Environmental health issues and the solution in Indonesia: A narrative review

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A R T I C L E   I N F O

ABSTRACT

Indonesia is a rich country in natural resources but also vulnerable to environmental degradation. Factors such as rapid urbanization, industrialization, and intensive agriculture have led to serious environmental degradation. Holistic and sustainable solutions are needed, requiring further support. The aim of this narrative review is to present various environmental health issues and the solution in Indonesia that can effectively build awareness, motivate action, and guide more sustainable environmental restoration efforts. This study uses a narrative review method. The literature review was conducted through PubMed NCBI and ScienceDirect databases. Keywords used include "Environmental Health Issues And Solutions In Indonesia" AND/OR "Environmental Health Issues In Indonesia and Their Solutions". The criteria for articles in this study are that they must be in English, full text, open access, research articles or review articles, with results and discussions related to environmental health issues in Indonesia along with their solutions, and published within the last 10 years (2012-2022). We found 11 articles that discuss these topics. In the intricate tapestry of Indonesia's environmental landscape, the harmonious interplay of governmental, industrial, and communal efforts, guided by robust policies and inclusive engagement, weaves the threads of sustainability and resilience into the fabric of the nation's future.

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INTRODUCTION

In the modern era, characterized by technological advancements and industrialization, environmental health issues have become a pressing global concern. Increased human activities, urban expansion, and the exploitation of natural resources have significantly impacted human health and ecosystems worldwide. One of the key aspects of environmental health issues is the rise in environmental pollution. Research related to this needs special attention due to the urgent need

to understand the complex dynamics between the environment and human health and to identify effective solution strategies (Awewomom, et al., 2024); (Inauen, et al., 2021).

The Emissions Gap Report 2023, compiled by the United Nations Environment Programme, highlights the escalating challenges due to greenhouse gas emissions, rising temperatures, and increasingly intense climate impacts. In 2022, global greenhouse gas emissions reached a record high of 57.4 GtCO2e, with fossil fuel combustion and industrial processes accounting for two-thirds of the total emissions. The rapid increase in methane (CH4), nitrous oxide (N2O), and fluorinated gases (F-gases) further exacerbates these environmental challenges (Inauen, et al., 2021); (GE, Chrysolite, Utami, Wijaya, & Friedrich, 2016). The emissions of gases ultimately lead to increased air pollution. According to the latest WHO report, 99% of the global population is exposed to air pollution levels that elevate the risk of diseases such as heart disease, stroke, chronic obstructive pulmonary disease, cancer, and pneumonia. WHO statistics indicate that air pollution contributes to 6.7 million deaths annually, with household air pollution remaining a significant concern in 2021 as 2.3 billion people relied on polluting fuels and technologies for cooking (Awewomom, et al., 2024); (King, 2018).

The clean water crisis is also a major concern in environmental health discussions. Water pollution from industrial, agricultural, and domestic waste has reduced the availability of clean and safe water for human consumption and basic sanitation needs. Consequently, waterborne diseases remain a serious threat to public health in many countries, particularly in less developed regions (Inauen, et al., 2021). In 2021, the global water crisis continued, affecting more than 2 billion people in countries experiencing water scarcity, a situation expected to worsen due to climate change and population growth. In 2022, at least 1.7 billion people worldwide used drinking water contaminated with feces, posing severe public health risks. Microbial contamination from these sources is a major threat to water safety, causing diseases such as diarrhea, cholera, dysentery, typhoid, and polio, leading to approximately 505,000 diarrhea-related deaths annually. While 73% of the global population had access to safely managed drinking water services in 2022, inequalities persist (Boyd, 2022).

The critical role of human behavior in addressing environmental health issues amid global concerns about rising temperatures, extreme weather events, and the depletion of natural resources cannot be ignored. This highlights the interconnectedness between environmental issues and human health and well-being, emphasizing the urgent need for action and behavior change to mitigate negative impacts. Addressing these issues requires understanding the complex dynamics between environmental factors and human health, assessing health risks, developing mitigation strategies, and promoting public health interventions to create sustainable solutions and improve public health outcomes (Awewomom, et al., 2024); (Benson, Obasi, Akinwande, & Ile, 2024). Anthropogenic activities, such as industrialization and transportation, are major contributors to environmental contamination, leading to serious health problems and economic consequences (Prodanova, Naslednikova, & Tarasova, 2023).

