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Research Article

Microplastics in Indonesia's Aquatic Ecosystems: Hidden Threats to Human Health and Environmental Sustainability

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Abstract: Microplastics have become a widespread environmental threat in Indonesia's aquatic ecosystems, an archipelagic country that has historically and recently been recorded as one of the world's major contributors to plastic pollution. Although studies on the presence of microplastics in Indonesian waters have been quite developed in terms of the quantity of publications, synthesis that specifically integrates the dimensions of human health and environmental sustainability in an integrated manner is still relatively limited, making it difficult to formulate a comprehensive picture for research and policy development. This study aims to identify the distribution and characteristics of microplastics in Indonesia's aquatic ecosystems, analyze their impact on human health, and examine their implications for environmental sustainability. The approach used is Systematic Literature Review (SLR) following the PRISMA protocol with the PICOS framework, covering articles published in the range of 2017–2026. Of the 64 articles identified, 15 primary studies were obtained along with one comparative narrative review that was synthesized thematically. The results of the synthesis show that microplastics are widespread ranging from small rivers to open seas, with local anthropogenic pressures, rather than the mere presence of water bodies, as the main determinant of pollution intensity, while mangrove areas consistently function as natural accumulation points. In the health dimension, the consumption of marine products was identified as the most documented route of exposure, although the level of quantifiable risk was still limited by the lack of Indonesia's population-based toxicology reference values. This synthesis also reveals significant geographical biases, with the majority of studies concentrated on the island of Java. These findings confirm that microplastic pollution is a multidimensional issue that connects ecosystem quality, food safety, and public health, and recommends expanding research to the eastern region of Indonesia and developing local toxicology reference values as future research priorities.

Keywords: microplastics; aquatic ecosystems; human health; environmental sustainability; systematic literature review

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1. Introduction

Indonesia is the largest archipelagic country in the world with more than seventy percent of its territory in the form of waters, a geographical condition that should make the sea and rivers the main source of life for millions of its inhabitants (Abbas et al., 2022). However, this condition is inversely proportional to the reality of waste management which is still far from adequate. For more than a decade, Indonesia has been widely known as one of the largest contributors of marine plastic waste in the world, even being ranked second globally in a widely cited reference study (Jambeck et al., 2015). A more recent study from Cottom et al., (2024) shows a shift in the global contribution map, with India now occupying the top position as a producer of plastic waste emissions to the environment at 9.3 million tons per year, followed by Nigeria at 3.5 million tons, and Indonesia in third place with 3.4 million tons per year. Despite the shift in rankings, these findings confirm that Indonesia remains consistently in the group of countries that are the world's major contributors to plastic pollution, a fact that shows that this problem is not an issue that has subsided over time, but rather an ongoing environmental crisis that requires serious attention from various parties.

Plastic waste that is not properly managed ultimately undergoes a physical, chemical, and biological degradation process in the environment, decomposing into particles smaller than five millimeters in size known as microplastics (Octoriani et al., 2026). In contrast to large-sized plastic waste which is relatively easy to identify, microplastics are a much more hidden threat because their microscopic size makes them difficult to detect with the naked eye, while their ability to spread and accumulate across various environmental matrices is much wider and more persistent. The most comprehensive systematic review to date, conducted by Cordova and Wang (2026) and published in Frontiers in Marine Science, synthesizes findings from 497 publications reporting the presence of microplastics in various environmental matrices across the Indonesian archipelago, covering freshwater and marine waters, sediments, and aquatic biota. The study confirms that microplastic pollution is no longer an issue localized to one or two points of water, but a phenomenon that has spread widely and systemic throughout the archipelago's aquatic ecosystems, although the distribution of research is still geographically uneven, because more than sixty percent of the studies are concentrated on the island of Java while the eastern Indonesia region is still rarely documented.

Various field studies in recent years have also strengthened this picture. Microplastic contamination has been reported in various water bodies in Indonesia, ranging from the Kahayan River in Central Kalimantan, the Tallo River in Makassar, the Citarum River in West Java, to coastal areas such as the Batang Anai Estuary in Padang Pariaman and the waters of Nasi Island in Aceh Besar. Manullang et al., (2022) emphasized that microplastic research in Indonesian marine waters in the range of 2015 to 2022 still leaves important gaps in the aspects of environmental risk assessment and integrated waste management. The geographical distribution of these findings shows that microplastic pollution has gone beyond the boundaries of administrative areas and certain types of aquatic ecosystems, present both in urban rivers with dense industrial activities and in coastal areas relatively far from population centers.

