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RESEARCH ARTICLE

Marine Macro-Debris Pollution on the Coast of Negeri Haruku Village

Pencemaran Sampah Laut Makro di Pantai Desa Negeri Haruku

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Abstract. Marine debris is an environmental issue of both national and global concern, particularly marine macro-debris. This study was conducted to determine the level of marine macro-debris pollution along the coast of Negeri Haruku village. Data were collected at three sites considered representative of the Negeri Haruku coastline. A 100-m shoreline transect was used for data collection and divided into 20 segments, from which five segments were randomly selected for sampling. The Clean Coast Index (CCI) was calculated to assess beach cleanliness, while the Plastic Abundance Index (PAI) was used to measure the proportion of plastic debris relative to the total amount of beach debris. The results showed that plastic debris dominated other debris types at all observation sites. This was reflected in the PAI values, namely 4.82 at the site near the river mouth, indicating high plastic density; 1.51 at Hii Beach, indicating moderate plastic density; and 6.09 at Totu Beach, indicating high plastic density. Totu Beach had the highest CCI value of 22.2, indicating a very dirty condition, while the site near the river mouth had a CCI value of 12.6, indicating a dirty condition. In contrast, Hii Beach was classified as clean, with a CCI value of 3.82. A paradoxical pattern was also observed in this study: even at a site with no apparent human activity, debris density was higher (5.55 ± 0.77 items/m²) than at the other two sites. This suggests that the debris may have originated from other locations and been transported by ocean currents. Based on the Clean Coast Index, only Hii Beach was classified as clean, whereas the site near the river mouth and Totu Beach were classified as dirty.
Keywords: Negeri Haruku, marine debris, pollution, beach.

Abstrak. *Sampah laut merupakan salah satu isu lingkungan yang tidak hanya dirasakan secara nasional tetapi juga secara global, khususnya sampah laut makro. Penelitian tentang sampah laut makro dilakukan untuk menentukan tingkat pencemaran sampah laut di pesisir pantai desa Negeri Haruku. Pengambilan data dilakukan pada tiga lokasi yang dianggap dapat mewakili pantai desa Negeri Haruku. Panjang garis pantai yang digunakan untuk pengambilan data adalah 100 meter, yang kemudian dibagi dalam 20 segmen. 5 segmen akan diambil secara acak untuk pengambilan data. Indeks Kebersihan Pantai (Clean Coast Index atau CCI) dihitung untuk mengetahui tingkat kebersihan pantai sedangkan Indeks kelimpahan plastik (Plastic Abundance Index/PAI) untuk mengukur jumlah plastik terhadap jumlah total sampah di pantai. Hasil penelitian menunjukkan bahwa, sampah jenis plastik mendominasi jenis lainnya di setiap lokasi pengamatan. Hal ini dapat dilihat dari hasil perhitungan indeks PAI, untuk lokasi dekat muara Sungai 4,82 (kategori kepadatan tinggi), Pantai Hii 1,51 (kategori kepadatan sedang) dan Pantai Totu 6,09 (kepadatan tinggi). Pantai Totu memiliki nilai CCI yang tinggi (22,2) yang artinya sangat kotor, pantai dekat muara 12,6 yang artinya kotor dan kategori bersih hanya pada pantai Hii (3,82). Salah satu fenomena yang paradoksal didapati juga dalam penelitian ini, yaitu lokasi yang tidak ada aktivitas penduduk sekalipun, didapati kepadatan sampah lebih tinggi (5,55±0,77 item/m²) dibandingkan kedua lokasi lainnya. Dengan demikian diperkirakan sampah tersebut juga merupakan kiriman dari lokasi lain yang dibawa oleh arus. Berdasarkan indeks kebersihan pantai, hanya lokasi Hii yang termasuk kategori bersih sedangankan lokasi dekat muara dan pantai Totu tergolong kotor.*
Kata Kunci: Negeri Haruku, sampah laut, pencemaran, pantai.