Reducing pollution must involve the adoption of cleaner production technologies, enforcement of regulations, promotion of sustainable transportation, and implementation of proper waste disposal systems (Inauen, et al., 2021). Preventive environmental management approaches are essential, yet the implementation of environmental policies needs careful attention to tackle global challenges (Oloruntobi, et al., 2023). Recent studies have explored strategies such as computable general equilibrium models and the enforcement of environmental policies, which demonstrate potential for effective pollution control (Inauen, et al., 2021). Strengthening institutions and global environmental governance is crucial to mitigating environmental impacts and ensuring sustainable development. Addressing global pollution requires a holistic approach, proactive management strategies, and international cooperation to transition towards sustainability and reduce the negative impacts of pollution on the planet (Oloruntobi, et al., 2023).

RESEARCH METHOD

This study uses the Narrative Review method with a qualitative descriptive approach. The protocol used is PRISMA flowchart diagram. While the literature search strategy used in this research is to analyze the inclusion and exclusion criteria that have been determined based on the language, article types, outcome, and year of publication.

Table 1. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Language	English	Indonesia, French, Spanish, Russian, Chinese, Arabic
Article Types	Full text, free access, research article, and review article	Abstract article; paid article; books, conference papers, protocols
Outcome	Results and discussion of articles related to environmental health issues in Indonesia along with solutions	Environmental issues discussed outside Indonesia; Environmental issues in Indonesia without any explanation of the solutions
Year of Publication	Last 10 years (2012-2022)	More than 10 years

This study uses electronic databases, namely Pubmed NCBI and ScienceDirect. The keywords used in English are "Environmental Health Issues And Solutions In Indonesia" AND/OR "Environmental Health Issues In Indonesia and Their Solutions". The data obtained were extracted manually and analyzed descriptively.
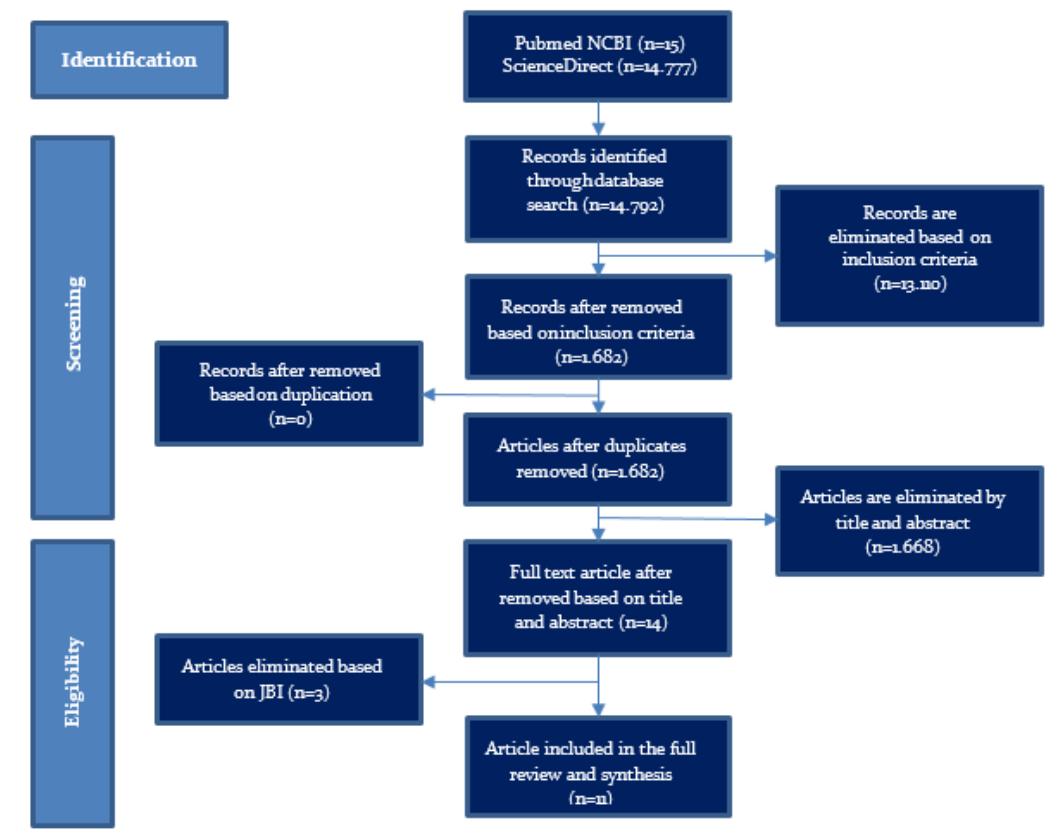