What makes this issue even more urgent to be studied in depth is the chain of impacts that do not stop at the ecological aspect alone, but continue to directly affect human health. Microplastics that pollute the waters eventually accumulate in the bodies of aquatic biota such as fish and shellfish, which are then consumed by humans through the food chain. Hantoro et al., (2026) estimate that the microplastic intake from seafood consumption of residents of Semarang, Central Java, ranges from 11.6 to 43.6 particles per capita per day, with variations depending on age group, where adults tend to have the highest intake levels compared to the group of toddlers. The study also cites global findings that about 57 percent of microplastic intake in humans comes from aquatic products, especially seafood, in rapidly industrializing regions such as Southeast Asia. Similar findings were reported by Ningrum et al., (2023) which identified microplastic contamination in the form of fibers, fragments, granules, and filaments in the digestive tract of fish and shellfish in the coastal area of Jember Regency, in line with estimates that Indonesian waters receive around 100,000 to 400,000 tons of plastic waste every year that have the potential to contaminate marine food sources. These findings confirm that the path of exposure to microplastics to humans is not just a theoretical potential risk, but a contamination that has actually occurred in protein sources consumed by people every day.

Interestingly, when explored further, scientific studies on microplastics in Indonesia are not a completely new topic, in fact they have developed quite a lot in terms of the quantity of publications. However, the synthesis by Cordova and Wang (2026) reveals a very fundamental research gap, namely of the 497 microplastics publications they reviewed, almost ninety-four percent of them still focus on descriptive aspects in the form of distribution and characterization of polymers, while studies that specifically examine toxicological impacts and health implications are only around two percent, and studies that touch on socio-economic and policy aspects Plastic waste management is not even up to one percent of the overall literature reviewed. This condition reveals an important research gap, namely that although data on the existence and distribution of microplastics in Indonesian waters is quite abundant, systematic mapping that specifically highlights the wedge between threats to human health and environmental sustainability is still relatively limited in an integrated manner.

Based on these conditions, the main problem raised in this study is no longer just identifying the presence of microplastics in various Indonesian aquatic ecosystems, but how published scientific evidence describes the relationship between microplastic pollution and human health risks and environmental sustainability in an integrated manner. Until now, information on these three aspects is still scattered in various studies with different focuses, locations, and approaches so that there is no comprehensive synthesis that can provide a comprehensive picture as the basis for research development and policy formulation for microplastic pollution management in Indonesia.

To answer these problems, this study adopts the Systematic Literature Review (SLR) approach by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol. This approach was chosen because it provides a systematic, transparent, and replicable procedure in the process of identification, selection, evaluation, and synthesis of scientific literature so as to minimize potential bias in the selection of reference sources (Page et al., 2021). Compared to conventional narrative reviews, the PRISMA-based SLR approach allows for a more comprehensive integration of scientific evidence from various studies, so that the relationship between microplastic pollution, its impact on human health, and its implications for environmental sustainability can be analyzed more fully.

2. Materials and Method

This study uses the Systematic Literature Review (SLR) method which follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to ensure transparency and repeatability of the literature selection process (Page et al., , 2021). The SLR stage begins with the determination of keywords relevant to the topic of microplastics in Indonesia's aquatic ecosystems, followed by the process of identifying articles through online literature search. The articles obtained are then selected through a screening stage based on the suitability of the title and abstract, and continue with the selection of eligibility based on the inclusion and exclusion criteria that have been set.

