Regional Studies in Marine Science 90 (2025) 104460

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Meta-analysis of the spatial distribution and composition of plastic macro-debris in Indonesia

Max R. Kelly [a,*], Muhammad Reza Cordova [b,d], Susan Jobling [c], Richard C. Thompson [a]

[a] School of Biological and Marine Sciences, University of Plymouth, Plymouth PL4 8AA, United Kingdom
[b] Research Center for Oceanography, National Research and Innovation Agency (BRIN), Jakarta 14430, Indonesia
[c] The Partnership for Plastics in Indonesian Societies (PISCES), Centre for Pollution Research and Policy, Brunel University of London, Uxbridge, Middlesex UB83PH, UK
[d] Research Center for Oceanology, National Research and Innovation Agency (BRIN), Tangerang Selatan, Indonesia

ARTICLE INFO

Keywords:
Plastic pollution
Litter
Macro-debris
Indonesia
Intervention

ABSTRACT

Plastic pollution is recognised as a global environmental problem with Indonesia identified as a major contributing source. However, a comprehensive understanding of pollution patterns remains hindered by fragmented data and methodological inconsistencies across studies. This study synthesises data from 44 peer-reviewed publications, spanning 68 field locations and 328 individual study sites across 19 provinces, to map the spatial distribution and composition of plastic macro-debris in Indonesia. We identified plastic bags, plastic food packaging, and plastic bottles as the three most prevalent item types, occurring as top three ranked items in 65 %, 63 %, and 40 % of field locations, respectively. Items were recorded across seven different environment types: beach (n = 43 field locations); river (n = 16); mangroves (n = 3); seabed (n = 2); coral reef (n = 2); sea surface (n = 1) and inland areas (n = 1), with research effort concentrated in Java, accounting for 40 % of all field locations. Despite Indonesia's environmental and regional diversity, multivariate analysis revealed no significant differences in litter composition between environment types or provinces, indicating that common plastic items dominate pollution across Indonesia. These findings underscore the need for coordinated national action targeting high-prevalence items and highlight the value of widespread beach litter monitoring as a proxy for broader environmental pollution patterns.

1. Introduction

Indonesia is recognised as a major contributor of plastic pollution to the environment (Cottom et al., 2024). Each year, Indonesia generates approximately 42 million tonnes (MT) of municipal waste, of which 7.8 MT is plastic. However, only 40–50 % of this waste is formally collected (Ministry of Environment and Forestry of The Republic of Indonesia, 2025; NPAP, 2020; World Bank, 2021), resulting in an estimated 3–4 MT of plastic leaking into the environment and approximately 350,000 tonnes discharged into the marine environment annually (Cottom et al., 2024; NPAP, 2020; World Bank, 2021). It has been suggested that the principal underlying causes of plastic leakage are from high population densities, inadequate waste management infrastructure, limited environmental management budgets and a general lack of public awareness (Lestari and Trihadiningrum, 2019; Meijer et al., 2021). For example, it is estimated that 4.9 million tonnes of plastic waste is mismanaged annually in Indonesia, including uncollected waste, disposal to open dumpsites, and leakage from within formal municipal solid waste management systems (World Bank, 2021).

Indonesia is the world's largest archipelagic nation, comprising 17,508 islands and a population of approximately 280 million people. Administratively, the country is divided into 38 provinces, encompassing 416 regencies, 98 municipalities, over 7000 districts, and more than 83,000 villages (Machdi, 2021; UK Government, 2025). Approximately 70 % of the population live within 50 km of Indonesia's extensive 54,716 km coastline with the majority (>55 %) concentrated in the provinces of Java, which accounts for just 30 % of the nation's total land area (Central Intelligence Agency USA, 2025; Sui et al., 2020). Java is also home to several rivers identified as major sources of global marine plastic pollution, including the Bekasi, Citarum, and Porong. Collectively, Indonesia's rivers discharge up to an estimated total of 42,000 tonnes of plastic into the marine environment annually (Mai et al., 2023). This pollution is further exacerbated by seasonal patterns, with monsoon rains contributing up to three times more litter discharge than

* Corresponding author.
E-mail address: max.kelly@plymouth.ac.uk (M.R. Kelly).

https://doi.org/10.1016/j.rsma.2025.104460
Received 2 June 2025; Received in revised form 28 August 2025; Accepted 29 August 2025
Available online 29 August 2025

in the dry season, highlighting the magnitude of Indonesia's plastic pollution challenge (World Bank, 2021).

In response to these challenges, the Indonesian government has launched several major policy initiatives: the Marine Debris Presidential Decree No. 83/2018 aims to reduce marine plastic debris by 70 % by 2025; the Solid Waste Management Presidential Decree No. 97/2017 targets a 30 % reduction of waste at the source; and the broader national goal is to achieve a circular economy for plastics by 2040 (Nurhati and Cordova, 2020). Achieving these targets, however, requires a comprehensive understanding of the types and composition of litter present in the environment, to inform evidence-based policy and targeted interventions.

The first reports describing plastic litter in the marine environment of Indonesia date back to 1986, highlighting a large accumulation of plastic bags, footwear, and expanded polystyrene (EPS) blocks used by local fishers to suspend fishing nets in the water column (Willoughby, 1986). Over the past decade, the number of studies quantifying plastic pollution across Indonesia has increased substantially (Purba et al., 2019; Vriend et al., 2021). However, these studies differ widely in methodology, reporting litter in varying units, such as mass (Husrin et al., 2017), item counts (Isyrini et al., 2019), per unit area (m^2) (Syakti et al., 2017), or per unit volume (m^3) (Sur et al., 2018), or as percentages of total litter composition (Fitria et al., 2020; Kurniawan and Imron, 2020; Purba et al., 2017); as is also common across the world (Haarr et al., 2022). Thus comparisons or integration across data sets is challenging and limits their ability to guide specific interventions (Lusher and Primpke, 2023).

Whilst previous studies have reviewed and catalogued the extent of previous research effort in Indonesia (Purba et al., 2019; Vriend et al., 2021), the spatial distribution of litter across different environment types and provinces remains unexplored. Therefore, the aims of this study were to a. map the spatial distribution of plastic macro-debris across Indonesia, b. identify the most prevalent types of litter across all surveyed environments, and c. determine whether the composition of the most prevalent item types differs by environment type or provincial region. It is anticipated that the findings will contribute to a more nuanced understanding of plastic pollution in Indonesia and will support more effective, geographically tailored interventions at both local and national scales.