Figure 1. Prisma flow diagram

RESULTS AND DISCUSSIONS

Here are the numbers of articles obtained from the search, adjusted according to the inclusion criteria, and finally selected through complete review and synthesis: the number of articles obtained from the search: 14,792 articles, the number of articles that met the inclusion criteria: 1,682 articles, and the number of articles selected after complete review and synthesis: 11 articles. All articles describe environmental health issues in Indonesia along with their solutions. The results of the analysis will be presented in the following table (Table 2):

Table 1. Data extraction

No	Writer	Title	Method	Issues	Solutions
1	Omeyer, Lucy C.M., et al.	Priorities to inform research on marine plastic pollution in Southeast Asia	Survey Analysis Thematic Approach	Sources of plastic pollution in the Southeast Asian marine environment, driven by various factors including rapid economic growth, increasing living standards, large-scale tourism industry, and rising use of single-use plastics. More than half of the rivers in Southeast Asia are predicted to be among the world's largest contributors to plastic waste.	1. Understanding and targeting waste leakage points from land to sea in Southeast Asia is key to reducing plastic pollution. 2. Sustainable plastic economy development can be a crucial tool to engage local businesses and communities. 3. The need for international legislation to regulate plastic waste trade and hold transnational companies accountable.
2	Rhodes, Christopher J.	Plastic pollution and potential solutions	Review	Plastic production has significantly increased since 2004, reaching a total of 8.3 billion tons of new plastic mass. Plastic pollution has significant impacts on the environment, animals, and human health, especially when plastic is poorly managed and ends up in the oceans.	1. Bioplastics, although only contributing 0.5% of global plastic production, are being explored as an alternative. 2. Oxo-plastics, containing additives to aid degradation. 3. Circular economy approach, similar to permaculture principles, emphasizes extensive recycling.
3	Siddiqui, Shahida Anusha, et al.	Black soldier fly larvae (BSFL) and their affinity for organic waste processing	Experimental Research involve direct observation of Black Soldier Fly (BSFL) Larvae Development Process in Converting	Increasing human population leads to higher food demand, resulting in increased volume of organic waste. Organic waste contributes to water, air, and soil pollution and	1. BSFL, especially Hermetia illucens, has shown potential in converting organic waste into high-quality nutrition. They can be used as feed for pets, fish, and poultry,

No	Writer	Title	Method	Issues	Solutions
		Organic Waste into High-Quality Biomass.		can also spread pathogens. This excess waste poses threats to human health and the environment.	as well as residual fertilizer. 2. Improving BSFL feed formulations and delivery methods can enhance insect body nutrient content, making it more valuable as feed., menjadikannya lebih bernilai sebagai bahan pakan.
4	Gomez-Sanabria, Adriana, et al.	Sustainable wastewater management in Indonesia's fish processing industry: Bringing governance into scenario analysis	Description of fish processing industry, estimation of COD load and greenhouse gas emissions from wastewater treatment until 2030, and scenario usage.	Indonesia faces significant challenges in managing wastewater from its fish processing industry, contributing to water pollution in rivers with high levels of water pollution. The effluent contains organic pollutants, including chemical oxygen demand, which can degrade water quality and damage aquatic ecosystems.	1. Implementation of National Wastewater Policy such as the use of aeration lagoons plus activated sludge. 2. Adoption of Climate Change Policies incentivizing the use of swimbed technology. 3. Co-benefit scenarios with Vertical and Horizontal Coordination to facilitate Up-Flow Anaerobic Sludge Blanket (UASB) plus activated sludge. 4. Enhancing collaboration between government agencies, stakeholders, and international organizations to address these challenges.
5	Spiegela, Samuel J., et al.	Phasing Out Mercury? Ecological Economics and Indonesia's Small-Scale Gold Mining Sector	Comparative Study involve interviews with small-scale gold miners and document analysis from the UN and the Indonesian government.	Despite global efforts to limit mercury trade, new domestic mercury production has changed the dynamics of mercury pollution in Indonesia. Mercury pollution in Small-Scale Gold Mining has severe environmental and	1. Promotion and adoption of clean technologies as alternatives, such as cyanidation or gravity concentration methods. 2. Conducting awareness campaigns and educational programs to inform miners about the dangers