The inclusion and exclusion criteria in this study were compiled using the PICOS (Population, Intervention, Comparison, Outcome, Study Design) framework:

Table 1. PICOS (Population, Intervention, Comparison, Outcome, Study Design)

Components	Criteria
Population	Indonesia's aquatic ecosystems (rivers, estuaries, coastal areas, and seas)
Intervention/Exposure	Presence and exposure to microplastics in water, sediment, or biota media
Comparison	Comparison between aquatic ecosystem types and/or between geographical areas in Indonesia
Outcome	Distribution/characteristics of microplastics, impacts on human health, and implications for environmental sustainability
Study Design	Primary research articles, review articles, and scoping reviews that have a clear methodology

Inclusion criteria include: (1) articles relevant to microplastics in Indonesia's aquatic ecosystems according to the PICOS framework above, (2) published in the 2017-2026 range, (3) in Indonesian or English, and (4) have clear data and methodology. Exclusion criteria include: (1) popular media coverage that is not a scientific research article, (2) policy documents or institutional reports that are not peer-reviewed journal articles, (3) the type and status of the peer-reviewed document cannot be ascertained, and (4) the full text cannot be accessed through the available access channels.

The identification stage resulted in 64 unique articles obtained through online library searches. A total of 34 articles were excluded at the initial stage because they did not meet the inclusion criteria (not scientific articles or unclear document types), leaving 30 articles screened based on the suitability of titles and abstracts. All 15 articles were successfully searched for retrieval, with 5 of them still awaiting full access verification because they could potentially be behind a paywall.

The data analysis in this study was carried out through a thematic narrative synthesis approach. Data from each article were extracted into a study characteristics table that included the author's name, year of publication, research location, sample type (water, sediment, or biota), microplastic identification methods, and key findings. The synthesis was carried out by grouping the findings into three major themes according to the research objectives: (1) the distribution and characteristics of microplastics according to the type of aquatic ecosystem, (2) the pathways and impacts of exposure on human health, and (3) the implications for environmental sustainability and policy direction. Article quality is assessed through a simple quality appraisal that includes topic relevance, methodological clarity, and data completeness, with findings from quality articles a stronger methodology placed as the primary basis for drawing conclusions.

3. Results and Discussion

Table 3. Characteristics of Studies Included in the Synthesis

Author (Year)	Location	Sample Type	Abundance	Key Findings
Zakiah et al., (2024)	Central Kalimantan (S. Kahayan)	Water, sediment, fish	Water 2.92±2.62 items/L; sediment 6.93±3.15 items/kg	58.89% of fish contaminated (2.03±3.42 items/individual)
Suparno et al., (2024)	Padang Pariaman (Batang Anai Estuary)	Water	37-77 particles/L	Fragment dominant, black color, size >1,000 µm
Firdaus et al., (2020)	Jagir Estuary, Surabaya	Sediment	92-590 particle/kg	The highest on the coast of Wonorejo, dominated by fiber (57%)
Lestari et al., (2020)	Surabaya River	Water (3 depths)	Surface 1.47-43.11; middle 0.76-12.56; base 1.43-34.63 particles/m³	Highest abundance at the surface and downstream end of the river
Ni'am et al., (2022)	East Surabaya	Urban sediments & mangroves	Undetectable-598 particles/kg	Urban areas 1-2 orders of magnitude higher than mangroves
Khoironi et al., (2020)	Pond Lorok, Semarang	Sediment & coastal water	Focus on the rate of degradation, not a single abundance	Gradual degradation of polypropylene according to depth; Dominated by fibers and filaments
Widada et al., (2025)	Pekalongan Waters	Water & sediment	Detailed data on the full article*	Distribution related to batik and fishery industry activities
Wicaksono et al., (2021)	Tallo River, Makassar	Water & sediment	Water 0.74-3.41 item/m³; sediment 16.67-150 items/kg	Higher in the dry season, rising downstream
Yona et al., (2019)	Eastern Java Sea	Surface sediment	Up to 896.96±160.28 particles/kg	Highest abundance in mangrove areas
Harmayani et al., (2025)	Bali (Sungai Tukad Badung)	Water & sediment	Water 48.5-105.4 particles/L; sediment 225.33-589.33 particles/kg	Highest near the estuary due to urban and commercial activities
Syakti et al., (2017)	Coast of Indonesia (multi-location)	Macro-litter & floating microplastics	Detailed data on the full article*	Indonesia's earliest microplastics study indexed by Scopus
Agustina et al., (2024)	Rice Island, Aceh Besar	Coastal sediments	Detailed data on the full article*	Characterization of coastal sediment microplastics
Hantoro et al., (2026)	Semarang, Central Java	Seafood	11.6-43.6 particles/capita/day	Highest intake in the adult group compared to toddlers
Al Abid & Windusari (2024)	South Sumatra (Musi River)	Fish consumption (biota)	Detailed data on the full article*	Gastrointestinal health risks associated with fish consumption
Wahyudin et al., (2024)	Biawak Island, West Java	Mangrove sediments & reef fish	Detailed data on the full article*	The first evidence of MP on mangrove sediments and reef fish at this location
Basri et al., (2021)**	Indonesian Waters	Narrative overview	-	Emphasizing the health implications of MP pollution in Indonesia