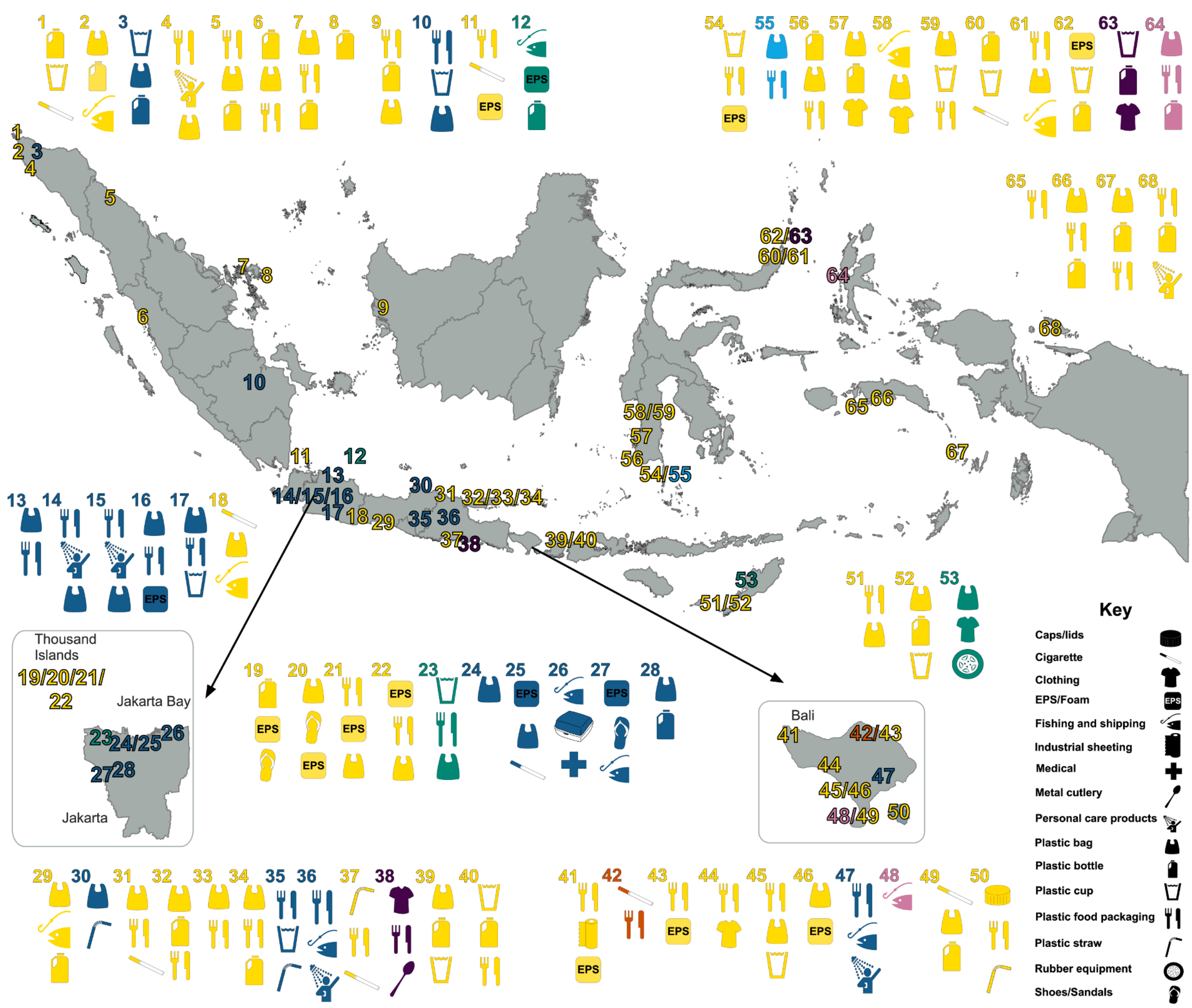

Fig. 1. The spatial distribution and composition of prevalent plastic item types across Indonesia. N = 44 studies across 68 field locations depicted in the figure encompassing 328 field sites and 16 different item types. Order of the icons, from top to bottom, at each of the numbered field locations indicates ranking of the most abundant item types recorded. The colour of graphics indicates environment type: Beach (yellow); River (dark blue); inland (orange); Mangrove (green); Seabed (pink): Coral reef (purple), Sea surface (light blue). The approximate location of each study is presented and the individual studies are described in Table S2 with the corresponding citation.

2. Methods

2.1. Collating existing data sets describing plastic pollution in Indonesia

We conducted a comprehensive synthesis of an initial 105 peer-reviewed studies in the primary literature to assess patterns in the most prevalent types of litter in Indonesia. Relevant research articles were identified using the Scopus database with the search terms: “Plastic” OR “Litter” OR “Debris” AND “Beach” AND “Indonesia.” Additional research articles were also obtained from the reviews of Vriend et al. (2021) and Purba et al. (2019) (PRISMA flow diagram of literature search shown in Figure S1). To account for inconsistencies in sampling methodologies, including variations in units of measurement across studies conducted in Indonesia, we employed a ranking-based approach to identify trends in the most frequently reported litter items. For each study, we identified the top three most abundant item types based on the quantification method applied in that specific study. This approach then enabled comparison of the highest-ranked litter items across all studies conducted within Indonesia. However, for a more granular level of analysis, where some studies covered multiple regencies or different environment types (e.g., both river and beach sites, or multiple rivers across different regencies), the top three items of litter were determined separately for each distinct sampling area. These sampling units were treated as individual data entries, referred to here as ‘field locations,’ with the top three ranked litter items identified for each (Fig. 1).

Studies were excluded if they reported only one item type or grouped plastic under a general category without specifying item types. In addition, plastic fragments and microplastics were excluded from the rankings as they are difficult to accurately identify through visual in situ surveys and are often untraceable to specific sources. However, these smaller particles often originate from the breakdown of larger macroplastic items (Thompson et al., 2024). Therefore, while our study focuses on macroplastics, effective interventions targeting these items could also reduce microplastic pollution in the longer-term.

The final dataset comprised 44 studies published between 1986 and 2024 that provided information on the relative abundance of macrodebris in Indonesia, with the majority (n = 42) published within the last decade. Across these studies, 16 distinct litter categories were identified among the top three most commonly reported item types (Table S1). To ensure consistency, item descriptors were initially selected from the 121 OSPAR marine litter categories (Wenneker and Oosterbaan, 2010) and subsequently harmonised to account for the varying terminology used across the studies in our Indonesian dataset (Table S1).

2.2. Analysis of item composition by environment and province

To assess whether item types differed significantly among environment types and by provinces, we conducted two individual permutational multivariate analysis of variance (PERMANOVA) tests using the adonis2() function from the vegan package (Oksanen et al., 2020) in R. This method tests for differences in the multivariate composition of items across groups by comparing within-group and between-group distances in a dissimilarity matrix. We used a Jaccard distance matrix based on presence-absence data to focus on differences in item types rather than abundance due to our ranked approach to identify the most prevalent item types. To address the unbalanced sampling effort, where the number of field locations differed between environment type or province, a PERMANOVA was chosen for its robustness to unequal group sizes (Anderson, 2001). The test statistic was generated from 999 permutations of the dataset, providing a non-parametric *p*-value for significance testing. All analyses were conducted in R (version 2023.06.0 +421), and statistical significance was assessed at $\alpha = 0.05$.