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INTRODUCTION

Marine debris pollution has become a global environmental problem. Previous research has shown that macro-debris and mesoplastic debris (>5 mm) account for approximately 86% of the 250,000 metric tons of plastic potentially floating in the ocean (Schernewski et al., 2023). Marine debris refers to all persistent solid materials that are manufactured or processed and subsequently discarded, disposed of, or abandoned in marine and coastal environments, including materials such as glass, metal, paper, and plastic (UNEP & NOAA, 2012). Marine debris consists of items produced or used by humans and then intentionally discarded into waters, rivers, or beaches; items accidentally lost, including those lost at sea during severe weather events, such as fishing gear and cargo; and items deliberately disposed of on beaches and coastal areas (UNEP, 2009).

Previous studies have shown that current circulation, tidal dynamics, and shipping activities can transport marine debris (Díaz-Torres et al., 2017; Galgani et al., 2010; Hinojosa & Thiel, 2009). Plastic debris is a type of floating marine debris that can be easily transported across marine environments (Depledge et al., 2013; Law, 2017). The impacts of marine debris include its entry into the food chain and potential threats to human health, disturbance to marine fauna, accumulation and dispersal of toxic substances, environmental degradation, and pollution (KLHK, 2017).

Plastic debris in the marine environment can degrade into microplastics, which may be readily ingested by marine biota. A previous study in Ambon Bay waters showed that microplastics had been detected in farmed fish (Tuhumury & Sahetapy, 2022). Marine debris may originate from both land-based and sea-based activities. Debris in coastal areas is largely associated with human activities and has implications for ocean health. Current fluctuations also have a significant effect on the distribution of marine debris in coastal areas (Rahim et al., 2020). Rivers also function as one of the sources of marine macro-debris, which is subsequently transported by currents, waves, and tides (Noya & Tuahatu, 2021).

This study was conducted in Negeri Haruku, an area well known for its local wisdom. Negeri Haruku is particularly recognized for *sasi lompa* in the Learisakayeli River as a form of local wisdom. *Sasi lompa* is a customary law that prohibits the harvesting of lompa fish (*Thryssa baelama*) for a certain period in order to maintain the sustainability of its population. Lompa fish (*Thryssa baelama*) spawn in rivers and subsequently grow in the marine environment. The accumulation of debris on beaches may affect seawater quality. Indirectly, fish inhabiting the surrounding waters may also be affected by such environmental conditions. In addition, Haruku is frequently visited by many people who come to witness the opening ceremony of *sasi lompa*. Therefore, this study is expected to provide input for the Government of Negeri Haruku in managing beach debris.

Accordingly, it is important to determine the level of marine macro-debris pollution along the coast and in areas surrounding the river. Moreover, coastal debris may originate from other locations and be transported by tidal currents. Debris pollution in a given area may originate locally, either through direct disposal onto beaches or into coastal waters, or it may be transported from more distant areas by ocean currents, wind, rivers, and surface runoff (Veiga et al., 2016). To date, no study has been conducted on marine macro-debris pollution in Negeri Haruku, particularly regarding the Clean Coast Index, debris types, and debris density on its beaches. Thus, this study provides baseline data for marine debris management in Negeri Haruku. Through this study, the types and density of marine debris on the coast of Negeri Haruku can be identified, along with the level of beach cleanliness. Therefore, this study aimed to assess marine macro-debris pollution along the coast of Negeri Haruku, including debris types, debris density, and beach cleanliness levels.

MATERIAL AND METHODS

This study was conducted in Negeri Haruku Village, which is part of Haruku Island and is located east of Ambon Island. Geographically, it is located at 128°25′09.3″ E and 3°35′55.6″ S and is categorized as a small island, where all impacts of land-based

activities can easily reach the coastal area. Sampling was conducted at three stations considered representative of the beach area in Haruku Village (Figure 1). Data collection was carried out in May 2023.