No	Writer	Title	Method	Issues	Solutions
				health consequences, including pollution hotspots, ecological damage, and toxic exposure exceeding safe levels.	of mercury exposure and the benefits of adopting clean technologies.
6	Nindhia, Tjokorda Gde Tirta, McDonald, Morag, & Styles, David.	Greenhouse gas mitigation and rural electricity generation by a novel two-stroke biogas engine	Attributional Life Cycle Analysis evaluates the technical performance and environmental balance of applying BioMiniGen installed in farms in Bali.	The importance of Bali Cattle for the cattle industry in Indonesia and Malaysia due to their adaptability to tropical climates, efficiency in utilizing low-quality feed, high disease resistance, ease of reproduction, and quality of meat produced. Environmental benefits from small-scale anaerobic digestion of livestock manure and other organic waste from these farms include the availability of biogas as a fuel source.	There are several BioMiniGen performances on a larger scale in Bali Cattle Farms: 1. in generating electricity from biogas, 2. environmental impact of biomass electricity, and 3. potential economic benefits as well as 4. greenhouse gas reduction.
7	Meehan, Fiona,Tacooni, Luca, & Budiningsih, Kushartati.	Are national commitments to reducing emissions from forests effective? Lessons from Indonesia	Semi structured interview approach were conducted from 28 key stakeholders at the national level during the April 2016-March 2017.	Agriculture, forestry, and land-use changes (including peat fires) accounted for most of Indonesia's emissions in 2014, making it the largest emission source by sector.	The target of establishing 120 Forest Management Units during the implementation of the National Action Plan for Greenhouse Gas Reduction (RAN-GRK) has been achieved.
8	Aprilia, Aretha, Tezuka, Tetsuo, & Spaargaren, Gert.	Inorganic and hazardous solid waste management: Current status and challenges for Indonesia	A survey was conducted to collect data from respondents given different colored plastic bags, and measurements of wet waste were taken.	Although policies have existed, there are still shortcomings in proper hazardous waste separation and disposal, resulting in potential environmental pollution and health risks.	1. Increasing public awareness through education and outreach programs about better waste management practices. 2. Implementation of automated sorting equipment can improve waste sorting efficiency.
9	Putri, Pradwi Sukma Ayu & Wardiha, Made	Identification problems in the implementation	Quantitative data were collected	In Kampong Sodana, the majority of the	1. Conducting FGDs can be an effective approach

No	Writer	Title	Method	Issues	Solutions
	Widiadnyana	plan of appropriate technology for water and sanitation using FGD approach (case study: Kampong Sodana, Sumba Island, East Nusa Tenggara Province)	through field surveys on existing water and sanitation facilities conditions in Kampong Sodana, while qualitative data were collected through FGDs to verify the collected quantitative data.	community still use simple sanitation facilities such as pit latrines and manually obtain water from reservoirs on hillsides. Local policies and traditional beliefs still influence their sanitation behavior.	and allow for open dialogue, enabling researchers to understand community perceptions, priorities, and challenges related to water and sanitation issues. 2. Other efforts include increasing knowledge and awareness among local communities about healthy living practices, sanitation, and hygiene.
10	Widyaningsih, Niluh, et al.	Linkage model between sustainable consumption and household waste management	Study using questionnaire based on Abraham Maslow's hierarchy of needs and consumer behavior theory, along with in-depth interviews in 4 areas of Duren Sawit District implementing the 3R principle	Inadequate waste management system in Jakarta, particularly in East Jakarta, facing significant challenges in handling the increasing waste volume. Despite efforts to address waste management, there is still a considerable amount of waste not properly managed, posing environmental and public health risks	1. Policy makers and stakeholders can develop interventions to enhance waste management practices 2. Correlation analysis reveals the relationship between consumption behavior and waste management practices 3. System Dynamics Analysis aids in understanding the complex interactions and feedback cycles within the waste management system 4. Intervention Strategies: Internal Intervention - promoting green motivation and advocating green lifestyle among households External Intervention - implementing the 3R approach (Reduce, Reuse, Recycle) at the community level.
11	Gaborit, Pascaline.	Climate adaptation to Multi-Hazard climate related	Qualitative Multi disciplinary Analysis	Cities in Indonesia affected by rising sea levels and floods face various	1. It is essential to develop existing local resilience strategies and

No	Writer	Title	Method	Issues	Solutions
		risks in ten Indonesian Cities: Ambitions and challenges	conduct experts at least 12 interviews per city and organized 4 focus group discussions for each city.	challenges related to vulnerability to natural disasters. Cities like Bandar Lampung, Cirebon, Gorontalo, Kupang, Mataram, Ternate, Banjarmasin, Pangkal Pinang, Samarinda, and Pekanbaru have diverse risks, ranging from floods to forest fires.	responses applied by these cities to address disaster risks, including early warning systems, infrastructure improvements, land use planning, and community engagement initiatives. 2. Strengthening collaboration among government agencies, civil society organizations, academia, and the community to develop comprehensive and effective adaptation strategies.

