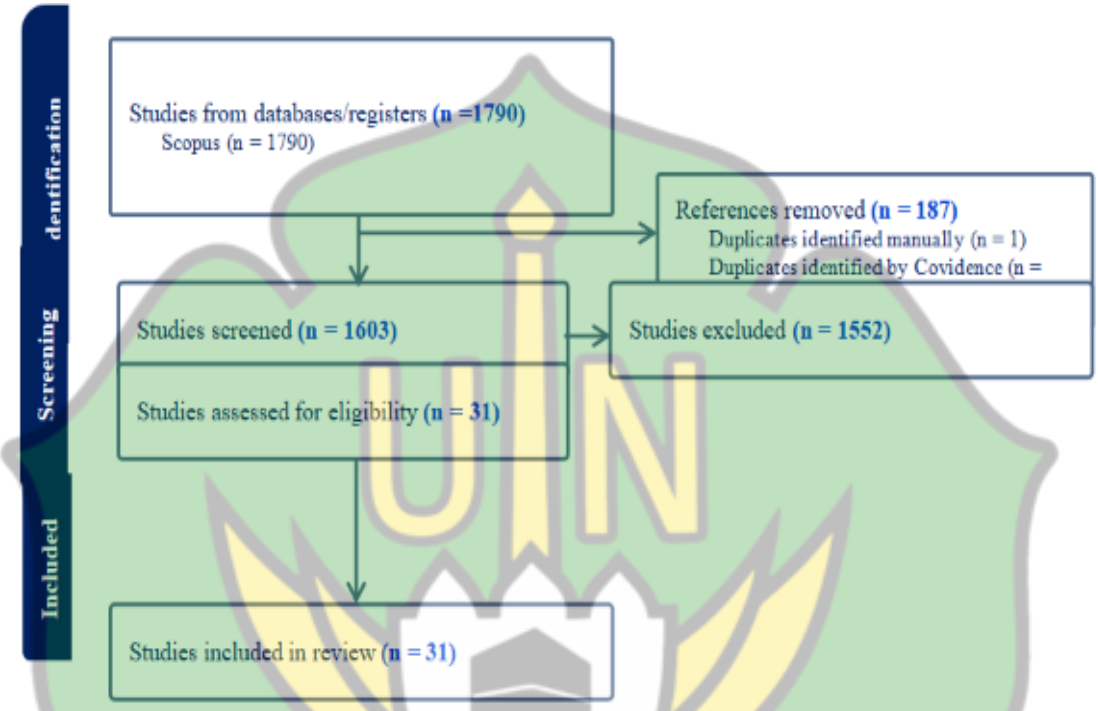
Country	Population (2024)	Number of Islands	Percentage of Coastal Population	System of Government	Form of State	State Status	Other Similar Characteristics
Philippines	119.1 million	7,641	81%	Presidential	Unitary State (Republic)	Developing Country	Archipelagic State, Climate, Geographical Location, ASEAN Member
Indonesia	284.97 million	17,024	59%	Presidential	Unitary State (Republic)	Developing Country	Archipelagic State, Climate, Geographical Location, ASEAN Member
Malaysia	34.2 million	879	70%	Constitutional Monarchy	Federal State	Developing Country	Federal State, Climate, Geographical

	Location, ASEAN Member

Source: Processed by the Author.

Articles that meet the eligibility criteria above will then undergo further processing using the convidence software, which produces a PRISMA diagram.

Table 4
Desain PRISMA



Source: Processed by the Author using Covidence Software.

Based on the results of the PRISMA method that has been conducted, it can be concluded that out of a total of 1790 identified journal articles, 196 were excluded due to data duplication. Subsequently, 1594 journals were further identified, resulting in 1552 journals not meeting the inclusion and exclusion criteria, leaving only 22 journals to be used in the literature review that correspond to the answers to the questions in this paper.

C. RESULTS AND DISCUSSION

1. Publication Trend

This research is based on the observation of data consisting of 1,790 scientific articles related to marine waste management in ASEAN countries. The visualization of these 1,790 articles can be seen in the Vos Viewer Visualization image displayed below.

