

Review Article

# Marine plastic debris in Indonesia: Baseline estimates (2010-2019) and monitoring strategies (2021-2025)

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## ARTICLE INFO

## ABSTRACT

*Article history:*

Submitted 30 September 2020

Revised 1 October 2020

Accepted 2 October 2020

Published online 31 December 2020

*Keywords:*baseline  
Indonesia  
marine debris  
monitoring  
plastic

Indonesia set the mission to reduce marine plastic debris by 70% between 2018-2025 with a global significance to support the UN Sustainable Development Goal 14.1. This article assesses marine debris baseline estimates in Indonesia before 2020 from available contributions and provides recommendations for monitoring marine debris mitigation between 2021-2025. Widely ranging model estimates of plastic debris released into seas highlight the roles of data source, the spatial resolution of models, and in situ data to provide representative baseline values. Recognizing the strengths and uncertainties of available contributions, model outputs converge on a baseline value of  $0.52 \pm 0.36$  million tons (Mt) per year prior to 2020 in Indonesia, therefore setting a targeted reduced number of 0.16 Mt of marine debris releases in 2025. The Indonesian Institute of Sciences showed a preliminary value of plastic debris accumulation in beaches at  $113.58 \pm 83.88$  g/m<sup>2</sup> monthly or equivalent to 0.40 Mt/year by assuming plastic debris is most pervasive within 3 meters from Indonesia's 99,093 km-long coastlines. It is important to distinguish that while river monitoring data informs land-based plastic debris releases, stranded beach debris represents a fraction of debris that is not present in the water column and bottom sediments. Moving forward, monitoring initiatives to mitigate marine debris should leverage on nationwide municipality-level model estimates (e.g., the source to leakage route framework of the National Plastic Action Partnership) as well as in situ river and coastal particularly but not limited to sites co-identified in previous monitoring studies (i.e., Medan, Batam-Bintan, Padang, Jakarta-Seribu Islands, Semarang, Pontianak, Bali, Lombok, Makassar, Manado, Bitung). The latter should be conducted at least seasonally, considering evidence of monsoonal variations of marine debris release and accumulation in Indonesia. Indonesia's vastness and regional diversity require coordination among stakeholders (government agencies, research institutions, universities, NGOs, citizen scientists) to monitor progress in the environments.

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## 1. Introduction

The Indonesian government has set a national action plan to reduce plastic debris by 70% between 2018-2025 with a further ambition to achieve near-zero plastic pollution in Indonesia by 2040, highlighting the importance of measuring outcomes with respect to available baseline data. Without policy interventions and deliverable actions, business as the usual scenario has projected increased annual plastic debris releases into Indonesian seas by 30% from 0.62 to 0.78 million tons (Mt)

between 2017-2025 (NPAP, 2020). Through the Presidential Decree Number 83/2018, Indonesia aims to set the projection back through community awareness, the intervention of plastic debris at river outlets and marine sources, import taxes, incentives for biodegradable plastics, and the conversion of plastic waste. The initiatives carry a global significance in achieving the UN Sustainable Development Goal 14.1 to reduce land-based plastic debris (Ryberg *et al.*, 2018), considering Indonesia as a major contributor to marine plastic debris (e.g., Jambeck *et al.*, 2015; Lebreton *et al.*, 2017).

We provide an assessment of marine debris baseline estimates in Indonesia prior to 2020 by taking into

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account available studies and reports with their strengths and uncertainties, and recommendations for monitoring progress towards meeting the 70% reduction target in 2025.