Waste Pollution and The Solution

The study provides data on the generation and composition of household solid waste in Jakarta. It is necessary to discuss the prevalence of improper waste separation and disposal practices among households and then propose interventions such as the enforcement of waste management regulations, increased public awareness, and investment in waste management infrastructure (Aprilia, Tezuka, & Spaargaren, 2013). Additionally, there needs to be a discussion on the correlation between household consumption patterns and waste generation, emphasizing the need for sustainable consumption and waste management practices. This should be followed by proposing a model linking sustainable consumption patterns and household waste management, integrating insights from correlation analysis and system dynamics analysis, and supporting intervention strategies targeting individual behaviors (internal interventions) and community-level practices (external interventions) (Widyaningsih, Tjiptoherijanto, Widanarko, & Seda, 2015).

A comprehensive analysis of the historical trajectory and contemporary challenges in waste and resource management since the 1970s highlights the importance of learning from past experiences to guide future planning. It explains the transition from primitive control measures to environmentally friendly management, emphasizing the key role of legislation in setting standards, ensuring accountability, and facilitating industrial equity. Additionally, it describes the paradigm shift towards recycling, driven by the rising costs of traditional disposal methods, environmental concerns such as methane emissions and climate change, and an increasing recognition of the limitations of purely technical approaches. Despite significant progress, especially in the Global North, the study highlights persistent global disparities, with the Global South facing significant barriers due to institutional and financial constraints. It advocates for a Sustainable Integrated Waste Management approach, blending technical solutions with governance demands, emphasizing the importance of partnerships, financial viability, proactive policies, and data-driven decision-making (Wilson, 2023).

Policy imperatives such as sustainable financing, rethinking recycling strategies, and extended producer responsibility are highlighted as key to advancing the waste management

agenda (Wilson, 2023). Furthermore, the study advocates for an inclusive approach, blending top-down strategies with grassroots initiatives and prioritizing the needs of marginalized communities. With waste management assuming greater political importance, as evidenced by recent UN resolutions, the study welcomes the potential paradigm shift towards prioritizing global waste and resource management. It calls for collaboration, innovation, and sustained investment to address emerging challenges such as plastic pollution, electronic waste, and the transition towards a circular economy (Widyaningsih, Tjiptoherijanto, Widanarko, & Seda, 2015). Finally, it is essential to recognize the contributions of diverse stakeholders and emphasize the importance of knowledge transmission to future generations of waste managers and resource researchers (Wilson, 2023).

Plastic Pollution and The Solution

The global increase in plastic production has significant environmental impacts, including marine pollution. Microplastics, formed from the breakdown of larger plastic fragments, pose threats to marine organisms and potentially human health through the food chain. The study raises concerns about the absorption and concentration of harmful chemicals by microplastics, which can endanger organisms that ingest them (Omeyer, et al., 2022). The current economic model governing plastic production fails to adequately account for recycling and waste disposal costs, leading to significant environmental consequences. Most plastics end up in landfills or the environment, causing pollution. Non-degradable plastic waste accumulates in ecosystems, posing threats such as ingestion by marine animals, leading to physical harm or even death. Microplastics, due to their small size, can cause internal and external damage to marine organisms and act as carriers for harmful chemicals. Synthetic polymers in plastics release toxic compounds, potentially causing health issues like inflammation and metabolic disorders. Detecting microplastics in the environment is challenging but crucial for understanding pollution levels and developing effective mitigation strategies (Ziani, et al., 2023).

A sustainable plastic economy is emphasized as a potential solution to reduce plastic waste and reliance on fossil resources. Effective interventions such as technology transfer from developed countries and targeting waste leakage points are suggested to combat plastic pollution in Southeast Asia (Omeyer, et al., 2022). Various techniques for managing plastic waste include recycling, landfilling, incineration, and both mechanical and chemical recycling. Plastic waste is repurposed in sectors like construction, agriculture, and 3D printing. Despite these efforts, much waste still ends up in landfills, emitting greenhouse gases. Incineration produces harmful pollutants, although advanced methods can mitigate the risks. Mechanical recycling recovers plastics with uniform composition, while chemical methods break down polymers into raw materials. Techniques such as methanolysis and pyrolysis produce valuable products like diesel. Plastic bottles aid agriculture, and recycling for 3D printing filament closes the loop in a circular economy (Babaremu, et al., 2022).

