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Marine debris characteristics in various coastal typologies in the Gunungkidul coastal area of Yogyakarta—Indonesia

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Abstract

Marine debris is one of the environmental issues that can be brought on by rapid human development and activity, including marine tourism, like what happened in the coastal area of Gunungkidul, Indonesia. The issue of marine debris might decrease the environmental quality and impact tourism in Gunungkidul. This study aims to identify the characteristics of coastal typologies in Gunungkidul and analyze their influence on the characteristics of marine debris. Google Earth images and the Digital Elevation Model were used to interpret and classify the typology across the study area based on their physical characteristics. Marine debris samples, either macro or meso-sized, were collected using the transect method for each beach. Based on the imagery interpretation combined with elevation data from DEMNAS, there are three typologies in the Gunungkidul coastal area, i.e., pocket, non-pocket, and cliff beaches. Cliff typology was eliminated and only pocket and non-pocket beaches were used as marine debris sample collection locations. Hence, four beaches were chosen as study areas, i.e., Seruni, Drini, Sepanjang, and Sedahan; each represents each coastal typology. About 193 macro-sized and 217 meso-sized debris were found in our research area, totaling 1380.31 g. Compared to non-pocket beaches, pocket beaches contain more marine debris. The higher slopes of the pocket beach typology will trap marine debris and make it challenging to reenter the water. On pocket beaches, oceanographic processes concentrate marine debris in one location. Still, on non-pocket beaches, marine debris can disperse and return to the sea more readily due to the cycling of currents near the coast.

Keywords Coastal typology · Pocket beach · Marine debris · Coastal pollution · Gunungkidul

1 Introduction

The problem of marine debris has arisen since the 1970s, with plastic being the predominant form of marine debris. In addition, global plastic manufacturing experienced tremendous growth, about 190 times higher in 2015 compared with 1950, which was only about 1.7 million tons [61]. Marine debris refers to any solid material that comes from human activity on land or at sea and is purposefully or mistakenly discharged into the marine and coastal environment [39, 81, 83]. Marine debris can enter coastal areas through activities at sea and on land [5]. Marine debris is produced from various activities such as industry, tourism, domestic and other activities that result in environmental pollution [13, 39, 63, 84, 85]. Based on its size, marine debris can be grouped into micro marine debris with a size < 0.5 cm, meso marine debris with a size of 0.5–2.5 cm, and macro marine debris with a size > 2.5 cm [26, 81]. In

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addition, marine debris can also be divided based on its material, namely: plastic, glass, iron, cloth, paper, rubber, and wood [34].

Numerous elements, including coastal typology, geomorphology, hydro-oceanographic parameters, and human activities in a coastal area, have an impact on the quantity and spatial distribution of marine debris [31, 39, 63, 81]. The coastal typology factor is influenced by the type of beach material, the shape of the beach, and the vegetation [16]. The beach material, e.g., rocky/cobble beach tend to have less concentrations of microplastics at the beach surface than the layer below and show that the source is dominated by marine waters than beach sands [18]. Furthermore, marine debris in the sandy beach tend to more common compare with muddy beach [62]. From geomorphological perspective, geomorphological parameters play a crucial role in defining the distribution of marine debris and require further investigation due to their impact on the fate and rate of accumulation of marine debris on the seabed [16, 31]. For example, a beach slope with an inclination exceeding 35° may acts as a constraining factor for the accumulation of debris [42].

Currents, waves, and tides that occur close to the coast are examples of hydro-oceanographic parameters. Large amounts of marine debris can be carried by waves with great energy [2, 39]. High-energy waves arise and have the potential to produce severe storms, especially during the rainy season [38]. Furthermore, tourism, plantations, fisheries, and aquaculture are only a few examples of human activity elements that might increase the number of marine debris [41, 44, 79].