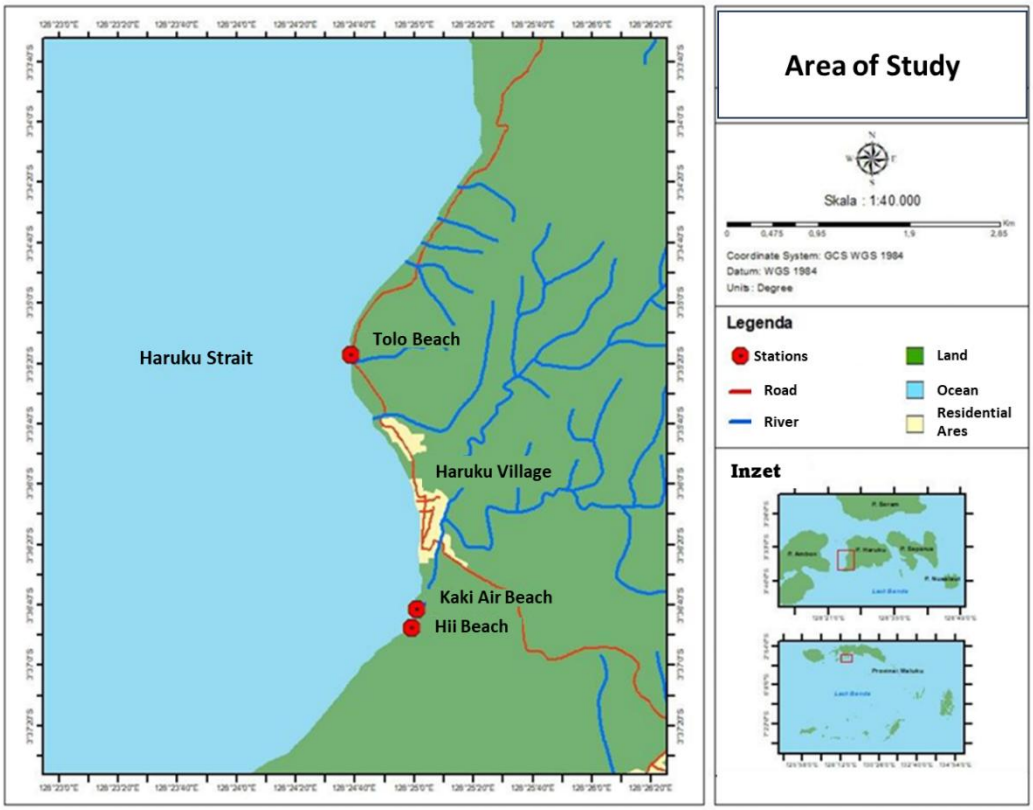


Figure 1. Map of the Study Location

Data collection was carried out in May 2022 along the coast of Haruku Village. Marine macro-debris was collected at low tide from three locations (Table 1). For data collection, a 100-m shoreline transect was established and divided into 20 segments, each measuring 5 m in length. The width of each segment followed the topography of each site. Subsequently, four segments were randomly selected using a random number table to count the debris within each segment (Lippiatt et al., 2013).

The debris recorded in this study was macro-debris, defined as debris measuring >2.5 cm to 1 m (Lippiatt et al., 2013). Transect width varied among locations according to beach topography. The position of each sampling location was determined using a Global Positioning System (GPS). Marine macro-debris found within each segment was collected and then identified based on the marine debris identification guide by Tangaroa Blue (2016).

Table 1. Sampling locations

Station	Location Name	Longitude	Latitude	Substrate
S1	Hii Beach	128°25′02″ E	3°36′41″ S	Sand
S2	Beach near the river mouth	128°25′03″ E	3°36′36″ S	Sand
S3	Totu Beach	128°24′42″ E	3°35′03″ S	Rocky sand

Data were analyzed using the following formula to determine debris density (Terzi & Seyhan, 2017):

$$D = \frac{n}{w \times l} \quad \text{..... (1)}$$

where D is marine debris density, n is the total number of marine debris items, w is transect width, and l is transect length in meters.

The Clean Coast Index (CCI) was calculated based on the quantity of marine debris following Alkalay et al. (2007). The CCI was used to determine the level of beach cleanliness:

$$CCI = \frac{\text{Total litter items}}{\text{Length (m)} \times \text{Width (m)}} \times K \quad \text{..... (2)}$$

The CCI scale ranges from 0 to >20, with the following categories: very dirty (>20), dirty (10.1–20), moderately clean (5.1–10), clean (2.1–5), and very clean (0–2).