Policy interventions, regional action plans, and geopolitical regulations are discussed as crucial strategies for addressing plastic waste trade and demanding corporate accountability (12). Many countries have enacted laws to tackle microplastic pollution, such as the Microbead-Free Waters Act in the US and the Commonwealth Clean Oceans Alliance in the UK. These laws target the production, distribution, and use of plastics, promoting alternatives and recycling. Additional measures include providing incentives for plastic waste collection, imposing taxes on plastics, and regulating waste disposal practices. International bodies like ASEAN and the European Commission have proposed regulations, while initiatives like the Ocean Plastics Charter aim to reduce single-use plastic usage and increase recycling rates by 2030. Addressing microplastic pollution requires a multifaceted approach involving innovation, legislation, cooperation, and public engagement (Ziani, et al., 2023).

Mercury Pollution and The Solution

The use of mercury in Artisanal Small Scale Gold Mining (ASGM) presents socio-economic and technological challenges related to ending mercury use in ASGM. This study discusses the spread of contaminated sites in ASGM regions globally and highlights the lack of literature on mercury production, trade flows, and usage in Asia. It emphasizes concerns about domestic mercury mining's impact on efforts to reduce mercury use in ASGM in Indonesia (Spiegela, et al., 2018).

Mercury, unique for its liquid state under standard conditions, poses significant threats to aquatic ecosystems and human health. Anthropogenic sources, primarily small-scale and artisanal gold mining, significantly contribute to atmospheric mercury emissions. ASGM alone accounts for about 38% of global mercury emissions, totaling 838 tons in 2015. The consequences of mercury exposure vary depending on its form and dose, with inhalation being the primary absorption route. Acute mercury poisoning from metallic mercury exposure can lead to severe respiratory symptoms, while chronic exposure results in neurological disorders and kidney damage. To address anthropogenic mercury pollution, the Minamata Convention on Mercury was adopted in 2013. However, despite international efforts, mercury pollution remains a significant challenge in the ASGM sector, necessitating a comprehensive approach to effectively mitigate health and environmental impacts. This review examines occupational mercury exposure and related health effects among ASGM miners in middle- and low-income countries, providing insights into affected workers and associated symptoms and diseases (Taux, Kraus, & Kaifie, 2022).

To effectively manage mercury trade and prevent its diversion for artisanal and small-scale mining use, countries can undertake various actions. These include investigating how mercury enters and is traded within ASGM sites, reviewing and establishing domestic legislation consistent with the Minamata Convention, developing import approval processes, implementing licensing and manifest schemes to track mercury flows, and establishing coordination mechanisms with other countries. Additionally, countries should evaluate proposed mercury imports to ensure compliance with their National Action Plans and Convention obligations, particularly those prohibiting mercury supply from primary mining and chlor-alkali plants. Strategies for managing trade should include documentation procedures, evaluation criteria for proposed imports, and mechanisms for obtaining import approval. Furthermore, countries can develop strategies to prevent mercury diversion to ASGM by implementing licensing requirements, transport manifest requirements, and coordination with neighboring countries. Engaging stakeholders, particularly ASGM communities, is crucial for effectively implementing National Action Plans. Public health strategies should address mercury exposure risks, especially for vulnerable populations such as children and pregnant women, through data collection, health worker training, awareness raising, and intersectoral engagement. Finally, preventing exposure in vulnerable populations requires targeted outreach approaches, regulation enforcement, inspections, integrating child labor issues, and cooperation with relevant agencies. When guidelines from organizations like WHO are available, countries should incorporate them into their strategies to further enhance mercury risk management in ASGM (Mercury, 2017).