The existence of marine debris threatens the coastal ecosystem, such as entanglement of living things, bleeding in the organs of living things, disruption of the breeding process, the release of toxic pollutants, as well as the ecosystem and environmental degradation, [32, 77, 80], including in the marine protected areas in Indonesia [64]. In addition, the presence of marine debris also affects the decline in beach cleanliness and impacts decreasing coastal economic activity and the tourism industry [29]. For example, the municipalities in the Northeast Atlantic region are still grappling with the significant expenses related to the elimination of marine debris. United Kingdom towns expend around €18 million annually on the removal of marine debris, reflecting a 37% rise in expenses over the past decade. Furthermore, marine debris removal also incurs an annual cost of around €10.4 million for municipalities in the Netherlands and Belgium [53].

The southern coastal area of Yogyakarta province is one of the locations that have the potential to be affected by hazards from marine debris [39, 81], even though Yogyakarta has various beaches which are tourist destinations, including beaches in Gunungkidul Regency. Gunungkidul Regency has a shoreline of 72 km with a total of 21 beaches, so tourism is the most significant contribution to regional budget revenues. Gunungkidul Regency's tourism sector revenue comes from several elements, namely regional fees, entertainment taxes, and hotel and restaurant taxes. During the Christmas and New Year holiday periods in 2022, beach tourism in Gunungkidul Regency contributed to a total number of tourists of 177,890 people and a total income of IDR 1,262,375,700 or around 72,138 euros (Gunungkidul Regency Tourism [33]). Furthermore, during the Eid vacation from April 10 to 15, 2024, beach tourism in Gunungkidul Regency attracted a total of 176,631 tourists, generating a total income of IDR 2.08 billion or approximately 118,868 euros [68].

The south coast of Gunungkidul has unique characteristics and potential compared to other areas. The southern coast of Yogyakarta has prevailing oceanographic conditions influenced by season variations [11, 55, 58]. Variations of this season affect the conditions of currents, waves, and tides. The southern coast has three main seasons: the western wind season, the eastern wind season, and the transitional wind season [38]. The season system in the southern sea of Indonesia has the characteristics of the reversal of the wind direction, which causes a pattern of water movement with a different mass [58, 82]. Anomaly sea surface height variability shows upwelling and downwelling stronger in the southern sea than in the north. This is allegedly due to the influence of the geographical location of the two seas. The southern sea is an open sea with the power of the circulation of the Indian Ocean, while the North Sea is located in a closed sea [48, 65]. This will undoubtedly affect the oceanographic process on the southern coast, including in Gunungkidul. The potential is in the form of natural landscapes and potential natural wealth [20]. Massive development of regional potential can cause environmental problems, one of which is the problem of marine debris. Massive development, many settlements, and tourism activities can increase the amount of marine debris [39, 74, 85].

The emergence of problems in the form of marine debris can affect the quality of tourist objects. It can lead to a potential decrease in the number of tourists who come and the economic valuation given. Therefore, research is needed to determine the character of marine debris to become the basis for good planning and management in the Gunungkidul coastal area. This study aims to identify marine debris characteristics in various coastal typologies in the Gunungkidul coastal area of Yogyakarta, Indonesia. The results of inventories can be used as foundational information for coastal environmental management to preserve and even improve the quality of the coastal environment in Gunungkidul. Given that research on marine debris in Yogyakarta is constrained, the study of marine debris in Gunungkidul is required to support government actions and assess the adverse effects it may have.

2 Materials and methods

2.1 Study area

This research was conducted at Seruni, Drini, Sepanjang, and Sedahan beaches in Gunungkidul, Yogyakarta, Indonesia (Fig. 1). Gunungkidul Regency, located in the Special Region of Yogyakarta, has a dominant geomorphological condition composed of tectonic and karst processes [46]. The southern coast of Gunungkidul, encompassing Seruni, Drini, and Sedahan beaches, is classified as a geomorphological unit with sand derived from limestone [7, 72, 73, 76]. These processes also impact the formation and development of coastal typologies in Gunungkidul, which were shaped by the historical background of the karst Gunung Sewu area [75].