Potential debris sources, including land-based and sea-based sources, were also identified following Ribic et al. (2012). Based on the collected data, the proportion of plastic debris relative to total debris was calculated using the Plastic Abundance Index (PAI) (Rangel et al., 2020a; Rangel et al., 2020b):

$$PAI = \frac{\sum \text{plastic litter items}}{\log_{10} \sum \text{total litter items}} \quad \text{..... (3)}$$

According to the PAI, beaches were classified into five categories: 0 indicates very low abundance, 0.1–1 indicates low abundance, 1.1–4 indicates moderate abundance, 4.1–8 indicates high abundance, and >8 indicates very high abundance.

RESULTS AND DISCUSSION

Percentage of Marine Macro-Debris

Based on the data, seven types of marine macro-debris were found at the study sites, namely plastic, glass, paper, rubber, cloth, metal, and others. Plastic had a higher percentage of occurrence than the other debris types. This pattern was observed at all three sampling locations (Figure 2). Plastic is the most commonly found type of marine debris in freshwater and marine environments due to its widespread use and persistence.

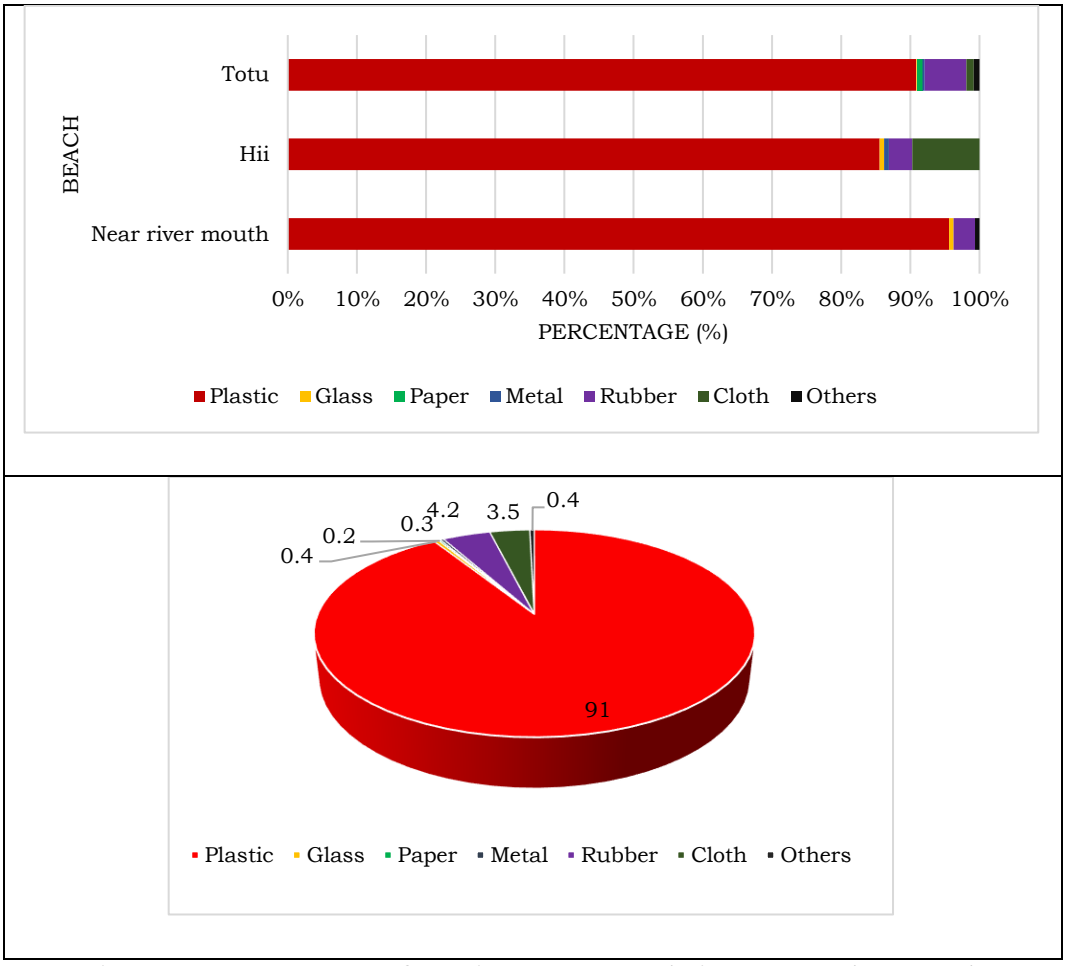


Figure 2. Percentage of Marine Macro-Debris on Haruku Beach (upper graph: by location; lower graph: based on total values).