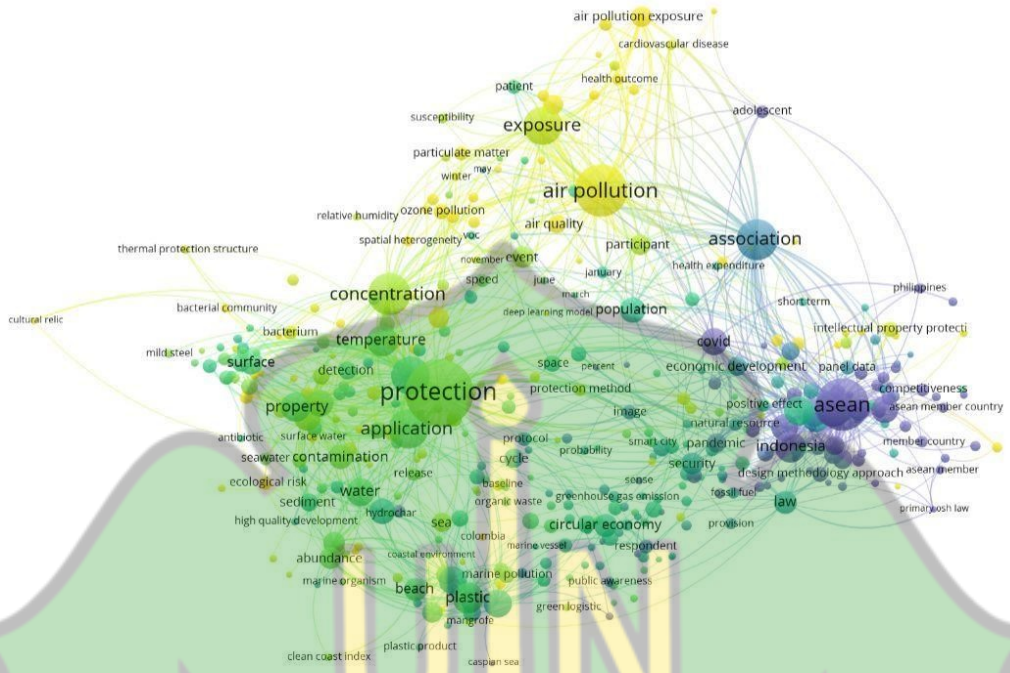


Figure 1 Data Visualization Results
Source: Processed by Researchers using VosViewer

Figure 1. The map of keyword relationships in scientific publications on environmental issues in ASEAN is shown in a bibliometric visualization using VOSviewer. This map identifies several main clusters, including air pollution, environmental protection, and policy, with key terms such as "air pollution," "protection," and "ASEAN." The air pollution cluster emphasizes the effects of pollution on health, while the protection cluster focuses on waste management and sustainability. Law and economic development are related to environmental issues within the policy cluster. The visualization overlay shows that these topics, especially those related to water pollution and the circular economy, are emerging rapidly between 2023 and 2025. This shows that academics are increasingly paying attention to environmental issues in this field.

From the visualization above, it can be seen that the topic of marine waste management in ASEAN countries is a frequently researched subject, with many studies related to smart cities conducted from 2023 to 2025. Out of the 1790 identified scientific articles, after applying the inclusion and exclusion criteria, only 22 articles were used in this literature review, as shown in the image below.

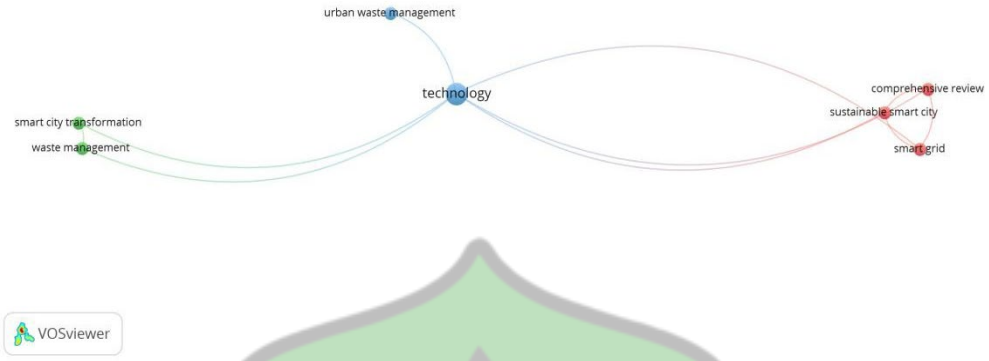


Figure 2 Data Eligibility Visualization Results
Source: Processed by Researchers using VosViewer

Figure 2. VOSviewer data visualization shows that technology is a central keyword linking research themes such as environmental management, smart city transformation, and sustainable energy systems. The green cluster links waste management with smart city development, highlighting the importance of the strategic aspects of waste management. The blue cluster emphasizes the role of technological innovation in enhancing waste management efficiency thru digital systems and automation. The red cluster connects sustainable smart cities with intelligent energy management. Overall, the research is moving toward an integrated approach with technology as the foundation in the development of waste management, energy management, and environmental governance.