The selection of the sampling area was based on several criteria [26, 39], i.e., (1) accessibility throughout the year or during specific seasons, (2) sandy or gravel beach material; (3) no coastal hard structures; (4) low to moderate slope; (5) no clean-up activities during sampling; (6) no waste management facilities on site; (7) no sensitive habitats and no threatened species; and (8) have different characteristics. The beach's location is determined by its typology, morphological factors, oceanography, and human activity [36]. The four beaches are impacted by the beach's slope as well. Due to the oceanographic features, the beach always faces south, which is the orientation that puts it immediately in front of the Indian Ocean.

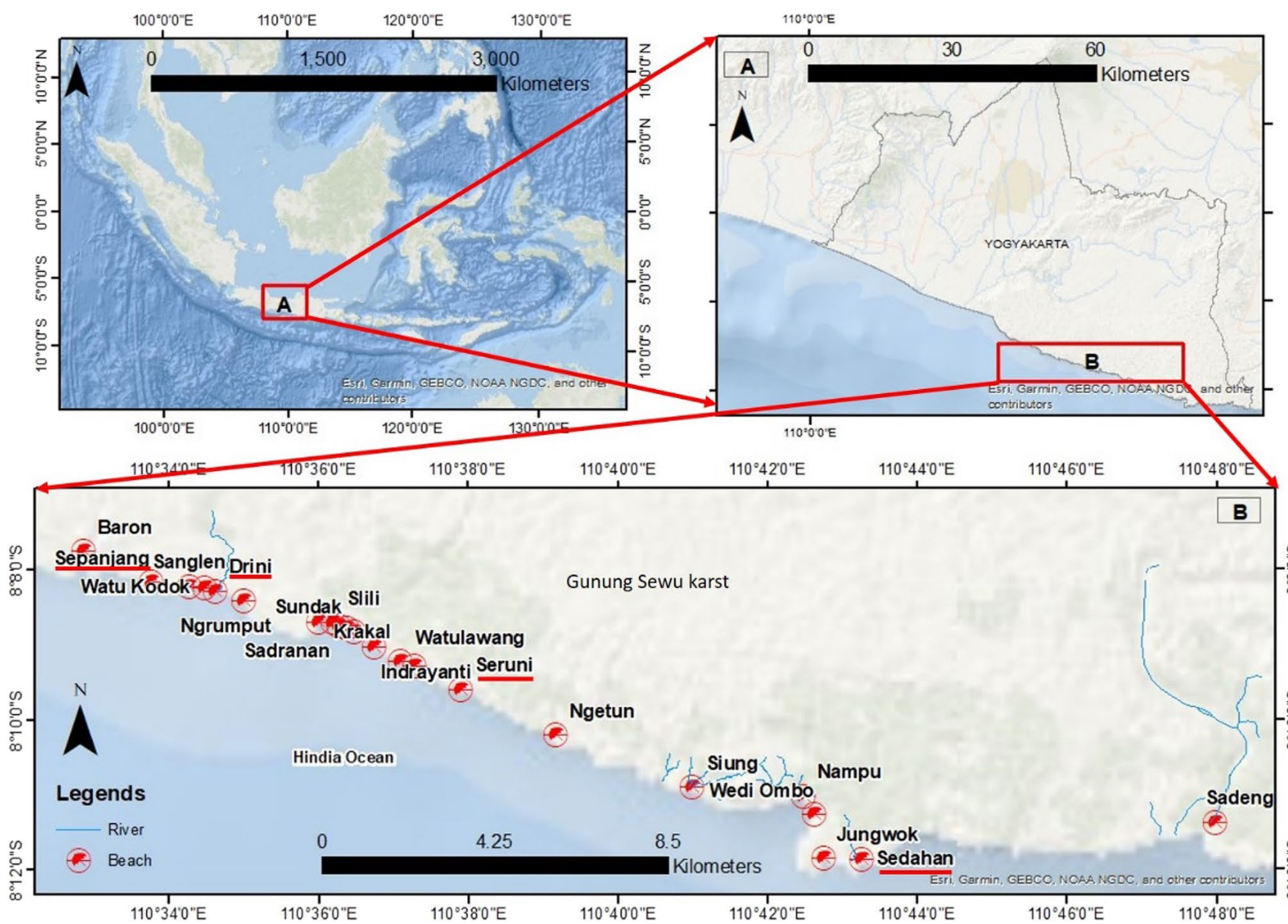


Fig. 1 The spatial distribution of beaches (**b**) in Gunungkidul Regency (**a**), e.g., Baron in the western part and Sadeng in the eastern part. From around 20 beaches, four beahces were selected based on the 8 specific criteria, i.e., Sepanjang, Drini, Seruni, and Sedahan