Comparison with state-of-the-art is an important part. This section can provide a more
The synthesis in this review includes 15 primary studies that discuss the distribution, characteristics, and impacts of microplastics in Indonesia's aquatic ecosystems, accompanied by one comparative narrative review (Basri et al., , 2021) used to frame the state of the art. The primary study locations are spread across various types of waters, ranging from large rivers, estuaries, to coastal areas, including Kalimantan (Kahayan River), Sumatra (Batang Anai Estuary, Musi River), Java (Citarum River, Surabaya River, Pekalongan coast, East Surabaya, Jagir Estuary, Tambak Lorok Semarang, Biawak Island), Bali (Tukad Badung River), Sulawesi (Makassar Tallo River), and Aceh (Rice Island). Nine of the fifteen primary studies are located on the island of Java, while eastern regions of Indonesia such as Kalimantan, Sulawesi, and Sumatra are relatively underrepresented. The inequality of the distribution of this research location will be discussed further as one of the limitations of the synthesis in the following:

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Distribution and Characteristics of Microplastics by Aquatic Ecosystem Type

Microplastics are consistently detected in all types of aquatic ecosystems studied in this review, both in surface water compartments, sediments, and biota. In large river systems, their existence is identified from upstream to estuary areas, with pollutant sources varying according to regional characteristics. In the Kahayan River, Central Kalimantan, the abundance of microplastics in the water was recorded at an average of 2.92 ± 2.62 items per liter and in sediments 6.93 ± 3.15 items per kilogram of dry weight, with nearly 59 percent of the ninety fish examined showing microplastic contamination in their digestive tract (Zakiah et al., 2024). A similar pattern appears in the Batang Anai Estuary, West Sumatra, with water abundance ranging from 37 to 77 particles per liter, dominated by black fragments measuring more than a thousand micrometers (Suparno et al., 2024).

A similar picture appears in coastal areas and estuaries in East Java. Research at Tambak Lorok, Semarang, identified a gradual degradation process in polypropylene plastics, ranging from photooxidation on the surface of the water to biodegradation at a depth of one hundred and seventy centimeters, with degraded microplastics dominated by the form of fibers and filaments (Khoironi et al., 2020). Research in the Jagir Estuary, Surabaya, documented the abundance of sediment microplastics ranging from 92 to 590 particles per kilogram, with the highest concentration found in the coastal sediments of Wonorejo, and dominated by the fiber form by 57 percent (Firdaus et al., 2020). These findings are in line with the monitoring of macro-litter and floating microplastics in various coastal locations in Indonesia by Syakti et al., (2017), a study recorded as one of the earliest studies of Indonesian microplastics indexed by Scopus, showing that the accumulation of microplastics in coastal zones does not only come from river inputs, but also from maritime activities and coastal tourism.

The pattern of increasing abundance downstream observed in the Jagir Estuary was also confirmed in the Tallo River in Makassar. The abundance of microplastics in water ranges from 0.74 to 3.41 items per cubic meter and in sediments 16.67 to 150 items per kilogram, with higher values recorded in the dry season than in the rainy season and significantly increasing downstream (Wicaksono et al., 2021). This seasonal pattern has not been widely reported in other studies in this corpus, so it is one of the findings that is quite typical of the eastern region of Indonesia.