Here is the analysis of marine waste management in the three countries. based on relevant indicators, as well as the challenges faced in the implementation of smart environment-based waste management policies.

Table 5
Distribution of Reviewed Articles by Country, Research Focus, Method, and Number of Articles

No	Country	Article Focus	Method	Number of Articles
1	Philippines	Plastic Waste Management; Marine Debris Monitoring; Plastic Waste in Ports; Technology for Plastic Waste Reduction	Policy analysis; implementation of technologies such as IoT and microplastic sensors	4
2	Indonesia	Plastic Pollution from Fishing Ports; Multilayer Plastic Waste and Recycling; Marine Mammal Protection and Pollution; Microplastic Management in Rivers; Use of Renewable Energy for Waste Management; Circular Economy for Plastic Waste Reduction; Geothermal Energy Potential for Marine Waste Management Technology	Policy initiatives; use of IoT-based technology; renewable energy; circular economy	7
3	Malaysia	Microplastics and Marine Ecosystem Health; Marine Spatial Management and Bureaucracy; Impact of Monsoon Season on Microplastics;	Use of detection technology; data-based	11

	Marine Waste Management in Ports; Prediction of Microplastic Zones; Public Participation and Environmental Awareness; Microplastic Contamination in Bivalves; Tourism Impact on Marine Pollution; Organic Waste Management and Renewable Energy; Pharmaceutical Pollution in Water Sources; Microplastic Detection and Biodegradable Technology	monitoring; policy analysis
Total		22

Source: Processed by the Author.

2. Smart Environment: Marine Waste Management in ASEAN

Marine waste management in ASEAN, especially in the Philippines, Indonesia, and Malaysia, is a major challenge faced by developing countries with extensive coastal areas. These three countries encounter various issues related to plastic waste and suboptimal waste management. Each country implements different policies and technologies in their efforts to manage marine waste.

a. Management of Marine Waste in the Philippines

Marine waste management in the Philippines faces various challenges that require an integrated approach between policy, technology, and public awareness. Various studies show that although the Philippines has adopted several policies and technologies to address plastic waste in the sea, significant obstacles remain, such as limited infrastructure, low public awareness, and a lack of effective law enforcement. Therefore, the implementation of stricter policies and technological innovations such as IoT-based monitoring and microplastic sensors is highly necessary.

Table 6
Marine Waste Management in the Philippines

Indicator	Author	Policy Focus	Challenges
Plastic Waste Management	(Sulistyorini et al., 2025)	Implementation of the Zero Waste policy in Indonesia that can be adopted in the Philippines	Challenges in changing public attitudes toward plastic waste and inadequate infrastructure
Marine Debris Monitoring	(Sangprasert & Inthavisas, 2025)	Use of ultrasonic sensor technology and IoT for marine debris monitoring	Lack of monitoring systems in the Philippines and the need to improve efficiency in waste management
Plastic Waste in Ports	(Yuwono et al., 2025)	Improvement of waste management in ports and strengthening law enforcement	Insufficient waste management infrastructure and low awareness among port communities
Technology for Plastic Waste Reduction	(Fabinyi, 2018)	Implementation of technologies such as microplastic sensors and plastic waste reduction policies	Marine waste management hindered by weak policies in addressing plastic waste

Source: Processed by the Author

Marine waste management in the Philippines faces significant challenges despite the adoption of various policies and technologies. One of the main challenges is the low public awareness of plastic waste management, exacerbated by limited infrastructure and weak law enforcement, especially in port communities. Although the implementation of Zero Waste policies in Indonesia can serve as a model, the Philippines still struggles to change public attitudes toward

plastic waste. Moreover, although technologies such as ultrasonic sensors and IoT have proven effective in monitoring marine debris, the Philippines still needs a more efficient monitoring system and broader technology implementation. Strengthening policies to reduce plastic waste and using advanced technologies like microplastic sensors are key to improving existing marine waste management, but this is hindered by policies that have yet to decisively address the issue.