## 2. An Ensemble of Model-based Estimates for Marine Plastic Debris Releases in Indonesia (2010-2020)

Widely ranging model-based estimates of plastic debris release into seas globally (1.15-12.7 Mt/year) and in Indonesia (0.20-1.29 Mt/year) underline the roles of data source, the spatial resolution of models, and *In situ* data to provide representative baseline values (Figure 1). Jambeck *et al.* (2015) laid down a framework for estimating marine plastic debris releases from mismanaged plastic waste by populations living within 50 km from the coast in 192 countries. While the study adopted the World Bank database reported in Hoornweg and Bhada-Tata (2012), a similar approach by Lebreton and Andradry (2019) combined the Waste Atlas (2006) database with high-resolution population data and yielded lower estimates of marine debris releases. The earlier study ranked Indonesia as the second-largest contributor to marine plastic debris, while the latter as the ninth worldwide. The National Plastic Action Partnership (NPAP) applied the waste mass flow analysis using secondary data from 514 regencies and cities to capture regional diversity across Indonesia and provided estimates of marine debris releases are within uncertainty ranges of the previously mentioned studies (NPAP, 2020). An assessment by the World Bank focused on 15 hotspot cities for releasing plastic debris into Indonesian seas in

western and central Indonesia by combining modeling and field checks to gain a local understanding of waste management, societal behaviors, and plastic debris in the environments (World Bank, 2018). It is worth highlighting the role of physical barriers in waterways in reducing plastic debris releases. By considering artificial barriers such as dams, Lebreton *et al.* (2017) showed significantly lower global and country-specific values. The model assumption is in line with Cordova and Nurhati (2019) that showed significantly lower values using *In situ* river monitoring data in Jakarta Bay that may be attributed to the presence of net booms and river clean-ups.

Recognizing their strengths and uncertainties (Table 1), the models show an ensemble mean value of  $0.52 \pm 0.36$  Mt/year as a baseline for marine plastic debris releases in Indonesia prior to 2020, therefore setting a targeted reduced number of 0.16 Mt of marine debris releases in 2025. While other studies estimated global marine debris releases (e.g., EUNOMIA, 2016; Schmidt *et al.*, 2017; UNEP, 2018), herein, we included only those with corresponding reported values from Indonesia.

Based on field sampling in 18 beaches over the period 2018-2019, the Indonesian Institute of Sciences or LIPI reported an average monthly plastic debris accumulation (Cordova *et al.*, 2019) of  $113.6 \pm 84$  g/m<sup>2</sup> or 0.40 Mt/year, assuming that plastic debris is most pervasive within 3 meters from Indonesia's 99,093 km-long coastlines (BIG and Indonesian Navy, 2018). It is important to distinct that while river monitoring data informs land-to-sea plastic debris releases, stranded beach debris represents a fraction of plastic debris that is not present in the water column and bottom sediments. The stranded beach debris data also showed that 47.6  $\pm$  11.8% of the collected debris were buoyant plastic materials.