2.2 Coastal typology identification

The typology was obtained by defining the coastal physical characteristics using Google Earth images interpretation to classify the typology across the Gunungkidul coastal area. Interpretation uses image interpretation elements such as shape, texture, color, shadow, and orientation from the image features to know each physical feature [45, 54]. To make sure the border between each typology, the Indonesian Digital Elevation Model (DEMNAS), which is freely accessed at https://tanahair.indonesia.go.id/, provided by the Indonesian Geospatial Agency (BIG) since 2018 with a spatial resolution of 0.27 arcsecond and vertical resolution less than 2 m, was also used [10, 56]. The Indonesian digital elevation model is used to recognize the elevation border of each physical feature.

2.3 Marine debris data collection

Marine debris data were collected on March 10–11, 2023, which categorized as the transition season between the west and east monsoons. The debris collected through field measurements can reveal its characteristics. Geomorphological elements and the coastal typology categorization are taken into consideration when sampling marine debris. Four separate beaches were sampled for marine debris; two had pocket beach typologies, and the others did not, i.e., non-pocket beach. Meanwhile, it is further separated into tourist and non-tourist beaches based on their designation. On each beach, the sampling area was 100 m long and ran parallel to the water's edge. The sampling area comprised 20 m broad transects, each of which had a 5 m by 5 m sub-transect (Fig. 2a; [26, 36, 39]). Samples of marine debris were collected using a transect sampling technique from all sampling area on each sub-transect (Fig. 2b, c).

Using a shovel, the meso- and macro-size marine debris was lowered to a depth of 3 cm. Wire mesh measuring 0.5 cm × 0.5 cm (meso) and 2.5 cm × 2.5 cm (macro) was used to separate the size of the marine debris (Fig. 2d). The sampling area was divided between four distinct beaches, making the total sampling area 400 m long. In each beach, meso- and macro-sized samples samples were taken from a 1 m by 1 m sub-sub-transects. Each beach has 125 sub-sub transects; hence, the total is 1000 sampling areas in the form of sub-sub transects.

The characteristics of marine debris are examined after determining the marine debris mass, composition, and density. The amount of marine debris per square meter, or marine debris mass (M), is calculated by dividing the total amount by the sub-transect box size. It is expressed in grams per square meter (g/m^2). Equation 1 contains the formula for determining the mass of marine debris. The percentages (%) used to calculate the composition of marine debris. It is determined using Eq. 2 by dividing the abundance of marine debris per kind by the mass of marine debris as a whole. Types of marine debris include plastic foam (FP), plastic (PL), ceramics and glass (GC), fabric (CL), cardboard and paper (PC), metal (ME), wood (WD), rubber (RB), and another material (OT) [26, 39, 81]. The amount of marine debris per square meter or per area of the sub-transect box is known as marine debris density (K) (Eq. 3).

$$M = \frac{total\ marine\ debris\ weight\ (grams)}{length\ (m) \times width\ (m)} \tag{1}$$

$$Percentage\ (\%) = \frac{x}{\sum_{i=1}^{n} xi} \times 100 \tag{2}$$

$$K = \frac{The\ amount\ of\ marine\ debris\ per\ type\ (pcs)}{length\ (m) \times width\ (m)} \tag{3}$$