2. Marine Waste Management in Indonesia

Marine waste management in Indonesia faces complex challenges and requires a comprehensive approach. This country has a significant contribution to marine plastic pollution, most of which comes from fishing ports and coastal activities. Various policies have been implemented to address this issue, such as the Indonesian Ocean Month Initiative and the MMAF Decree, but their implementation still faces obstacles related to a lack of collaboration, public awareness, and adequate infrastructure. In addition, the implementation of smart technologies such as IoT-based sensors and efforts to reduce multilayer plastic waste are also necessary to enhance management effectiveness.

Table 7
Marine Waste Management in the Indonesia

Indicator	Author	Policy Focus	Challenges
Plastic Pollution from Fishing Ports	(Maruf et al., 2024)	Indonesia Ocean Month initiative and MMAF Decree No. 130 of 2023	Limited collaboration among the government, private sector, and local communities in managing plastic waste at ports
Multilayer Plastic Waste and Recycling	(Annisa et al., 2025)	Reduction of single-use plastics and strengthening of the Extended Producer Responsibility (EPR) policy	Limited recycling systems, particularly for multilayer plastic waste that is difficult to recycle
Marine Mammal Protection and Pollution	(Sahri et al., 2020)	Protection of marine mammals and reduction of underwater noise pollution	Weak regulatory enforcement and the absence of comprehensive policies to address pollution affecting marine mammals
Microplastic Management in Rivers	(Lestari et al., 2025)	Management of microplastics in rivers contributing to marine pollution	Lack of monitoring and management of microplastic pollution affecting water quality and marine ecosystems
Use of Renewable Energy for Waste Management	(Hasan et al., 2012)	Application of renewable energy for marine waste management	Dependence on fossil fuels, which hinders the implementation of green energy–based solutions for marine waste management
Circular Economy for Plastic Waste Reduction	(Herrador & Van, 2024)	Implementation of circular economy policies to reduce single-use plastics	Limited implementation of circular economy policies and insufficient support for circular-based waste management
Geothermal Energy Potential for Marine Waste Management Technology	(Wahid et al., 2025)	Utilization of geothermal energy to support marine waste management technology	Suboptimal utilization of geothermal and other renewable energy potentials in marine waste management

Source: Processed by the Author

Marine waste management in Indonesia still faces significant challenges despite the implementation of several policies. The main issue lies in the lack of collaboration between the government, the private sector, and local communities, especially in managing plastic waste at fishing ports. In addition, the limited recycling system and dependence on fossil fuels hinder the efficiency of waste management, especially multilayer plastic waste that is difficult to recycle. Although policies such as Extended Producer Responsibility (EPR) and the circular economy have been introduced, their implementation is still limited, and strengthening regulations as well as increasing public awareness are urgently needed. Moreover, the potential of renewable energy, such as geothermal energy, has not been optimally utilized in supporting more sustainable marine waste management solutions.

3. Management of Marine Waste in Malaysia

Marine waste management in Malaysia faces significant challenges, particularly related to microplastics that contaminate marine ecosystems and pose risks to human health. To address this issue, Malaysia has implemented various data-driven and innovative technologies and policies, such as the use of microplastic detection sensors, application-based reporting systems, and the Smart Environment approach that involves information technology and stakeholder collaboration. However, challenges such as weak law enforcement, lack of public awareness, and inefficient waste management remain major obstacles.