3. Results and discussion

3.1. Most prevalent item types across Indonesia

Across the 44 studies, 68 individual field locations, encompassing 328 individual study sites were identified and mapped across Indonesia, incorporating seven environment types: beach (n = 43); river (n = 16); mangrove (n = 3); seabed (n = 2); coral reef (n = 2); sea surface (n = 1) and inland areas (n = 1) (Fig. 1 and listed in Table S2). Irrespective of environment type, plastic bags were the most dominant item type, recorded as a top three ranked item in 65 % of field locations across Indonesia (Fig. 1 and Fig. 2). This may result from the majority of goods, including food and beverage items, being transported by consumers in single use plastic bags throughout Indonesia, which may then be discarded directly into the environment after use or used as a waste receptacle for the disposal of multiple items of household waste (Damanhuri and Padmi, 2012; Giesler, 2018). For example, Widyarsana et al. (2020a) estimate 34 % (283,00 tonnes/year) of household waste in Bali is illegally dumped into the environment each year. This waste is often disposed of in plastic bags as it is commonly perceived that plastic bags are not problematic to the environment (Spranz and Schlüter, 2023).

Therefore, interventions lie in both improved waste management systems as well as measures to reduce single use plastic bags, which could include policy-driven incentives for businesses and public awareness initiatives. This finding is also consistent with broader studies across Southeast Asia. For instance, research in the Philippines and Vietnam also identifies plastic bags and food packaging as dominant components of plastic litter, often linked to high consumption of single-use items and inadequate waste collection infrastructure (De Guzman, 2024; Thanh et al., 2024). This regional alignment highlights the shared challenges and suggests that similar policy approaches could be effective across multiple nations.

Plastic food packaging was the second most prevalent item type, ranked among the top three in 63 % of field locations (Fig. 1 and Fig. 2). Food packaging encompassed rigid and flexible plastic films as well as Styrofoam food containers (Table S1). These classifications reflect our standardised approach (detailed in Table S1), aligned with OSPAR monitoring guidelines (Wenneker and Oosterbaan, 2010), which helps to reconcile inconsistencies in how studies label item types. For instance, some studies used the term ‘food packaging’ (Honingh et al., 2020; Kurniawan and Imron, 2020; Pe et al., 2020; Smith and Bernal, 2021; Widyarsana et al., 2020b) and others that used ‘food wrappers’ (Almiza and Patria, 2021; Fitria et al., 2020; Hermawan et al., 2017; Kamil et al., 2021; Lessy, 2020; Maharani et al., 2018; Purba et al., 2018) and one study that used ‘plastic packaging’ which included multiple items (Tuahatu et al., 2020). Therefore, this approach enabled us to create a unified dataset from the various terminologies used by authors across Indonesia, thereby allowing a robust comparison of litter types. In Indonesia, the food and beverage sector accounts for up to 65 % of the nation’s plastic consumption (Indonesian Ministry of Environment and Forestry, 2020), while globally, the food and beverage sector accounts for 10–20 % of plastic production (Yates et al., 2025). Although research into innovative packaging and improved collection systems has grown substantially in support of circular economy goals (Eriksen et al., 2019; Hahladakis and Iacovidou, 2018), food packaging remains a key target for reduction efforts due to its widespread prevalence in the environment.

Plastic bottles were the third most common item type across Indonesia, ranking among the top three items in 40 % of all field locations (Fig. 1 and Fig. 2). This was somewhat unexpected given their relatively high economic value in the waste stream, particularly polyethylene terephthalate (PET) bottles, which are typically prioritised by waste pickers over lower-value plastics such as polyethylene films used in food packaging (Putri et al., 2018; Supriyadi et al., 2000). For example, a study by Putri et al. (2018) involving interviews with 42

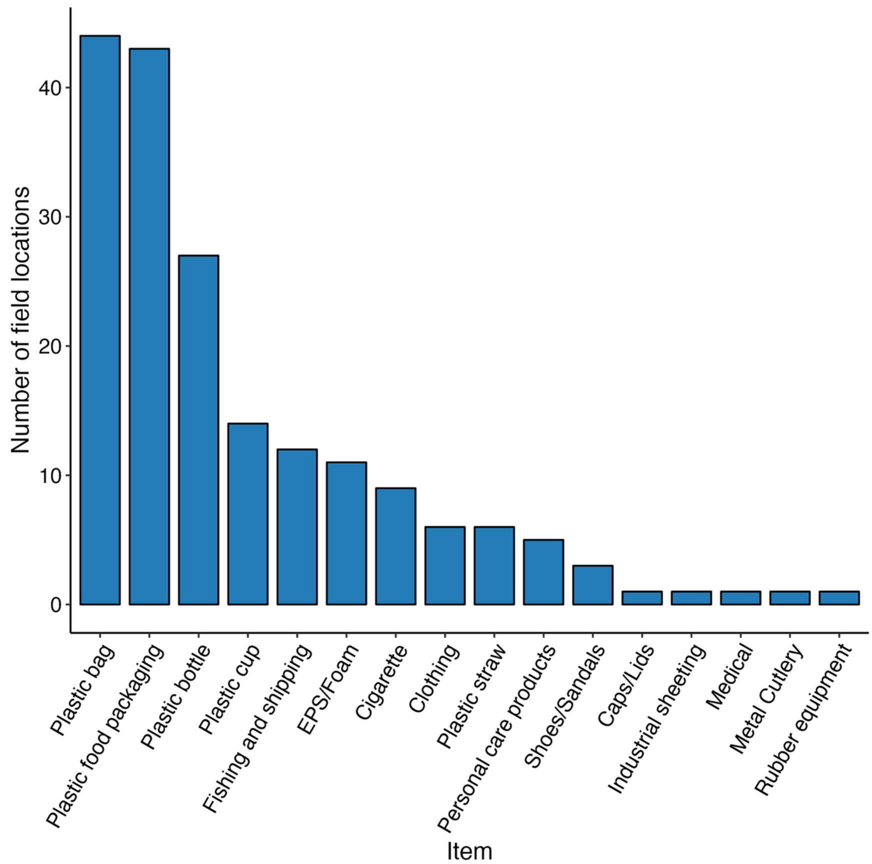

Fig. 2. The number of field locations where each item type was recorded as a top three item. N = 68 field locations across 44 studies. Item descriptors are highlighted in Table S1.

waste pickers across 42 subdistricts in Jakarta, found that all respondents collected PET bottles, 90 % collected rigid plastics, and only 10 % collected flexible plastics. Daily waste collection was reported by 91 % of participants. However, the market value of PET bottles is influenced by their quality; bottles contaminated with soil or sediment are categorised as second-class and are typically valued up to 30 % lower (Rp 2700/kg or approximately USD 0.18/kg) than first-class bottles (Rp 3750/kg or approximately USD 0.25/kg) (Kristina et al., 2018).