In the open sea sediment compartment, research in the eastern waters of Java Sea found that the abundance of microplastics reached up to 896.96 ± 160.28 particles per kilogram, with mangrove areas showing the highest abundance compared to other areas such as fish landing ports or the high seas (Yona et al., 2019). These findings indicate that mangrove ecosystems function as natural traps for current-carried microplastics, a pattern that was also confirmed in the first study on microplastic contamination in mangrove sediments and reef fish on Biawak Island, West Java (Wahyudin et al., 2024). A similar pattern, where areas with high population density show much greater abundance than conservation areas, was also confirmed in a study in East Surabaya, with sediment abundance in urban coastal areas recorded one to two orders of magnitude higher than protected mangrove areas (Ni'am et al., 2022). In the Surabaya River, the abundance of microplastics was recorded higher in the water surface layer (1.47-43.11 particles per cubic meter) than in the middle (0.76-12.56) and bottom (1.43-34.63) layers, with the downstream point showing the highest average abundance (Lestari et al., 2020), a pattern consistent with the findings in the Jagir Estuary in the same river flow.

Meanwhile, research in Pekalongan waters highlighted the link between the distribution of microplastics and local batik and fishery industry activities (Widada et al., 2025), and research in the Tukad Badung River, Bali, found water abundance ranging from 48.5 to 105.4 particles per liter and sediment from 225.33 to 589.33 particles per kilogram, with the highest concentrations found near the river mouth due to the intensification of urban and commercial activities in the vicinity (Harmayani et al., 2025). Similar characterization was also reported in the coastal sediments of Rice Island, Aceh Besar (Agustina et al., 2024).

Impact on Human Health

Seafood consumption is the most widely studied pathway of exposure to microplastics to humans in the synthesized literature. Hantoro et al., (2026) estimate that the intake of microplastics from seafood consumption of the population of Semarang, Central Java, ranges from 11.6 to 43.6 particles per capita per day, with intake levels varying according to age groups, where the adult group shows the highest intake compared to the group of toddlers. Basri et al., (2021) in their review also emphasized that microplastic pollution in Indonesian waters has direct implications for public health, although the toxicological mechanism still requires further study in the context of the specific Indonesian population. Consistent findings were also reported from a study on the identification of microplastic contamination in biota parameters along the Musi River, South Sumatra, which linked water pollution to potential gastrointestinal health risks in coastal communities that depend on these aquatic resources for daily consumption (Al Abid & Windusari, 2024). A broader thematic synthesis by Marikar and Ádám (2026) also confirms that microplastics are found widely in aquatic species consumed by humans throughout Indonesian waters, confirming the urgency of standardizing analytical protocols and strengthening related regulations.

Implications for Environmental Sustainability

The widespread distribution of microplastics in various types of Indonesian aquatic ecosystems has significant implications for environmental sustainability, especially associated with the government's policy target to reduce marine plastic waste by 70 percent by 2025. The consistent distribution pattern identified from upstream to coastal areas indicates that mitigation efforts require a cross-regional approach to the administration, considering that the source of pollutants in one region can have an impact on aquatic ecosystems in other areas through river flows to the sea.

Microplastic Distribution Patterns and Their Determinants

A synthesis of fifteen primary studies in this review confirms that microplastics have become widespread in Indonesia's aquatic ecosystems, ranging from small rivers to open seas, with wide variations in abundance between locations. The abundance of the Kahayan River, Central Kalimantan, an area with relatively low anthropogenic pressure, is recorded to be much lower than locations with high population density and industrial activity such as Tukad Badung in Bali and the urban coastal area of East Surabaya. This pattern is in line with the findings of the Jagir Estuary and the Surabaya River, which show higher abundance in the downstream segment which is densely populated with domestic and industrial activities, as well as with the findings of Ni'am et al., (2022) who found a strong correlation between population density and the dominant microplastic characteristics in coastal sediments. Thus, local anthropogenic pressures, not just the existence of water bodies themselves, appear to be the main determinants of the intensity of microplastic pollution in Indonesian waters.

The role of mangrove ecosystems and the geometry of water bodies in forming microplastic accumulation points also emerged as interesting patterns of this synthesis. Mangrove areas consistently show the highest abundance compared to other coastal areas, both in the Java Sea (Yona et al., 2019) and in the mangrove sediments of Biawak Island (Wahyudin et al., 2024). Both of these findings suggest that mangroves function as natural traps for microplastics. The implication is quite ironic, ecosystems that ecologically play an important environmental service such as mangrove forests are at risk of becoming a point of accumulation of pollutants in the long term, a paradox that deserves more attention in future microplastic studies.