Table 8
Marine Waste Management in the Malaysia

Indicator	Author	Policy Focus	Challenges
Microplastics and Marine Ecosystem Health	(Sheriff Adams, 2025)	Utilization of IoT-based technology and sensors to monitor microplastics	Lack of law enforcement and public awareness, particularly in rural areas
Marine Spatial Management and Bureaucracy	(Abdullah et al., 2016)	Strengthening stakeholder collaboration and the use of GIS in marine debris data management	Complicated bureaucracy and complex organizational structures that hinder coordination and management effectiveness
Impact of the Monsoon Season on Microplastics	(Arina et al., 2025)	Monitoring microplastics based on weather patterns and monsoon seasons	Dynamic changes in microplastic distribution patterns require rapid monitoring and policy adjustments
Marine Waste Management in Ports	(Bahri et al., 2025)	Installation of environmentally friendly technologies in ports, such as solar energy	Limited implementation of green technology across ports and inadequate waste management systems
Microplastic Zone Prediction	(Abd Wahid et al., 2025)	Use of GIS and Artificial Neural Network (ANN) models to map microplastic accumulation zones	Limited comprehensive implementation of data-based prediction systems across all coastal areas
Public Participation and Environmental Awareness	(Ahmed et al., 2020)	Establishment of multi-stakeholder platforms to enhance public awareness	Low public awareness and limited participation in marine waste management
Microplastic Contamination in Bivalves	(Amin et al., 2025)	Application of technology for detecting microplastics in marine samples	Difficulty in detecting microplastics across Malaysian waters, requiring more advanced technology
Tourism Impact on Marine Pollution	(Islam et al., 2024)	Waste management in tourism areas and stricter monitoring	Domestic waste and plastic pollution from tourism activities remain insufficiently controlled

		within Marine Protected Areas (MPAs)	
Organic Waste Management and Renewable Energy	(Yong et al., 2021)	Implementation of anaerobic digestion technology to manage organic waste	Limited organic waste management systems and slow adoption of renewable energy technologies
Pharmaceutical Pollution in Water Sources	(Arumugam et al., 2025)	Detection and treatment technologies for pharmaceutical waste to reduce microplastic contamination	Pharmaceutical residues are still detected despite treatment processes, indicating the need for more efficient technologies
Microplastic Detection and Biodegradable Technology	(Goh et al., 2025)	Use of microplastic detection sensors and biodegradable materials to reduce microplastic pollution	Weak law enforcement and low public awareness, particularly in rural areas, hinder policy effectiveness

Source: Processed by the Author.

Marine waste management in Malaysia faces significant challenges, particularly related to microplastics, which contaminate marine ecosystems and pose risks to human health. Various studies show that although technologies such as microplastic detection sensors and biodegradable materials have been implemented, difficulties in detecting microplastics across waters and the lack of law enforcement remain major obstacles. In addition, waste management in port and tourism areas, which is still limited to the application of environmentally friendly technology and strict supervision, requires infrastructure improvements and closer collaboration between the government, community, and industry sectors. Challenges also arise from low public awareness, especially in rural areas, which slows down the success of existing policies.

Data-based approaches such as the use of GIS and ANN models to map microplastic accumulation zones can enhance monitoring and planning for marine waste management. However, the implementation of such technology is still limited, considering that many coastal areas do not yet have a comprehensive data-based prediction system. In addition, issues related to pharmaceutical pollution in water sources and pollution due to tourism also need more attention, with an emphasis on more efficient technology for detecting pharmaceutical waste and more controlled waste management.

C. Comparative Analysis of Marine Waste Management in Malaysia, Indonesia, and Filipina

The following is a comparative analysis of the efforts to manage marine debris in the three countries.

Table 9
Marine Waste Management in Malaysia, Indonesia, and Filipina

Aspect	Malaysia	Indonesia	Philippines
Implemented Technologies	IoT, microplastic sensors, GIS, green technology	IoT sensors, renewable energy, Zero Waste approach	Ultrasonic sensors, IoT-based monitoring technology
Management Approach	SMART Environment framework and multi-stakeholder collaboration	SMART Environment approach and reduction of single-use plastics	Zero Waste–based management and technology-driven monitoring
Main Issues	Microplastics, bureaucratic complexity, lack of public awareness	Single-use plastics and pollution from ports	Plastic waste and inadequate waste management infrastructure
Community Role	Education and awareness through multilateral platforms	Collaboration among government, private sector, and communities	Enhancing awareness through community-based policies

Policy Effectiveness	Strengthening policies through data-driven technology	Policies remain limited and require further strengthening	Plastic waste reduction policies have not yet been fully optimized

Source: Processed by the Author

The management of marine debris in the ASEAN region shows characteristics that complex and diverse, influenced by differences in geographical conditions, levels of development, institutional capacity, and readiness for technology adoption. The comparison between Malaysia, Indonesia, and the Philippines shows that the implementation of the smart environment concept has not been evenly distributed. Nevertheless, each country provides important lessons in the effort to build a more sustainable marine waste management system.