Plastic bottles were most frequently recorded on beaches, where they ranked as a top three item in 51 % of beach field locations (Fig. 1). One possible explanation is that bottles found in these environments may have degraded over time or become contaminated, reducing their quality and likelihood of collection. However, there is currently no direct evidence to support this hypothesis. Alternatively, Cordova et al. (2022) observed that plastic bottle abundance increased with increasing distance from Java, which they attributed to Java's more active and established recycling infrastructure compared to other regions in Indonesia.

In comparison, caps and lids, industrial sheeting, and medical items were among the least frequently recorded across Indonesia (Fig. 2). Despite the Covid-19 pandemic, only one study noted an increase in medical-related litter, specifically in two rivers in Jakarta (Cordova et al., 2021), highlighting a more systematic analysis of the pandemics broader impact on plastic pollution patters is a key area for further research. The relatively low occurrence of caps and lids in this study contrasts somewhat with global trends in aquatic environments, where they rank as the sixth most common item found on shorelines (Morales-Caselles et al., 2021). Interestingly, data from the International Coastal Clean-up initiative ranks caps/lids as the fifth most common litter item on Indonesian beaches, following cigarette butts, plastic bags (combining 'grocery' and 'other types'), plastic bottles, and food packaging (Ocean Conservancy, 2024). This alignment between citizen science data and formal studies suggests a degree of consistency in litter composition patterns, reinforcing the value of citizen-led monitoring efforts.

3.2. Item composition by environment type

Plastic litter research in Indonesia has predominantly been concentrated on beaches and in rivers, which accounted for 63 % and 24 % of field locations, respectively (Fig. 1) and less attention has been given to other environments, with mangroves representing 5 % of field locations surveyed, followed by the seabed (3 %), coral reefs (3 %), the sea surface (1 %), and inland areas (e.g. residential areas away from the coast) (1 %). As a result, upstream sources and pathways of litter leakage are critically underexplored. This trend mirrors global research patterns, where marine litter studies are often concentrated on beaches, frequently facilitated through citizen science initiatives (Haarr et al., 2022). This downstream focus presents challenges for future assessment of intervention effectiveness, particularly as the focus is often distant from the original sources of pollution.

The percentage of field locations where each item type was recorded among the top three most common items was visualised using a heatmap for all environment types (Figure S2). However, due to limited data availability from the seabed, coral reef, sea surface, and inland environments (each with fewer than three field locations), only beaches (n = 43 field locations across 192 individual study sites), rivers (n = 16 field locations across 96 individual survey sites), and mangroves (n = 3 field locations across 11 individual survey sites) were included in the statistical analysis assessing differences in item composition between environment type (Table S2). A PERMANOVA based on Bray-Curtis dissimilarity (adonis2; 999 permutations) found no significant differences in item composition among these environments (F = 1.52, R^2 = 0.23, Df = 2, P = 0.465) (Fig. 3). Therefore, these findings, while based on a limited number of environment types, offer a robust starting point for targeted policy action. The consistency of item types across different environments implies that national-level policies focused on source reduction, legislative bans, product redesign, or circular economy strategies, rather than location-specific clean-ups are likely to have the greatest impact, although this remains to be proven.

Moreover, the findings suggest that beach-based monitoring could serve as a useful proxy for understanding plastic litter trends in other coastal habitats and river systems. Future research efforts may benefit from expanding data collection to encompass a wider variety of environments and examine the long-term ecological impacts of plastic pollution on different ecostyem types. A limitation of our approach is the lack of quantitative abundance data for comparing item types across sites. As a result, while our analysis identifies the specific item types on which to focus interventions, assessing the effectiveness of such interventions will ultimately require a more quantitative approach. Additionally, incorporating weighted analyses that account for differences in sample size and study methodology, could help provide a more accurate representation of abundance patterns and reducing potential biases introduced by ranking or presence-absence data.

3.3. Regional level patterns in litter

To enable more informed regional action, we also present the top ranked items, based on the percentage of field locations recorded at the provincial level, across all environment types. For this analysis, provinces with less than three field locations (Papua, Riau Islands, Banten, West Kalimantan) were excluded, whereas provinces with less than three field locations but in close proximity with others were grouped together. For example, East Nusa Tenggara and West Nusa Tenggara were combined as ‘Nusa Tenggara’, while South, North, and West Sumatra were grouped as ‘Sumatra’, and Maluku and North Maluku were merged as ‘Maluku’ (Fig. 4). A PERMANOVA analysis based on Bray-Curtis dissimilarity (adonis2; 999 permutations) revealed a marginal, non-significant difference in item composition between provinces