Water Pollution and The Solution

This study discusses the environmental consequences of untreated or inadequately treated waste from fish processing plants and proposes interventions such as the implementation of national waste policies and the adoption of climate change policies to mitigate environmental impacts (Gomez-Sanabria, et al., 2020). Waste treatment reflects a paradigm shift, transforming what was once considered a burden into a valuable asset. By leveraging technological advancements and embracing circular economy principles, this approach not only addresses water shortages but also generates energy, fertilizer, and supports sustainable development goals such as access to clean water and sanitation. Key focus areas include converting waste into clean water, energy, mitigating environmental impacts, and maintaining sustainable communities. Through

meticulous processes, waste becomes reusable, combating water scarcity and protecting natural resources. Technology aids in efficiency, process analysis, and decision-making. Additionally, it contributes to energy production, reducing reliance on fossil fuels, and promoting clean energy innovation. By repurposing waste, waste treatment supports sustainable resource management and mitigates environmental damage such as nutrient pollution, ensuring a greener future (Silva, 2023).

Challenges such as water scarcity and urbanization require innovative solutions, with decentralized approaches proving effective, especially in informal settlements (Silva, 2023). The lack of developed water and sanitation facilities in Kampong Sodana is an example from the above study. It emphasizes the importance of involving local communities in the development process and integrating local knowledge and traditions into the implementation of technology. It advocates the use of Focus Group Discussions (FGDs) to gather insights from local communities and identify challenges and preferences related to water and sanitation (Putriab & Wardiha, 2013). Furthermore, waste treatment promotes waste reduction and sustainable practices, advocating for decentralized methods and promoting water conservation awareness. It also ensures access to clean water, particularly in urban informal settlements, helping to build sustainable cities by addressing water supply barriers. However, challenges such as costs, energy usage, labor shortages, and sludge disposal must be addressed to improve treatment efficiency and meet sustainable water management goals. Solutions involve decentralized setups, technological advancements, and enhanced monitoring for compliance with standards and rapid interventions (Silva, 2023).

Gas Emissions and The Solution

The National Action Plan for Greenhouse Gas Reduction (RAN-GRK) outlines Indonesia's commitment to reducing greenhouse gas emissions (Meehana, Tacconia, & Budiningsih, 2019). The Indonesia Climate Data Explorer standardizes provincial emission data using 2010 as the base year, with some provinces excluded due to incomplete inventories. Emission data, adjusted to million metric tons of carbon dioxide equivalent (MtCO2e), are aggregated into sectors including agriculture and forestry, energy, transportation, industry, and waste. The national emission reduction target for 2020, compared to business-as-usual emissions, is tracked through annual monitoring reports, with the latest data from the 2016 implementation report of the Regional Action Plans for Greenhouse Gas Reduction (RAD-GRK) by Bappenas (GE, Chrysolite, Utami, Wijaya, & Friedrich, 2016).

This study discusses the challenges and limitations of existing policies and initiatives in achieving emission reduction goals, highlighting the need for monitoring, evaluation, and data verification to assess the effectiveness of emission reduction actions (Meehana, Tacconia, & Budiningsih, 2019). Mitigation activities are categorized by sector, while adaptation plans are included in some provincial documents. Development strategies integrate RAD-GRK plans to support emission reductions. Data limitations include incomplete 2010 emissions, inconsistent alternative sources, and limited public access to RAD-GRK documents. Despite these challenges, this tool provides a comprehensive overview to support Indonesia's climate goals (GE, Chrysolite, Utami, Wijaya, & Friedrich, 2016).

According to Indonesia's latest General National Energy Plan (RUEN) and Bappenas, the country aims to achieve a New and Renewable Energy (NRE) mix of 31% by 2050, with an ambitious target of 70% NRE to reach carbon neutrality by 2060. However, in 2020, NRE only accounted for 11.2% of the total energy mix. Major challenges for NRE usage include land limitations, high investment costs, fossil fuel subsidies, lack of NRE technology knowledge and human resources, high banking sector interest rates, and the need for efficient energy storage due to intermittent NRE supply. Despite these obstacles, the 2020-2024 Strategic Plan of the Ministry of Energy and Mineral Resources outlines directions for developing biomass power plants with a capacity of 1,295 MW using crude palm oil and other biomass, implementing co-firing in coal

power plants, developing small-scale biomass plants, producing bio-based CNG, promoting waste-to-energy plants, and increasing the blend of biofuels in diesel through the B30 program. Efficient biomass utilization requires a stable raw material supply chain and improved road infrastructure for transportation, potentially reducing production costs significantly. Indonesia's substantial biomass energy potential, especially from palm oil, rice husks, and other agricultural residues, remains underutilized but is crucial for achieving NRE goals (Hardhi, 2022). Studies on biomass utilization for power generation mention Bali Cattle Farming in Indonesia and Malaysia and the establishment of anaerobic digesters to process cattle manure into organic fertilizer. This study highlights the environmental benefits of small-scale anaerobic digestion and the potential role of renewable energy sources in enhancing rural energy security, presenting findings on the technical performance and environmental balance of implementing BioMiniGen for electricity generation from biogas produced by digesters installed on farms in Bali (Nindhia, McDonald, & Styles, 2021).