3 Results

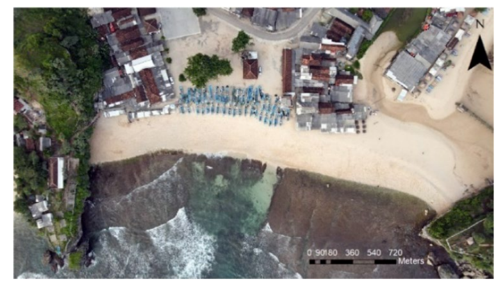
3.1 Coastal typology characteristics

Gunungkidul's coastal typology exhibits traits including pocket beaches, non-pocket beaches, and cliffs that divide the coasts. Pocket beaches, e.g., Sepanjang and Sedahan beaches, are in the shape of a bay with a physical barrier

Fig. 2 Illustration of the sampling area (**a**) comprised 20 m broad transects, each with a 5 m by 5 m sub-transect (**b**). All sampling stations in each sub-transect from which samples of marine debris were collected (**c**). Wire mesh was used to separate the size of the marine debris (**d**). Courtesy: Hibatullah [36]

in the form of a headland or hill, and have a pocket-like appearance [27]. Non-pocket beach, e.g., Drini and Seruni beaches, in contrast, has a straight beach aspect, while a cliff in Gunungkidul is a prominent geological formation consisting of a steep, nearly perpendicular rock face that ascends to great heights. According to its material, beaches with coarse-grained material such as rock or boulders, including several beaches in Gunungkidul, have the potential to accumulate much marine debris since the frictional forces produced when much debris is caught in rock cavities are significant [4, 21]. Table 1 shows the characteristics of each typology in the Gunungkidul coastal area; furthermore, Fig. 3 displays the spatial distribution of coastal typology in the Gunungkidul coastal area.

Table 1 Typological characteristics

Typology	Characteristics	Physical Features
Pocket beach	Primarily has a pocket- or bay-shaped shape and is surrounded by cliffs that can be identified using elevation data from DEMNAS	 Example of pocket beach in Sedahan beach (Courtesy: [36])
Non-pocket beach	It does not resemble a bay and has a predominant straight shoreline	 Example of non-pocket beach in Drini beach (Courtesy: [36])
Cliff	Coastal landforms that border the shore, very high or almost vertical (can be identified using elevation data from DEMNAS), and are close to the water	 Example of cliff that is the most common typology in Gunungkidul coastal area (Courtesy: Fatchurochman 2023)