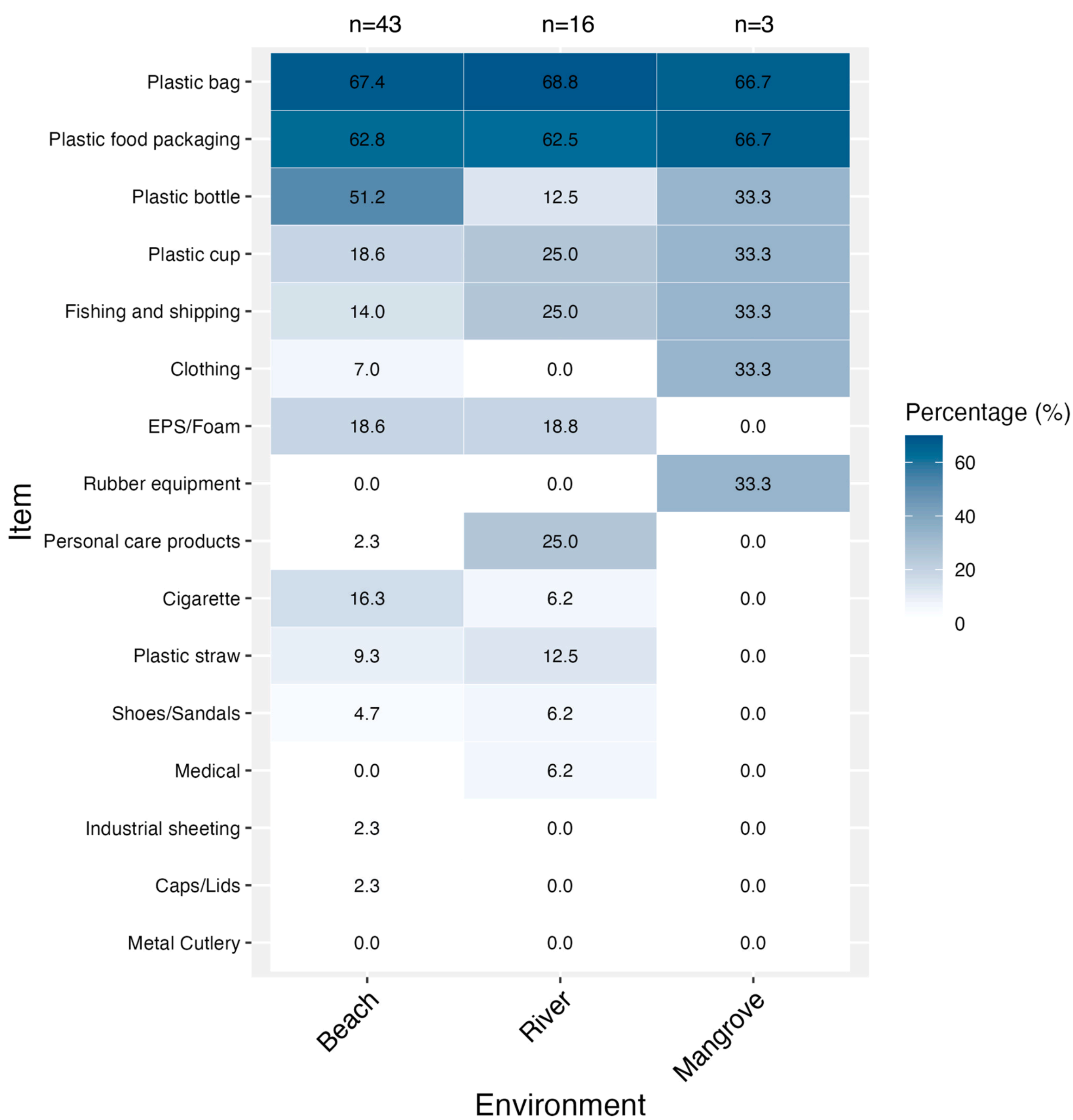

Fig. 3. The percentage of field locations where each item type was recorded as a top three item for each environment type with at least 3 field locations: Beach (n = 43 field locations), River (n = 16 field locations), and Mangrove (n = 3 field locations).

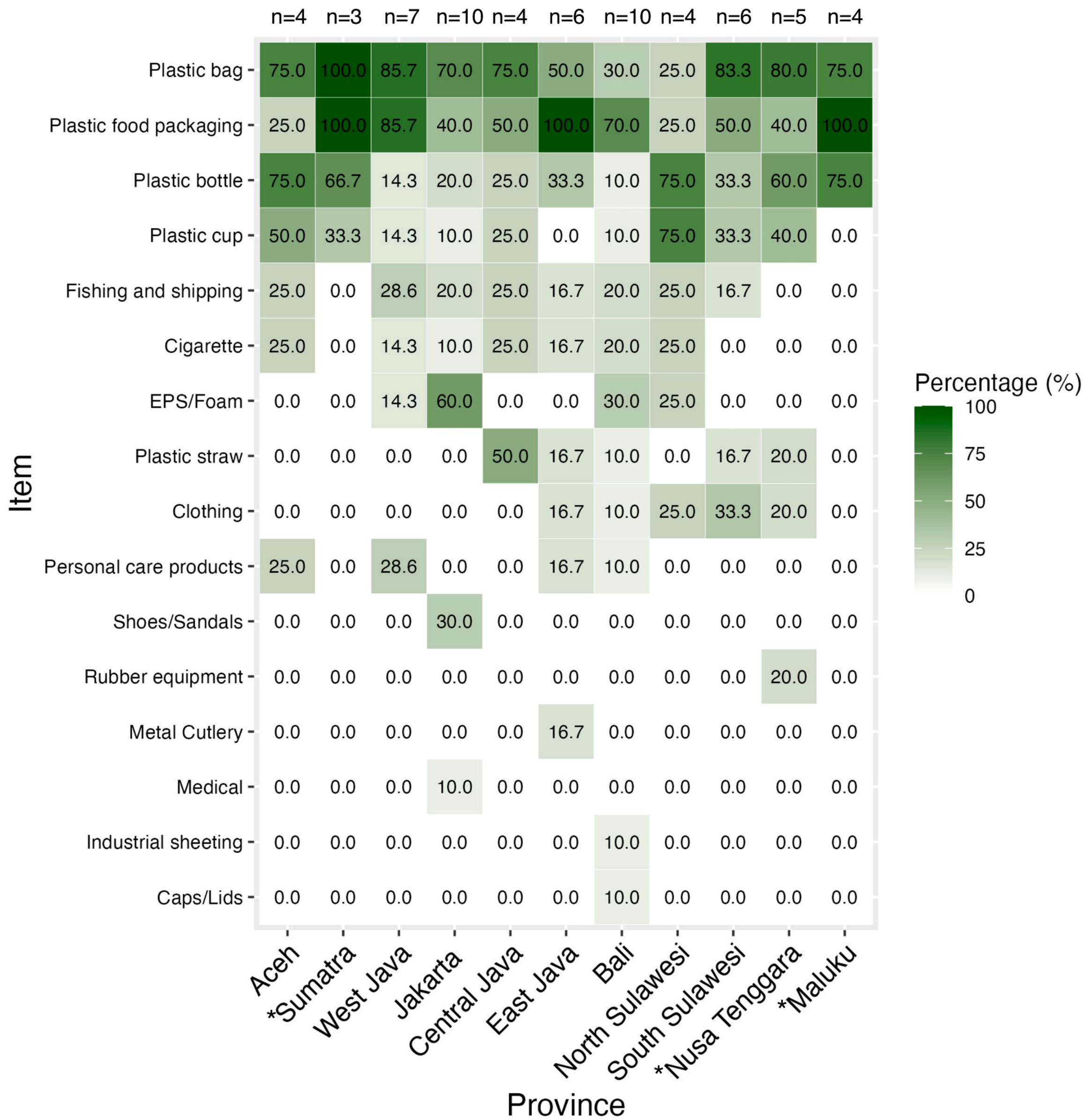

Fig. 4. The percentage of field locations where each item type was recorded as a top three item for each province. Provinces with an * indicate where multiple provinces have been combined: *Sumatra consists of North, West, and South Sumatra, *Nusa Tenggara consists of West and East Nusa Tenggara, and *Maluku consist of North Maluku and Maluku to ensure the number of field locations was at least three. The number of field locations for each province type is highlighted at the top of the figure. For instance, plastic bags were recorded as a top three item in three of the 4 field locations in Aceh (75 %).