The time dimension also gives nuances to the understanding of this pollution dynamic. The seasonal pattern observed in the Tallo River, with a significant increase in the abundance of microplastics in the dry season (Wicaksono et al., 2021), is likely related to a decrease in water volume so that the concentration of particles per unit volume also increases. This causal relationship has not been explicitly confirmed by the study and still requires further testing at other locations before it can be generalized as a seasonal pattern of tropical waters in general.

Bridging the Environmental and Human Health Dimensions

One of the main goals of this review is to integrate the findings of environmental distribution with human health impacts in a single synthesis framework, something that according to Basri et al., (2021) and emphasized by Cordova and Wang (2026) is still rarely explicitly done in the Indonesian microplastic literature. This synthesis found that the most documented exposure pathway is the consumption of marine products, as shown by both the study of cross-age microplastic intake in Semarang (Hantoro et al., 2026) and the study of contamination identification in consumption biota in the Musi River (Al Abid & Windusari, 2024). These two studies consistently confirm that although microplastics were detected in almost all of the species studied, the level of quantifiable health risk was still limited, mainly due to the limited human toxicological reference values that could be used as a comparison.

These limitations reveal a fundamental gap in Indonesia's microplastics literature, in line with the findings of Cordova and Wang (2026) that of the 497 Indonesian microplastics publications they reviewed, only about two percent specifically examined toxicological or health impacts. The abundance of microplastics in the environment has been documented quite well quantitatively, but the health consequences still depend on extrapolating toxicological data, most of which come from studies outside Indonesia. This condition suggests that the environmental-health synthesis in this review, while successfully connecting the two dimensions narratively, remains constrained by the inherent limitations of the available primary literature.

The findings of this synthesis have direct relevance to the policy target to reduce marine plastic waste by 70 percent by 2025 that has been launched by the Indonesian government. The wide variation in microplastic abundance between regions, from low-pressure waters such as Kahayan to urban waters such as Tukad Badung and East Surabaya, indicates that a nationally uniform mitigation strategy may be less effective than an approach tailored to the characteristics of each region's pollutant pressures. The finding that mangrove areas function as microplastic accumulation points also opens up opportunities for more targeted interventions, for example through periodic monitoring of these accumulation points as an early indicator of the effectiveness of upstream waste management policies.

The geographic bias identified in this synthesis, with nine of the fifteen primary studies located on the island of Java while the eastern region of Indonesia is relatively underrepresented, is in line with the findings of Cordova and Wang (2026) that more than sixty percent of national microplastics research is concentrated in Java. This kind of data gap carries policy implications that are no less important, because it risks making national policies reflect the conditions of Java more than the real conditions in other regions, even though the pattern of microplastic pollution in Makassar shows typical seasonal characteristics and does not necessarily apply the same in Java. The expansion of research to the eastern region of Indonesia is thus an urgent need, not only for the sake of completeness of scientific data, but also to ensure that national policies are built on a geographically representative evidence base.

4. Conclusion

This systematic literature review confirms that microplastics have become widespread in various types of Indonesian aquatic ecosystems, ranging from small rivers in areas with low anthropogenic pressure to densely populated urban coastal areas. These findings confirm that microplastics have become widespread in various types of Indonesian aquatic ecosystems, with population density and local industrial activity as the main determinants of pollution intensity, while river dams and mangrove ecosystems serve as natural accumulation points that increase long-term risks to ecologically important areas to be protected. In the health dimension, the most documented pathway of exposure is the consumption of marine products with a reported risk level that is still relatively low, although the limitations of Indonesia's population-based toxicology reference values make this conclusion need to be further confirmed. This synthesis also reveals the gap between relatively adequate environmental distribution data and limited health impact data, so bridging these two dimensions remains a major challenge for microplastics research in Indonesia.

Overall, these findings show that all of the research objectives, namely identifying the characteristics of the distribution of microplastics, analyzing their implications on human health, and evaluating their impact on environmental sustainability, have been achieved, while confirming that microplastic pollution is a multidimensional issue that connects ecosystem quality, food safety, and public health. This study has limitations because it only synthesizes literature that meets the PRISMA inclusion criteria without quantitative analysis through meta-analysis, so its interpretation depends on the quality and scope of available primary studies. Further research is suggested to expand coverage to eastern regions of Indonesia that are still under-represented, develop local population-based toxicology reference values, and direct mitigation strategies at accumulation points that have been identified as priority monitoring locations.

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