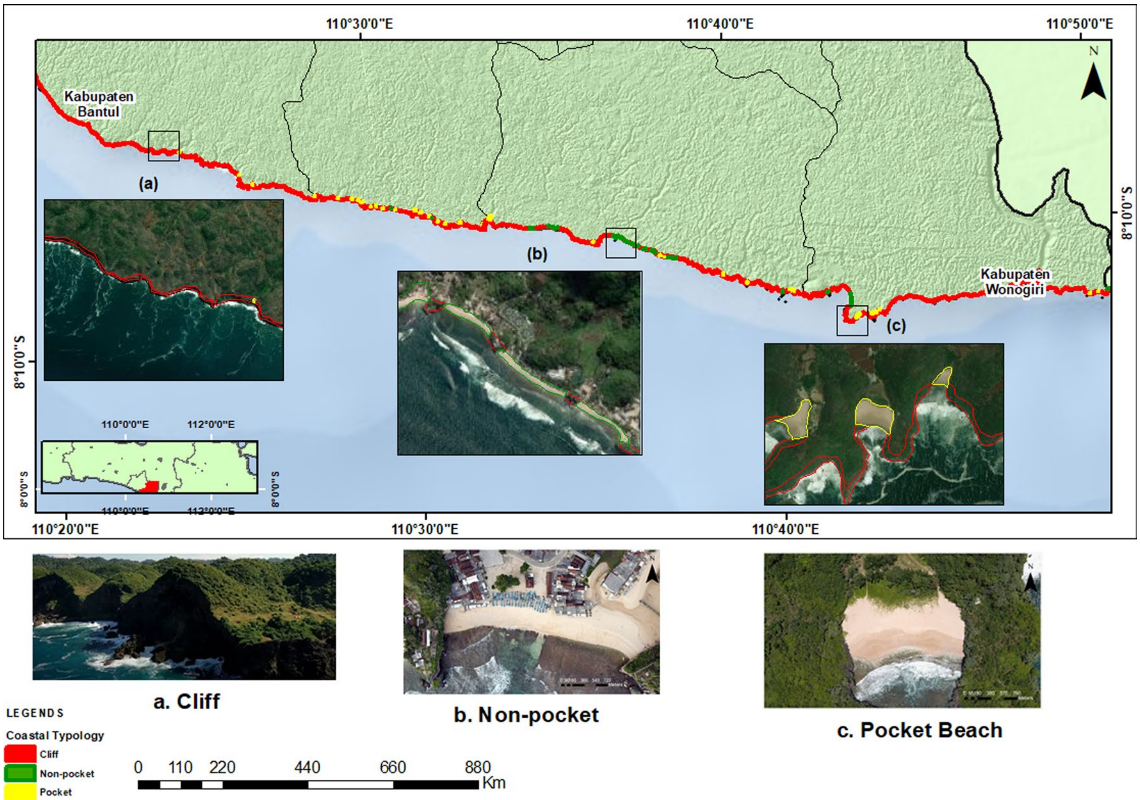


Fig. 3 Spatial distribution of coastal typology in the Gunungkidul coastal area which consist of (**a**) cliff, (**b**) non-pocket, e.g., in Drini beach, and (**c**) pocket beaches, e.g., in Sedahan beach. Along the Gunungkidul coastal area, cliff is more common than non-pocket or pocket beaches

3.2 Marine debris characteristics

Table 2 displays the beach tourist activities, specifically the attendance statistics of beachgoers, throughout the period of March 2 to March 9, 2023. According to the findings of beach manager interviews, there were three amount classes of tourists who arrived during a week: low (< 100 tourists), medium (100–300 tourists), and high (> 300 tourists) [36].

Tourism activities that have become an industry and are running intensively participate in increasing the abundance of marine debris [16, 17]. Drini and Sepanjang beaches have the most visitors compared with other beaches. Additionally, the number of visitors may influence the existing condition of marine debris. Tourism-related debris, such as plastic bottles, sandals, and broken glass, are dominated beaches with high tourism activity. Meanwhile, beaches with low tourism activity are dominated by little plastic, cork, and plastic foam marine debris [36, 39].

Table 3 displays the number of marine debris at Drini and Seruni beaches (non-pocket beaches). According to its size, Seruni beach is dominated by meso-sized marine debris with a total of 45 pieces. Meanwhile, the amount of macro-sized marine debris found at Seruni beach was 14 pieces. The most common marine debris type found was meso-sized plastic with 37 pieces. Then, at Drini beach, macro-sized marine debris makes up most of the marine debris, amounting to 66 pieces, and 41 pieces of meso-sized debris were also discovered. Plastic macro- and

Table 2 Classification of the beaches and the tourism activities on each beach

Beach	Typology	Tourism
Seruni	Non-pocket	Low touristic activity (92 visitors)
Drini	Non-pocket	High touristic activity (478 visitors)
Sepanjang	Pocket	High touristic activity (425 visitors)
Sedahan	Pocket	Low touristic activity (78 visitors)

Table 3 Marine debris characteristics at Drini and Seruni beaches (non-pocket beach)

Types	Macro-sized		Meso-sized	
	Number (pcs)	%	Number (pcs)	%
Drini beach				
Plastic	41	62.12	26	63.41
Plastic foam	14	21.21	8	19.51
Fabric	–	–	7	17.08
Glass and ceramic	11	16.67	–	–
Total	66	100	41	100
Seruni beach				
Plastic	11	78.57	37	82.22
Plastic foam	1	7.14	8	17.78
Fabric	2	14.29	–	–
Total	14	100	45	100

meso-sized debris are the most common type of marine debris, with a total of 41 pieces of macro-sized debris and 26 pieces of meso-sized debris.