($F = 1.51$, $R^2 = 0.22$, Df = 10, $P = 0.058$) (also see Figure S3, a nMDS plot showing the ordination of field locations by province). The small but noticeable effect size (R^2=0.22) and the *p*-value close to the significance threshold suggest some underlying provincial differences may exist between top ranked item types, but they are not statistically conclusive. These results indicate that provinces across Indonesia share similar dominant and problematic item types in their coastal and riverine environments.

The majority of field locations across Indonesia were situated in areas with high population densities, particularly on Java island (incorporating field locations within West Java, Jakarta, Central Java, East Java and Banten provinces) and Bali province, which accounted for 40 % and 15 % of field locations recorded, respectively (Fig. 1). Thus, whilst the majority of research effort has been focused in Java, this region represents over 55 % of Indonesia's population (Rahayu et al., 2023) indicating our results provide a robust representation of litter composition in the most populated regions of Indonesia. In contrast, there was no data available for several provinces including North, East, and South Kalimantan, Central Sulawesi, Central Sumatra, Jambi, Bangka Belitung, Lampung Bengkulu, Riau. Our findings indicate that these regions likely experience similar patterns of the most prevalent item types in coastal and riverine environments (Fig. 3 and Fig. 4). However, empirical data collected in these regions will help strengthen our understanding of national patterns, particularly in more rural communities.

Distinguishing between locally generated litter (e.g., from residents or tourism) and items transported from distant sources via ocean currents remains a significant challenge. While approaches, such as plastic bottle brand and origin analysis have been developed to trace litter sources (Ryan et al., 2019), applying these methods broadly across all item types is complex. Furthermore, whilst some studies have noted a correlation between seasonal changes and an increase in plastic debris, a comprehensive understanding of how these patterns affect the abundance of specific plastic item types in Indonesia is lacking. For example, research has shown that stronger winds and increased rainfall during monsoon seasons lead to a higher overall amount of plastic debris on beaches (Cordova et al., 2022) and in rivers (World Bank, 2021). However, long-term monitoring studies are still needed to track how these seasonal and temporal differences impact the composition of litter. Ultimately, gaining better insight into litter provenance using a source-focused approach is critical for designing and implementing the most effective, context-specific intervention strategies.

Interestingly, some approaches to reducing the levels of plastic pollution, such as waste management, are often handled by local governments in Indonesia, with funding varying significantly across regions. National estimates show that, on average, local governments allocate 0.07 % of their budgets to waste management, with Jakarta dedicating the greatest percentage at approximately 5 % of its regional budget (Cordova et al., 2022). The disparity in local government funding likely contributes to varying waste management outcomes across provinces. For example, a lack of funding in more rural areas has hindered the ability to deliver affective waste management infrastructure, where mis-managed landfill sites can act as common dumping grounds (Munawar et al., 2018; Zurbrügg et al., 2012). Some reports also indicate that 76 % of waste leakage occurs from small, medium, and remote cities and approximately 40 % or 57 million residents of Indonesia's urban population have insufficient access to waste collection services (NPAP, 2020; World Bank, 2021). Indonesia is a rapidly growing economy where between 1990 and 2018 the nations' GDP increased 10 fold from $10.6 billion USD to $104.2 billion USD, with a steady increase of population growth by approximately 1.5x over the same time frame (Sui et al., 2020). Therefore, waste management alone may be insufficient to stem the flow of litter into the environment and keep pace with the combined pressures of economic expansion, urbanisation, and rising consumer consumption.

This challenge is not unique to Indonesia. In other parts of Southeast Asia including Malaysia and Thailand, rapid urbanisation has considerably outpaced the development of formal waste collection systems, leading to increased leakage into the environment (Ng et al., 2023). Moreover, evidence from nations where plastic consumption has increased relatively consistently since the 1950s, underscores that waste management alone is insufficient to address the problem (Borrelle et al., 2020; Scientists Coalition for an Effective Plastics Treaty, 2024). Without concurrent strategies to reduce production and ensure that the plastics which are produced bring essential societal benefits and are intentionally designed for sustainability with end of life considerations from the outset, systemic progress will remain limited.

Some provinces have implemented interventions targeting specific items. For instance, in West Java, the city of Bandung has outlined a ban on Styrofoam-based food and beverage packaging, although its full implementation is still pending (Cordova and Nurhati, 2019). In addition, the sale of plastic bags has been prohibited in supermarkets in Jakarta (since 2020) and Bali (since 2019), covering over 40 cities (Asmadianto et al., 2020). Despite these initiatives, single use bags are still regularly used in local markets and online delivery services (Cordova and Nurhati, 2019). This continued usage likely contributes to the high frequency of plastic bags observed in Jakarta's rivers (Fig. 1), many of which are located near traditional markets, where they are prone to being littered into the environment (Van Emmerik et al., 2019).

4. Conclusion

Our findings consistently identify plastic bags, plastic food packaging, and plastic bottles as the dominant litter types in coastal and riverine environments of Indonesia. While some provincial-level interventions have been implemented, these item types persist widely across all of the studied regions, highlighting the need for coordinated, nation-wide action. The similarity in litter composition across the surveyed environments and provinces also suggests that beach-based monitoring can serve as a useful proxy for understanding broader pollution patterns in other coastal and riverine systems. However, a significant gap remains in monitoring litter in inland environments, particularly near the original sources of environmental leakage, where interventions could be most effective.

CRediT authorship contribution statement

Richard C. Thompson: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Conceptualization. **Susan Jobling:** Writing – review & editing, Project administration, Funding acquisition. **Max R. Kelly:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Muhammad Reza Cordova:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Richard Thompson is an unpaid co-ordiantor of the Scientists Coalition for an Effective Plastics Treaty. Other authors declare that they have no competing interests.

If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Acknowledgements

This work was supported by "A Systems Analysis Approach to Reduce Plastic Waste in Indonesian Societies (PISCES)", funded by UK Research and Innovation/UKRI and UK Global Challenges Research Fund/GCRF (Grant Ref: NE/V006428/1).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.rsma.2025.104460.

Data availability

All data are provided within the main text or supplementary data.

References

Almiza, G., Patria, M., 2021. Distribution and abundance of macroplastic at musi estuary, south sumatera, Indonesia. Journal of Physics: Conference Series. IOP Publishing, 012178.

Anderson, M.J., 2001. A new method for non-parametric multivariate analysis of variance. Austral Ecol. 26, 32–46.

Asmadianto, A., Arfah, K.A., Krismiyati, K., 2020. Policy implication of prohibition of using plastic bags at shopping centres. Int. J. Soc. Sci. 3, 116–121.

Borrelle, S.B., Ringma, J., Law, K.L., Monnahan, C.C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J., Leonard, G.H., Hilleary, M.A., 2020. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science 369, 1515–1518.