Climate Change and The Solution

Climate change, driven by human activities, significantly affects the global economy, society, and environment through increasing greenhouse gas emissions, resulting in global warming and climate changes such as rising temperatures, changing precipitation patterns, ice melting, and thermal expansion of water. Southeast Asia experiences warming trends, sea-level rise, increased rainfall, and more frequent extreme weather events. Coastal areas face pollution, resource overexploitation, and unsustainable land use, exacerbated by sea-level rise, ocean warming, increased acidification, and intense events. Coastal erosion is caused by internal factors like currents and sediment changes, external factors like storm surges and flooding, and human activities such as deforestation and urbanization. Relative sea-level rise from glacier melt, thermal expansion, local winds, and land movements impacts ecosystems and human activities, leading to flooding, salinization, and erosion. Case studies in Thailand and Vietnam show significant shoreline retreat and land subsidence due to sea-level rise, with Vietnam experiencing a notable rise of 3 mm/year. Storm surges from extreme weather events, including tropical cyclones and typhoons, exacerbate coastal erosion by creating higher waves and pushing seawater inland, causing severe damage to coastal systems and communities (Dong, Saengsupavanich, Ramli, Mohamed, & Yunus, 2024).

The study assesses the exposure of Indonesian coastal cities to climate-related disasters and identifies existing resilience strategies and responses. It discusses the challenges local governments face in prioritizing interventions and emphasizes the importance of multi-stakeholder cooperation in adaptation efforts. It advocates for comprehensive and effective adaptation strategies that address trade-offs and vulnerabilities, especially for marginalized populations (Gaborit, 2022). Another study investigates cultural knowledge of climate change in Nusa Tenggara Barat (NTB) Province and stakeholders' perceptions. This study highlights the diversity of views and understanding of climate change within communities and the importance of involving various stakeholders in adaptation planning, advocating for a deeper understanding of "climate knowledge culture" and integrating adaptation efforts with other challenges faced by NTB Province (Bohensky, et al., 2016).

As an example, coastal erosion poses a significant threat to coastal communities, causing land loss, property damage, and infrastructure collapse, as seen in areas like Cua Dai Beach and Kien Giang Beach. This erosion, exacerbated by climate-related factors such as sea-level rise, also increases flood risks, impacting roads, health facilities, and agriculture. Additionally, the decline in tourism activities due to coastal erosion affects economies, as seen in Vung Tau, Vietnam, and Kuala Terengganu, Malaysia, which rely heavily on beach tourism. To mitigate these impacts, adaptation measures are essential, including hard protection approaches like seawalls and revetments, soft protection methods such as permeable bamboo fences, and coastal management strategies like infrastructure enhancement and integrating hazard prevention into transportation planning. Defense structure vegetation and using natural management approaches can enhance

resilience against erosion and extreme weather events. Furthermore, community-based adaptation strategies, such as relocation and phased housing, are implemented in some areas, like Tambaksari-Sayung, Indonesia, to reduce the vulnerability of coastal communities (Dong, Saengsupavanich, Ramli, Mohamed, & Yunus, 2024).

CONCLUSION

Indonesia faces complex environmental challenges, including pollution from waste and plastic, wastewater pollution, exposure to toxic substances, greenhouse gas emissions, and climate change. Addressing these issues requires a holistic approach that integrates technological innovation, policy interventions, and community engagement. For pollution from waste and plastic, a shift towards a circular economy and stronger regulatory frameworks are needed. Effective wastewater management and decentralized water management are crucial for reducing pollution and supporting sustainable communities. Waste management should emphasize sustainable consumption, public awareness, and infrastructure investment. Reducing mercury use in artisanal mining requires comprehensive strategies and international cooperation. Furthermore, Indonesia's commitment to reducing greenhouse gas emissions necessitates the development of renewable energy technologies, enhanced data collection, and policy incentives. Finally, climate change adaptation requires protective measures, sustainable management, and community-based approaches to safeguard vulnerable populations and ecosystems. Collaboration among government, industry, communities, and researchers is essential to achieve sustainable development and environmental resilience in Indonesia.

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