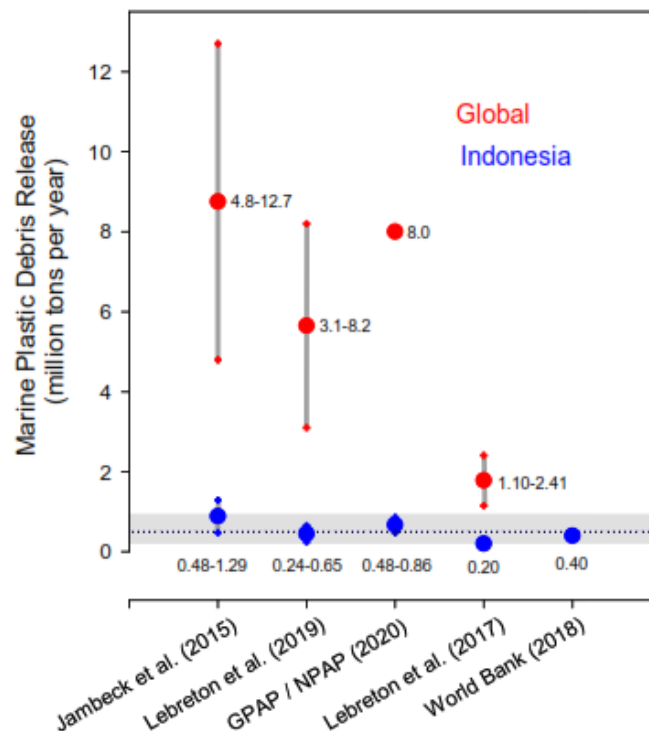


Figure 1. Model-based estimates of marine plastic debris releases into the oceans at globally (red) and in Indonesia (blue) based on Jambeck *et al.* (2015), Lebreton and Andradry (2019), GPAP, 2017, NPAP, 2020, Lebreton *et al.* (2017), and World Bank (2018). The dashed line denotes an ensemble mean value of  $0.52 \pm 0.36$  Mt/year in Indonesia

Table 1. Reference period, spatial resolution and methodology of available references providing baseline marine debris releases in Indonesia prior to 2020

Study	Reference Period	Spatial Resolution within Indonesia	Framework
Jambeck <i>et al.</i> (2015)	2010	Country-level	Model using coastal population, waste generated per capita, the fraction of plastic waste, and the fraction of mismanaged waste
Lebreton and Andradry (2019)	2017	Country-level	Model similar to the framework of Jambeck <i>et al.</i> (2015) with high-resolution (30×30 arc seconds) population combined with GDP distributions
GPAP (2017) / NPAP (2020)	2017	Regency and city level (N=514, representing mega, medium rural and remote archetypes based on the capability to transport and recycle plastic waste).	System model of waste mass flow analysis based on measurements in the waste system, reported by local governments
Lebreton <i>et al.</i> (2017)	unspecified	Country-level value for Indonesia was reported based on plastic load inputs from 40,760 watersheds.	Model similar to the framework of Jambeck <i>et al.</i> (2015) with monthly catchment runoff and the presence of artificial barriers
World Bank (2018)	2016	City-level (N=15, representing three tiers based on performance and commitment to solid waste management in western and central Indonesia).	Model using data on waste generated, waste composition, waste management systems, field analysis of waste disposal and capture, and in situ waste sampling in waterways and coastal areas.
LIPI (Cordova <i>et al.</i> , 2019)	2018-2019	Beach sites (N=18 spread across Indonesia with Aceh as the westernmost and Biak as the easternmost sites)	In situ measurement of stranded beach debris using a line transect alongside low tide line

### 3. Monitoring Strategy of Marine Plastic Debris Releases (2021-2025)

Monitoring plastic debris leakages into the marine environment in the coming years shall meet the criteria of comparability with baseline estimate, representative spatial coverage, and ease of methods of existing frameworks. Monitoring methods should leverage both nationwide municipality-level model estimates and *In situ* monitoring in the environments (e.g., rivers, coastal areas).

The nationwide system model developed by NPAP enables to monitor the reduction of plastic debris by sectors and municipalities following the system change scenario using secondary data from local governments. The World Bank 2018 report referred river waterways as 'non tidal zones' and coastal areas as 'tidal zones' reminds different roles of *In situ* monitoring data that could serve as ground truth for land-derived plastic waste releases and accumulation in coastal and marine environments. In other words, *In situ* river and coastal monitoring data are not complimentary, but both are necessary considering the information that they provide concerning model outputs. The ease of visual counting of macroplastic debris in the field makes it possible to scale up the monitoring data through a citizen science programs.

### 4. Where and When to Monitor

Future *In situ* river and coastal monitoring would benefit from comparison with previous monitoring efforts; however, this does not limit new monitoring sites to provide more representative spatial coverage (Figure 2). There were western and central sites surveyed by both the World Bank and LIPI report: Medan, Batam- Bintan,

Padang, Jakarta-Seribu Islands, Semarang, Pontianak, Bali, Lombok, Makassar, Manado and Bitung. We highlight the importance of including site based on population density as well as in small islands that are concentrated more in eastern Indonesia.