Central Intelligence Agency USA, 2025. The World Factbook. ⟨https://www.cia.gov/the-world-factbook/field/coastline/⟩.

Cordova, M.R., Nurhati, I.S., 2019. Major sources and monthly variations in the release of land-derived marine debris from the greater Jakarta area, Indonesia. Sci. Rep. 9, 1–8.

Cordova, M.R., Nurhati, I.S., Riani, E., Iswari, M.Y., 2021. Unprecedented plastic-made personal protective equipment (PPE) debris in river outlets into Jakarta bay during COVID-19 pandemic. Chemosphere 268, 129360.

Cordova, M.R., Iskandar, M.R., Muhtadi, A., Nurhasanah, Saville, R., Riani, E., 2022. Spatio-temporal variation and seasonal dynamics of stranded beach anthropogenic debris on Indonesian beach from the results of nationwide monitoring. Mar. Pollut. Bull. 182, 114035. https://doi.org/10.1016/j.marpolbul.2022.114035.

Cottom, J.W., Cook, E., Velis, C.A., 2024. A local-to-global emissions inventory of macroplastic pollution. Nature 633, 101–108. https://doi.org/10.1038/s41586-024-07758-6.

Damanhuri, E., Padmi, T., 2012. The role of informal collectors of recyclable waste and used goods in Indonesia. E. Damanhuri, InTech, Rijeka, 23-52.