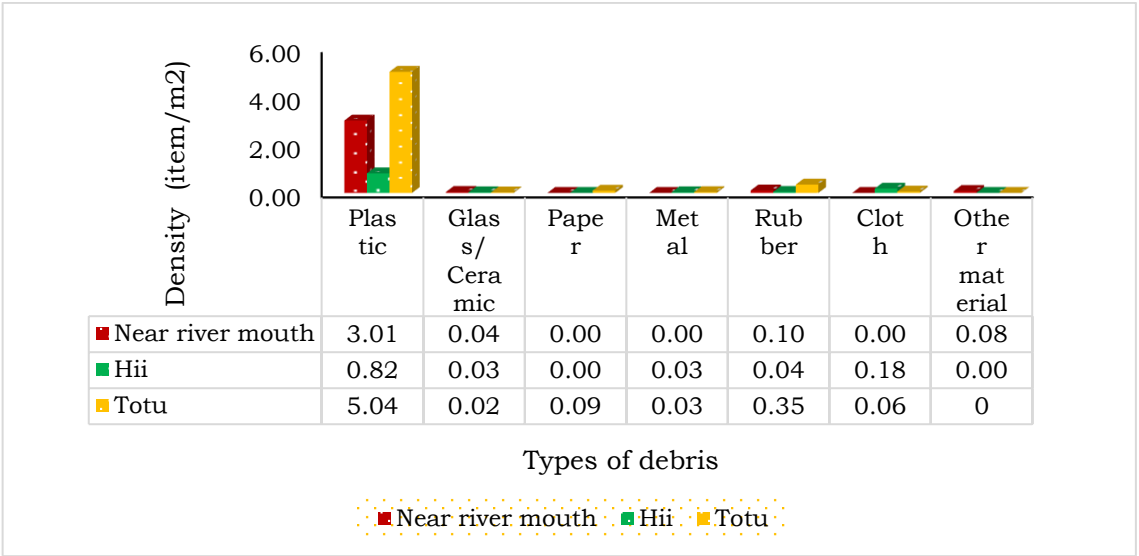
Plastic is widely used as packaging for consumer products, which has resulted in its frequent occurrence as waste. Approximately 250,000 tons of plastic are estimated to be floating in the marine environment, largely due to the role of prevailing winds and surface currents in dispersing plastic debris across the world's oceans (Eriksen et al., 2014). Between 1950 and 2019, annual plastic production increased exponentially from 1.7 million tons (Mt) to 368 Mt (Horton, 2023). The demand for plastic continues to increase because it is inexpensive and durable, leading to the growing accumulation of plastic waste in the environment (Horton, 2023).

Compared with other types of debris, plastic was more frequently found because most consumer goods, fast food packaging, cosmetic product packaging, pharmaceutical packaging, and even electronic products use plastic materials. This is mainly due to their low cost and durability. Plastic does not only dominate debris types in urban areas, but also in rural areas. This was confirmed in the present study, where plastic was the dominant debris type at all three study sites. Even on remote islands, marine debris can be transported along coastlines because of its buoyant properties, which make it more easily carried over long distances by wind, ocean currents, and tides (Lavers & Bond, 2017).

Density of Marine Macro-Debris

The results showed that seven types of marine macro-debris were found across the three study sites, namely plastic, glass/ceramic, paper, metal, rubber, cloth, and others. Overall, the highest density of marine debris was recorded at Totu Beach, with a value of 5.55 ± 0.77 items/m². Totu Beach is an area with no direct community activities on the beach because it is located relatively far from residential settlements. However, several vegetable gardens owned by residents of Negeri Haruku were found in the upper part of the area. This finding represents a paradoxical phenomenon, as a beach with no direct human activity showed a high density of marine debris. It is presumed that the marine debris found on Totu Beach originated from debris transported by tidal currents or from floating marine debris carried from other locations.