Table 4 displays the number of marine debris at Sepanjang and Sedahan beaches (pocket beach). According to its size, Sepanjang beach is dominated by macro-sized marine debris with a total of 83 pieces. Meanwhile, the amount of meso-sized marine debris found at Sepanjang beach was 68 pieces. Plastic macro- and meso-sized marine debris are the most common type of marine debris that has been found, with a total of 53 and 58 pieces. On the other hand, Sedahan beach is dominated by meso-sized marine debris with a total of 63 pieces. Meanwhile, macro-sized marine debris has a total of 30 pieces. Plastic macro-sized and meso-sized are the most frequently discovered marine debris. The most common type of marine debris that has been found at Sedahan beach were meso- and macro-sized plastic which are 35 and 19 pieces, respectively. Based on their characteristics, marine debris findings on Drini, Seruni, Sepanjang, and Sedahan beaches are dominated by plastic, as happened in several coastal areas worldwide [9, 39, 81].

Tables 5, 6 show marine debris by its mass. According to its mass, marine debris at Sedahan beach is dominated by macro-sized marine debris with a total mass of 384.74 g, while meso-sized marine debris has a total mass of 24.45 g. The mass of marine debris at Sedahan beach is dominated by macro-sized plastic, glass, and ceramic, each of which has a mass of 199.72 g and 129.52 g, respectively. Then, Sepanjang beach is also dominated by macro-sized marine debris with a total mass of 588.6 g, followed by meso-sized marine debris with a total mass of 13.2 g. Glass and ceramic, plastic, and rubber macro-sized marine debris dominated with each of which has a mass of 290.85 g, 187.26 g, and 64.76 g, respectively.

Table 4 Marine debris characteristics at Sepanjang and Sedahan beaches (pocket beach)

Types	Macro-sized		Meso-sized	
	Number (pcs)	%	Number (pcs)	%
Sepanjang beach				
Plastic	53	63.86	58	85.29
Plastic foam	20	24.10	7	10.29
Glass and ceramic	4	4.82	–	–
Paper and cardboard	3	3.61	3	4.42
Rubber	3	3.61	–	–
Total	83	100	68	100
Sedahan beach				
Plastic	19	63.33	35	55.56
Plastic foam	5	16.67	7	11.11
Glass and ceramic	5	16.67	2	3.17
Metal	–	–	1	1.59
Paper and cardboard	–	–	18	28.57
Rubber	1	3.33	–	–
Total	30	100	63	100

Table 5 Marine debris mass (grams) at Sepanjang and Sedahan beaches (pocket beach)

Types	Sepanjang beach		Sedahan beach	
	Macro-sized	Meso-sized	Macro-sized	Meso-sized
Plastic	187.26	10.05	199.72	8.64
Plastic foam	39.29	2.89	30.5	10.17
Glass and ceramic	290.85	–	129.52	4.25
Metal	–	–	–	1.08
Paper and cardboard	6.44	0.26	–	0.31
Rubber	64.76	–	25	–
Total	588.6	13.2	384.74	24.45

Table 6 Marine debris mass (grams) at Drini and Seruni beaches (non-pocket beach)

Types	Drini beach		Seruni beach	
	Macro-sized	Meso-sized	Macro-sized	Meso-sized
Plastic	142.05	3.91	80.39	1.84
Plastic foam	57.67	29.43	2.13	1.33
Fabric	–	0.17	4	–
Glass and ceramic	46.40	–	–	–
Total	246.12	33.51	86.52	3.17

Macro-sized marine debris also dominated Seruni beach in terms of mass, with a total mass of 86.52 g, followed by meso-sized marine debris, with a total mass of 3.17 g. Macro-sized plastic marine debris dominated with a total mass of 80.39 g. At Drini beach, macro-sized marine debris dominates by its mass with a total mass of 246.12 g, followed by meso-sized marine debris with a total mass of 33.51 g. Plastic, plastic foam, glass and ceramic macro-sized marine debris dominated, each with a mass of 142.05 g, 57.67 g, and 46.40 g, respectively.