*In situ* monitoring also would benefit from having a time continuity considering monsoonal variations of marine debris release and accumulation in Indonesia area (e.g., Cordova and Nurhati, 2019; Kurniawan and Imron, 2019).

### 5. Monitoring Methods

Currently, several protocols for *In situ* monitoring involve characterization of the collected debris (plastic, metal, glass, timber, etc.), plastic categories (plastic bottles, styrofoam, etc.), and estimation of plastics by abundance and weight such as the UNEP (Cheshire *et al.*, 2009), OSPAR protocol (2010), NOAA (Lippiatt *et al.*, 2013), and GESAMP (2019) protocols. These approaches may differ slightly in debris categories. An introduction of a new category that represents personal protective equipment may be useful with regard to the prolonged COVID-19 pandemic.

Besides manual collection techniques, the use of an unmanned aerial system (UAS) offers the collection of high-resolution, time-effective, cost efficient monitoring of over larger sections of natural and built environments compared to manual surveys (Manfreda *et al.*, 2018; Tmušić *et al.*, 2020). Recent works showed the application of UAS on mapping the debris of less than 2.5 cm using aerial images maps produced by drones (Bao *et al.*, 2018; GESAMP, 2019; Andriolo *et al.*, 2020). Furthermore, the UAS could identify hotspots and pathways of marine debris (Andriolo *et al.*, 2020; Gonçalves *et al.*, 2020; Tmušić *et al.*, 2020).

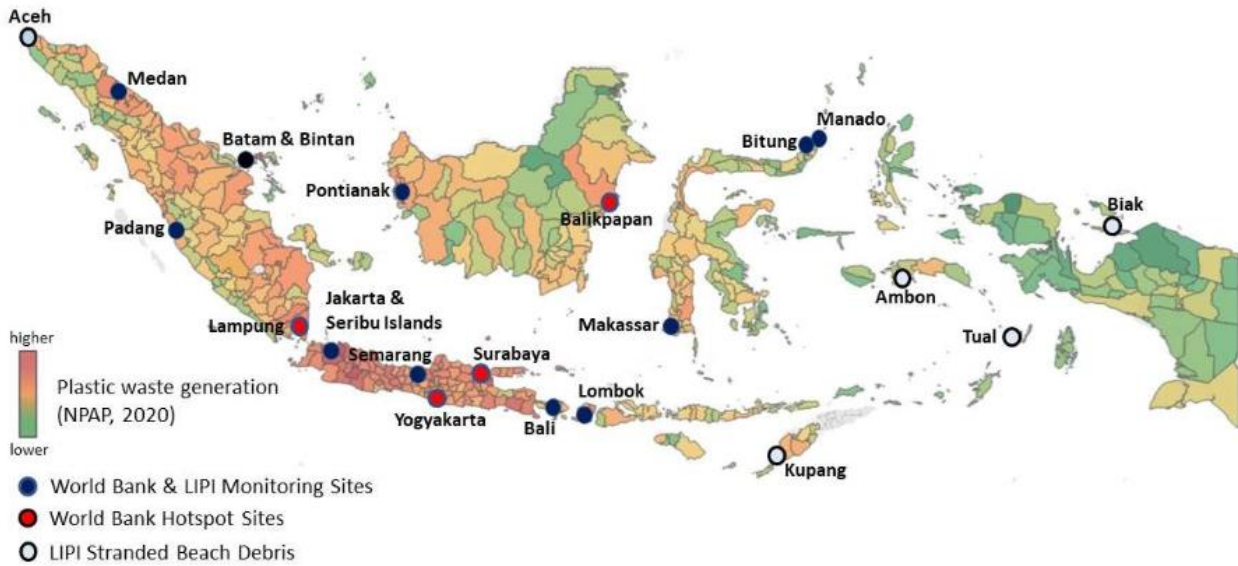


Figure 2. Sites covered in the NPAP (2020), World Bank (2018), and LIPI (Cordova *et al.*, 2019) reports. The shaded colors show the level of plastic generation in regencies and cities defined in the NPAP report. Among sites surveyed by the World Bank (red circle) and LIPI (light blue circle) reports, there were sites surveyed by both studied (black circle).