Plastic was the type of marine macro-debris with the highest density compared with other debris types (Figure 3), with values of 3.01 ± 1.58 items/m² near the river mouth, 0.82 ± 0.44 items/m² at Hii Beach, and 5.04 ± 0.67 items/m² at Totu Beach. In addition to plastic, paper also showed a relatively high density at Totu Beach. The paper debris found at this site consisted mainly of beverage cartons, such as boxed tea and ultra-high-temperature milk packaging. These packaged drinks are commonly consumed by both children and adults. Plastic was found in higher quantities than other types of marine macro-debris. Similar findings were also reported in studies on marine macro-debris in Ambon Bay (Tuhumury & Kaliky, 2019; Tuahatu et al., 2020; Tuahatu & Tuhumury, 2022).



	Plastic	Glass/ Ceramic	Paper	Metal	Rubber	Cloth	Other material
Near river mouth	3.01	0.04	0.00	0.00	0.10	0.00	0.08
Hii	0.82	0.03	0.00	0.03	0.04	0.18	0.00
Totu	5.04	0.02	0.09	0.03	0.35	0.06	0

Figure 3. Density of Marine Macro-Debris

In almost all locations, plastic has become the dominant type of marine debris, even in areas far from various human activities (Rahmayanti et al., 2020; Hendrawan et al., 2023; Rahim et al., 2020; Smith & Bernal, 2021; Vlachogianni et al., 2018). Plastic is widely used as packaging material and as a substitute for household utensils made of metal. Therefore, plastic is frequently found as marine debris.

Totu Beach is located far from community activities; however, plastic debris was present at a high density (5.04 ± 0.67 items/m²). Nevertheless, this value was much lower than those reported in studies conducted in Ambon Bay waters. This difference may be attributed to the fact that Ambon City functions as the provincial administrative center, with a high intensity of anthropogenic activities, whereas Negeri Haruku is an area with a smaller administrative scale and relatively lower activity density. The high density of marine debris at this site was presumed to be transported from other locations by tidal currents (Figure 3). Plastic has low density and can float; therefore, it can be transported globally by wind and currents, allowing it to disperse over very long distances from its source area (Nelms et al., 2017).

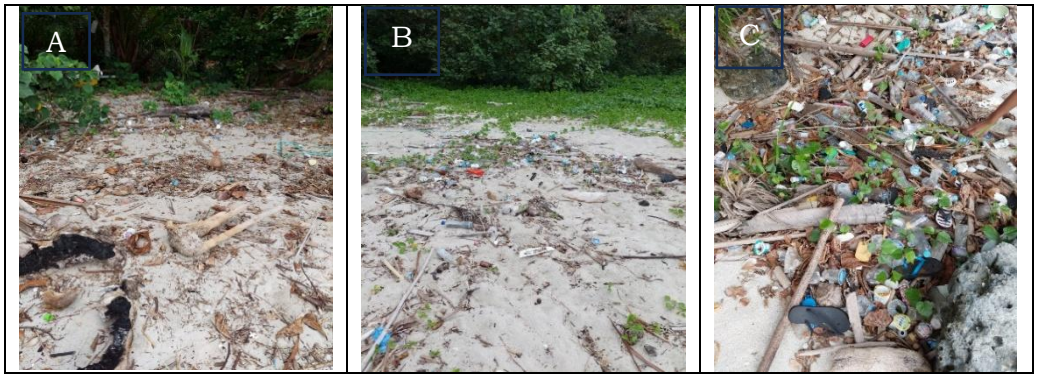


Figure 4. Marine Debris Near River Mouth (A), Hii Beach (B), and Totu Beach (C)

The amount of plastic in the environment is expected to increase along with the continued growth in plastic production and use. Plastic production has increased annually; however, waste management systems have not been able to keep pace with the rapid development and production of plastic materials (Horton, 2023). Previous studies have also shown that plastic debris had the highest density compared with other debris types at several river mouths flowing into Ambon Bay waters (Tuahatu et al., 2022). This indicates a high level of plastic use. As a result of this high level of plastic consumption, plastic waste is expected to continue increasing in the environment. The growing problem of plastic waste is rooted in the significant price disparity between plastic and metal, whereby the affordability of plastic has made it the preferred material in modern consumption patterns. In general, plastic is a strong material and is not easily degraded naturally; consequently, it decomposes very slowly in the marine environment (Allsopp et al., 2012).