In the context of waste and marine debris management, Malaysia tends to shows a more advanced approach with the utilization of technology, especially in the research and monitoring of microplastics. The use of Geographic Information Systems, Neural Network models, sensors, and spatial data-based approaches allows for more accurate identification of microplastic accumulation areas. However, the effectiveness of this approach is still limited by bureaucratic fragmentation and weak inter-agency coordination, which hinders the optimization of policies in the field.

Indonesia faces a significant challenge; the high volume of plastic waste originating from fishing ports and river flows indicates that the main issues are not only related to technological limitations but also to the low level of behavioral change in society and the weak implementation of policies. Although various initiatives such as zero waste, extended producer responsibility, and restrictions on single-use plastics have been implemented in several areas, their application is still inconsistent and monitoring is not optimal.

Meanwhile, the Philippines is in a relatively more vulnerable condition, with a significant contribution of plastic waste from the fisheries and coastal tourism sectors. The limitations of waste management infrastructure and the low compliance of business operators have led to a continuous increase in marine waste accumulation. Nevertheless, the Philippines has a great opportunity to develop a more effective management system thru the adoption of Internet of Things-based monitoring technology and strengthening the role of coastal communities in reducing marine debris.

From the perspective of energy management and environmental pollution, Malaysia stands out thru integration of renewable energy in port and waste management, such as the use of solar energy and shore power systems. This approach demonstrates a strong connection between energy efficiency, emission reduction, and the protection of marine ecosystems. Indonesia, despite having great potential in renewable energy such as geothermal and biomass, has not fully integrated energy policies with marine waste management systems, resulting in pollution control efforts being partial. The Philippines faces similar challenges, especially in coastal areas and small islands with limited access to clean energy, making it difficult for marine waste management to be supported by an environmentally friendly energy system.

In the dimension of environmental governance, Malaysia is relatively strong in the aspect planning and research, but still facing challenges in cross-sector coordination. Indonesia has a fairly extensive regulatory framework, but often experiences gaps between policy formulation and its implementation at the local level. The Philippines shows that weak oversight and the dominance of short-term economic interests can hinder efforts to protect the marine environment, even in areas that are supposed to be protected.

This comparison emphasizes that the success of implementing a smart environment in marine waste management heavily relies on the synergy between data-driven technology, implementable policies, and active community involvement. Technology serves as the primary supporting tool, but without strong governance, consistent law enforcement, and broad public participation, the transformation toward sustainable marine waste management will be difficult to achieve in the ASEAN region.

Conclusion and Recommendations

Conclusion

The management of marine waste in the Philippines, Indonesia, and Malaysia, viewed from the perspective of a smart environment, has shown significant and highly optimal transformations in improving the quality of environmental governance, despite facing major challenges that require collective and technology-based efforts to reduce negative impacts on marine ecosystems. Although the three countries have implemented different policies and technologies, key challenges remain, such as low public awareness, limited infrastructure, and weak law enforcement. The use of smart technologies such as microplastic sensors, IoT, and data-based monitoring systems can enhance the efficiency of marine waste management, but the implementation of these technologies is still hindered by various factors, including limited resources and suboptimal collaboration between the public and private sectors.

The application of the Smart Environment concept in marine waste management in the three This country offers potential solutions to improve the effectiveness and efficiency of waste management, especially plastic, which is one of the main threats to the quality of the marine environment. By enhancing collaboration among ASEAN countries and strengthening policies and technology implementation, it is hoped that marine waste management in the Philippines, Indonesia, and Malaysia can be significantly improved.

Recommendations

ASEAN countries need to strengthen cooperation in marine debris management policies, share technology, and conduct joint patrols to reduce plastic waste entering the oceans. The use of IoT-based technology, microplastic sensors, and GIS (Geographic Information System) should be expanded to monitor marine debris in real-time, especially microplastics, which is a major issue in these three countries. The governments of each country must be more stringent in reducing the use of single-use plastics and introducing waste management policies based on the circular economy, focusing on recycling technology and reducing multilayer plastic waste. In addition, education and public awareness need to be enhanced regarding the importance of marine waste management, especially thru community-based programs and the use of social media to increase public participation in waste management. Given the heavy reliance on fossil fuel energy sources, these countries also need to adopt renewable energy technologies to support more sustainable marine waste management, including the use of solar energy and biotechnology-based waste management systems. By integrating technology, data-driven policies, and public participation, ASEAN countries can create a cleaner and more sustainable environment while reducing the negative impact of marine debris on ecosystems and human health.

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