### 5.1 River Debris *In situ* Monitoring

Plastic debris monitoring has used networks of stationary stations such as bridges (e.g., Cordova and Nurhati, 2019; van Emmerik *et al.*, 2019), floating booms (Gasperi *et al.*, 2014) and possibly vessels, as well as active tracking methods (e.g., Ivar do Sul *et al.*, 2014). For instance, Gasperi *et al.* (2014) used a network of 26 existing floating booms to collect river debris. The tracking methods may actively monitor debris moving through the river system using the global positioning system (GPS) and the release of plastic marked objects that can be recovered and identified. For example, Ivar do Sul *et al.* (2014) used painted plastic materials to study preferential flow routes, accumulation and removals of plastic debris in mangrove forests with changes in hydrometeorological conditions.

### 5.2 Monitoring Stranded Beach Debris

For stranded beach debris monitoring, the surveyed beaches should be consistent in length (i.e., no less than 100 m), setting (i.e., sandy or pebble for Indonesia), and not regularly cleaned. If the beach has been cleaned, it is advised to survey after two months or depending on the sampling frequency to allow debris accumulation. The pervasiveness and composition of plastic debris can be determined using at least triplicates of large quadrats of a certain size. A team of trained observers could classify, count and weight debris the collected debris from the quadrants.

Besides the typical debris classification by types, studies have also classified debris by countries of origin and pre-disposal categories for stranded beach debris. Lee *et al.* (2012) classified debris by the country of origin from information on the manufacturing country and printed language to identify foreign debris. Debris can also be classified by pre-disposal categories, including end-user products, packaging material, fishery products, and

industrial materials other than fisheries. End-user products are consumer goods thrown away after use. Packaging materials are products for containment, safety, handling, and distribution of goods from manufacturers to customers (e.g., food wrappers, PET bottles). Because beaches accumulate large amounts of fishing-related debris, the categories can be isolated from other industrial items to identify attributing industries (Jang *et al.*, 2014).

## 6. Outlook and Conclusion

Using available data, this study calculates the baseline levels of marine debris in Indonesia prior to 2020 and gives recommendations for monitoring marine debris reduction between 2021 and 2025. The wide variability in model estimates of plastic garbage dumped into the seas highlights the critical role of data source, model spatial resolution, and *in situ* data in generating realistic baseline values. Recognizing the strengths and limitations of known contributions, model outputs converge on a baseline value of  $0.52 \pm 0.36$  million tons (Mt) per year in Indonesia prior to 2020, setting a target of 0.16 Mt of marine debris discharges in 2025. While river monitoring data provides insight into land-based plastic debris emissions, stranded beach debris represents a fraction of waste that does not penetrate the water column or bottom sediments. Monitoring activities targeted at minimizing marine debris should make use of both national municipality-level model estimates and *in-situ* river and coastal locations, preferably but not primarily those identified in prior monitoring studies. At the very least, the latter should be conducted seasonally, given the evidence of monsoonal changes in marine debris release and accumulation in Indonesia. Due to Indonesia's breadth and diversity of regions, collaboration among stakeholders is necessary to assess environmental development.

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## Declarations

### Author contribution

All authors contributed equally as the main contributor of this paper. All authors read and approved the final paper.

I.S. Nurhati: Writing - Original Draft, Writing - Review & Editing, Conceptualization, Formal analysis, Investigation, Visualization, Supervision. M.R. Cordova: Writing - Original Draft, Writing - Review & Editing, Conceptualization, Investigation, Validation, Data Curation.

### Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

### Conflict of interest

The authors declare no known conflict of financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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