Plastic and other non-degradable marine debris have various adverse impacts on the environment, the economy, and society (UNEP, 2016). Previous studies have shown that one of the main causes of stress and unnatural mortality in sea turtles is the ingestion of plastic debris (Sigler, 2014). The degradation of plastic debris in coastal areas is influenced by sunlight exposure (Horton, 2023), through which plastics can fragment into microplastics and nanoplastics and become mixed with sediments. At these sizes, plastic particles can be readily ingested by organisms.

The beach cleanliness categories based on the Clean Coast Index (CCI) values showed that the site near the river and Totu Beach were classified as dirty and very dirty, respectively (Figure 4). In contrast, Hii Beach was classified as clean (Table 2). Beaches categorized as dirty or very dirty may have ecological impacts on coastal organisms. Macro-debris, such as large plastic sheets covering the sediment, can create a physical barrier to oxygen exchange in the sediment, leading to anoxic sediment conditions. If this occurs, benthic organisms may experience mortality. Nevertheless, one of the *kewang* in Negeri Haruku has previously received the Kalpataru Award for environmental

protection. In addition, Negeri Haruku is also known for one of its local wisdom practices, namely sasi lompa. Many people from around Ambon City visit Negeri Haruku to witness the opening ceremony of *sasi lompa*. These conditions provide strong reasons to maintain the cleanliness of the Negeri Haruku coastline, as it represents a potential opportunity for ecotourism development.

Table 2. Classification of Beach Cleanliness Based on the CCI and PAI Indices

Location	CCI	CCI Classification	PAI	PAI Classification
Beach near the river mouth	12.60	Dirty	4.82	High density
Hii Beach	3.82	Clean	1.51	Moderate density
Totu Beach	22.22	Very dirty	6.09	High density

Based on the calculated Plastic Abundance Index (PAI), which measures the number of plastic items relative to the total amount of debris on the beach, Totu Beach showed a higher PAI value than the other two locations. This indicates that plastic debris dominated other debris types at this site. A high PAI value may represent an ecological time bomb. Macro-sized plastic debris dominating the beach can undergo degradation due to exposure to ultraviolet radiation and wave abrasion, eventually fragmenting into microplastics. Specifically at Totu Beach, this represents a contrasting condition, as no direct community activity was observed at the site, yet the abundance of plastic debris was relatively high. Totu Beach tends to be an open coastline, and this position allows it to receive water masses carrying debris from other locations.

In addition, although there is no direct community activity on Totu Beach, the site is geographically close to Negeri Rohomoni. In contrast, Hii Beach was classified as clean, as the beach is mainly used by fishers to repair their boats. Hii Beach is also relatively sheltered by the curvature of the coastline and nearby headlands. This condition may act as a natural barrier that prevents debris from reaching Hii Beach. The findings of this study suggest that waste management cannot be carried out only within the administrative area of a single local government, but must involve cross-village governance. Such an approach is needed to prevent transported debris from being carried from one location to another by ocean currents.

CONCLUSION

This study concludes that the coast of Negeri Haruku is experiencing significant anthropogenic pressure, as indicated by the dominance of plastic debris across all observation sites. This condition has serious ecological implications, with the dirty classification at Totu Beach and the river mouth area indicating a pollution load on the coastal ecosystem. The high accumulation of plastic debris may potentially trigger long-term microplastic fragmentation, which could contaminate the food chain in the local aquatic ecosystem.

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AUTHOR CONTRIBUTIONS STATEMENT

The authors declare that the contribution of each author to this manuscript was as follows: JWT served as the main and corresponding author and was responsible for designing the study, conceptualizing the research, collecting and analyzing the data, reviewing the data analysis, and revising the language of the manuscript. GDM, MCW and FRF served as co-authors and contributed to study design, research conceptualization, data collection, data analysis, and review of the data analysis.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest with any party regarding the publication of this article.

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