De Guzman, E., 2024. Breaking free from plastic: the Philippines' journey towards sustainable consumption and production. J. Interdiscip. Perspect. 2, 488–495.
Eriksen, M.K., Christiansen, J.D., Daugaard, A.E., Astrup, T.F., 2019. Closing the loop for PET, PE and PP waste from households: influence of material properties and product design for plastic recycling. Waste Manag. 96, 75–85.
Fitria, R., Diana, F., Riani, E., Yulianto, G., Najmi, N., 2020. Analysis of sources and composition of marine debris in Western and Southern aceh, Indonesia. IOP Conference Series: Earth and Environmental Science. IOP Publishing, 012059.
Giesler, K., 2018. The Plastic Problem: Plastic Pollution in Bali.
Haarr, M.L., Falk-Andersson, J., Fabres, J., 2022. Global marine litter research 2015–2020: geographical and methodological trends. Sci. Total Environ. 820, 153162.
Hahladakis, J.N., Iacovidou, E., 2018. Closing the loop on plastic packaging materials: what is quality and how does it affect their circularity? Sci. Total Environ. 630, 1394–1400.
Hermawan, R., Damar, A., Hariyadi, S., 2017. Daily accumulation and impacts of marine litter on the shores of selayar island coast, south sulawesi. Waste Technol. 5, 15–20.
Honingh, D., van Emmerik, T., Uijttewaal, W., Kardhana, H., Hoes, O., van de Giesen, N., 2020. Urban river water level increase through plastic waste accumulation at a rack structure. Front. Earth Sci. 8, 28.
Husrin, S., Wisha, U.J., Prasetyo, R., Putra, A., Attamimi, A., 2017. Characteristics of marine litters in the West Coast of bali. J. Segara 13.
Indonesian Ministry of Environment and Forestry, 2020. National Plastic Waste Reduction Strategic Actions for Indonesia.
Isyrini, R., La Nafie, Y., Ukkas, M., Rachim, R., Cordova, M., 2019. Marine macro debris from makassar strait beaches with three different designations. IOP Conference Series: Earth and Environmental Science. IOP Publishing, 012039.
Kamil, P.I., Susianto, H., Azmi, M., Jayanthi, L.D.D., 2021. Cheating in a public good game: river waste density and the impact of settlement zones on two of Indonesia's river basins. Int. J. River Basin Manag. 1–39.
Kristina, H.J., Christiani, A., Jobiliong, E., 2018. The prospects and challenges of plastic bottle waste recycling in Indonesia. IOP Conference Series: Earth and Environmental Science. IOP Publishing, 012027.
Kurniawan, S.B., Imron, M.F., 2020. Initial analysis of plastic debris accumulation in the estuary of wonorejo river, surabaya, Indonesia. E3S Web of Conferences. EDP Sciences, p. 07001.
Lessy, M.R., 2020. Benthic marine litter accumulation at selection beaches in ternate island, Indonesia. IOP Conference Series: Earth and Environmental Science. IOP Publishing, 012018.
Lestari, P., Trihadiningrum, Y., 2019. The impact of improper solid waste management to plastic pollution in Indonesian coast and marine environment. Mar. Pollut. Bull. 149, 110505.
Lusher, A.L., Primpke, S., 2023. Finding the balance between research and monitoring: when are methods good enough to understand plastic pollution? Environ. Sci. Technol. 57, 6033–6039.
Machdi, I., 2021. Statistical Yearbook of Indonesia 2021, in: Dissemination, D.o.S. (Ed.), BPS-Statistics Indonesia.
Maharani, A., Purba, N.P., Faizal, I., 2018. Occurrence of beach debris in Tunda Island, Banten, Indonesia, E3S Web of Conferences. EDP Sciences, p. 04006.
Mai, L., Sun, X., Zeng, E.Y., 2023. Country-specific riverine contributions to marine plastic pollution. Sci. Total Environ. 874, 162552.
Meijer, L.J., van Emmerik, T., van der Ent, R., Schmidt, C., Lebreton, L., 2021. More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Sci. Adv. 7 eaaz5803.
Ministry of Environment and Forestry of The Republic of Indonesia, 2025. Waste Managment Performance Achievements. ⟨https://sipsn.menlhk.go.id/sipsn/⟩.
Morales-Caselles, C., Viejo, J., Martí, E., González-Fernández, D., Pragnell-Raasch, H., González-Gordillo, J.I., Montero, E., Arroyo, G.M., Hanke, G., Salvo, V.S., 2021. An inshore–offshore sorting system revealed from global classification of ocean litter. Nat. Sustain 4, 484–493.
Munawar, E., Yunardi, Y., Lederer, J., Fellner, J., 2018. The development of landfill operation and management in Indonesia. J. Mater. Cycles Waste Manag. 20, 1128–1142.
Ng, C.H., Mistoh, M.A., Teo, S.H., Galassi, A., Ibrahim, A., Sipaut, C.S., Foo, J., Seay, J., Taufiq-Yap, Y.H., Janaun, J., 2023. Plastic waste and microplastic issues in Southeast Asia. Front. Environ. Sci. 11, 1142071.
NPAP, 2020. Radically reducing plastic pollution in Indonesia:A multistakeholder action plan national plastic action partnership (NPAP). World Economic Forum, Switzerland.
Nurhati, I.S., Cordova, M.R., 2020. Marine plastic debris in Indonesia: baseline estimates (2010-2019) and monitoring strategy (2021-2025). Mar. Res. 45.
Ocean Conservancy, 2024. International coastal cleanup 2024 Report, Ocean Conservancy.
Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P., O'hara, R., Simpson, G., Solymos, P., 2020. 2022. Vegan: community ecology package. R package version 2, 5-7 Preprint 3, 1–152.
Pe, E., Wardiatno, Y., Mashar, A., 2020. Macroplastic distribution, abundance, and composition which flows to cimandiri estuary, west java. IOP Conference Series: Earth and Environmental Science. IOP Publishing, 012031.
Purba, N.P., Syamsuddin, M.L., Sandro, R., Pangestu, I.F., Prasetio, M.R., 2017. Distribution of marine debris in biawak island, west java, Indonesia. World Sci. N. 281–292.
Purba, N.P., Ihsan, Y.N., Faizal, I., Handyman, D., Widiastuti, K.S., Mulyani, P.G., Tefa, M.F., Hilmi, M., 2018. Distribution of macro debris in savu sea marine national park (Kupang, Rote, and Ndana Beaches), east nusa tenggara, Indonesia. World Natr. Sci. 21.
Purba, N.P., Handyman, D.I., Pribadi, T.D., Syakti, A.D., Pranowo, W.S., Harvey, A., Ihsan, Y.N., 2019. Marine debris in Indonesia: a review of research and status. Mar. Pollut. Bull. 146, 134–144.
Putri, A.R., Fujimori, T., Takaoka, M., 2018. Plastic waste management in Jakarta, Indonesia: evaluation of material flow and recycling scheme. J. Mater. Cycles Waste Manag. 20, 2140–2149.
Rahayu, P., Rini, E.F., Andini, I., Putri, R.A., 2023. Development and urbanisation during the COVID-19 pandemic: regional vulnerability in java, Indonesia. Town Plan. Rev. 94, 411–433.
Ryan, P.G., Dilley, B.J., Ronconi, R.A., Connan, M., 2019. Rapid increase in asian bottles in the south Atlantic Ocean indicates major debris inputs from ships. PNAS 116, 20892–20897.
Scientists Coalition for an Effective Plastics Treaty, 2024. Cutting plastic pollution at the source: the case for upstream solutions. https://doi.org/10.5281/zenodo.14209812.
Smith, S.D., Bernal, E., 2021. Quantifying mismanaged waste in a small balinese coastal village: comparisons of standing stock in different habitats. Ocean Coast. Manag. 202, 105433.
Spranz, R., Schlüter, A., 2023. The plastic bag habit and the ocean bali: from banana leaf wrappings to reusable bags. Knowledge Systems, Policy Foundations and Thematic Analyses. In: Ocean Governance. Springer International Publishing, Cham, pp. 319–335.
Sui, L., Wang, J., Yang, X., Wang, Z., 2020. Spatial-temporal characteristics of coastline changes in Indonesia from 1990 to 2018. Sustainability 12, 3242.
Supriyadi, S., Kriwoken, L.K., Birley, I., 2000. Solid waste management solutions for semarang, Indonesia. Waste Manag. Res. 18, 557–566.
Sur, C., Abbott, J.M., Ambo-Rappe, R., Asriani, N., Hameed, S.O., Jellison, B.M., Lestari, H.A., Limbong, S.R., Mandasari, M., Ng, G., 2018. Marine debris on small islands: insights from an educational outreach program in the spermonde archipelago, Indonesia. Front. Mar. Sci. 5, 35.
Syakti, A.D., Bouhroum, R., Hidayati, N.V., Koenawan, C.J., Boulkamh, A., Sulistyo, I., Lebarillier, S., Akhlus, S., Doumenq, P., Wong-Wah-Chung, P., 2017. Beach macro-litter monitoring and floating microplastic in a coastal area of Indonesia. Mar. Pollut. Bull. 122, 217–225.
Thanh, N.T., Toan, P.V., Ty, T.V., Lavane, K., Minh, H.V.T., Duy, D.V., Kumar, P., Tantray, F.A., Meraj, G., 2024. Assessment and sustainable management strategies for plastic waste in can tho city, Vietnam: a circular economy approach. Water 16, 951.
Thompson, R.C., Courtene-Jones, W., Boucher, J., Pahl, S., Raubenheimer, K., Koelmans, A.A., 2024. Twenty years of microplastic pollution research—what have we learned? Science 386, eadl2746. https://doi.org/10.1126/science.adl2746.
Tuahatu, J., Noya, Y., Manuputty, G., 2020. Plastic pollution on the beaches of outer ambon bay. IOP Conf. Ser. Earth Environ. Sci. IOP Publishing, 012058.
UK Government, 2025. Indonesia Toponymic Factfile. ⟨https://assets.publishing.service.gov.uk/media/67852932c6428e0131881700/Indonesia_Toponymic_Factfile.pdf⟩.
Van Emmerik, T., Loozen, M., Van Oeveren, K., Buschman, F., Prinsen, G., 2019. Riverine plastic emission from Jakarta into the ocean. Environ. Res. Lett. 14, 084033.
Vriend, P., Hidayat, H., van Leeuwen, J., Cordova, M., Purba, N., Löhr, A., Faizal, I., Agustina, K., Husrin, S., Suryono, D., 2021. Plastic pollution research in Indonesia: state of science and future research directions to reduce impacts. Front. Environ. Sci. 9.
Wenneker, B., Oosterbaan, L., 2010. Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area. Edition 1.0.
Widyarsana, I.M.W., Damanhuri, E., Ulhusna, N., Agustina, E., 2020b. A preliminary study: identification of stream waste quantity and composition in bali province, Indonesia. E3S Web of Conferences. EDP Sciences, p. 05005.
Widyarsana, I.M.W., Damanhuri, E., Agustina, E., 2020a. Municipal solid waste material flow in bali province, Indonesia. J. Mater. Cycles Waste Manag. 22, 405–415. https://doi.org/10.1007/s10163-020-00989-5.
Willoughby, N., 1986. Man-made litter on the shores of the thousand island archipelago, java. Mar. Pollut. Bull. 17, 224–228.
World Bank, 2021. Plastic waste discharges from rivers and coastlines in Indonesia. In: Marine Plastic Series. East Asia and Pacific Region, Washington DC.
Yates, J., Deeney, M., Muncke, J., Carney Almroth, B., Dignac, M.-F., Castillo, A.C., Courtene-Jones, W., Kadiyala, S., Kumar, E., Stoett, P., 2025. Plastics matter in the food system. Commun. Earth Environ. 6, 176.
Zurbrügg, C., Gfrerer, M., Ashadi, H., Brenner, W., Küper, D., 2012. Determinants of sustainability in solid waste management–The gianyar waste recovery project in Indonesia. Waste Manag. 32, 2126–2133.