4 Discussion

Geomorphological processes impact how pocket, non-pocket, and cliff typologies are formed. The Gunung Sewu karst hills include Gunungkidul itself; according to geological evidence, the karst hills of Gunung Sewu are made up of the Miocene limestone-dominated Wonosari formation [35]. The Wonosari formation, uplifted and formerly comprised of seabed sediment, gave rise to the Gunung Sewu karst hills [69]. A cliff typology also forms a headland and acts as a natural barrier dividing the two coastal typologies in this area. The growth of pocket, non-pocket, and cliff is governed by geomorphological elements as well as oceanic processes, including currents and waves [30].

Based on their research in the United States of America, Dolan et al. [24] previously reported the parameters of the coastal typology, which are different from our findings. The categorization by Dolan et al. [24], which focuses on the coastal environment as an object of classification rather than coastal features or morphological aspects, simply in general, does not explain the morpho-structure that develops in that area. The coastal environment is a dynamic system of continuously interacting terrestrial, marine, and atmospheric processes [6, 57, 70]. It is a complex biophysical environment [3, 28, 47, 66, 82]. The dynamics of the processes will result in rapid occurrence and change since the processes that take place in the coastal environment cannot be separated from one another, as happened in developing countries, including Costa Rica and Indonesia [22, 47, 54, 66].

The number of marine debris collected can vary depending on coastal typology characteristics [16]. In the research area, pocket beaches, i.e., Sepanjang and Sedahan beaches, tend to accumulate more marine debris, i.e., 244 pieces compare with 166 pieces, since marine debris is transported more intensively in coastal areas and is more challenging to return to the sea due to the physical barrier existance in form of headland or hill [27, 51]. Marine debris does not seem to get more frequently on non-pocket beaches, i.e., Drini and Seruni beach, where it can disperse owing to wave activity and be carried back into the water [78]. However, compared with other beaches in Yogyakarta, i.e., Congot and Pasir Kadilangu (both situated in Kulon Progo), as well as Samas and Baru in Bantul, marine debris number in Gunungkidul are higher than that in Bantul and Kulon Progo [39, 81].

According to the findings of acquiring marine debris, Drini beach (non-pocket beach) has more marine debris than Seruni beach (non-pocket beach). The fact that Drini beach has been designated as a tourist destination and fishing activities that might increase the abundance of marine debris may explain why the two beaches belong to the same type of beaches, namely non-pockets, but have different marine debris characteristics [8, 19, 43, 49, 60, 86]. Tourist activities in Gunungkidul have been proven to play a major role in increasing the amount of marine debris, as also happened in Jordania, Belize, and North Sardinia island in Italy [2, 9, 16].

Both macro-sized and meso-sized, plastic is the most prevalent marine debris found on any beach in Gunungkidul. This phenomenon also happens worldwide [12, 14, 19, 23, 39, 52, 81]. Additionally, the beach's slope (Fig. 4) is one factor affecting the number of marine debris [42]. To encourage marine debris deposition because of wave transport, beaches with steeper slopes tend to have more abundant marine debris [16, 39].

According to Fig. 4, Sedahan, Drini, Sepanjang, and Seruni beaches have a beach slope of 8.62°, 8.62°, 9.09°, and 6.23°, respectively. The process of breaking waves and the power of the oncoming waves (swash) are both impacted by the slope [1, 67]. Compared to beaches with sloping slopes, i.e., Seruni beach, waves approaching the shore are more potent on steeper beaches, i.e., Sepanjang beach [39]. As opposed to the waves that approach the beach, a beach with gentler slope, i.e., Drini beach, experiences more backwash. However, other elements, particularly those related to oceanographic processes like near-shore current circulation, can also influence how much the abundance of marine debris [8, 63, 78]. According to its number, the amount of macro-sized marine debris in Gunungkidul, i.e., 193 pieces, is less significant than meso-sized marine debris, i.e., 217 pieces. However, the amount of macro-sized marine debris contributes to the mass of many marine debris items. Due to its greater mass than meso-sized marine debris (74.33 g), macro-sized marine debris (1305.98 g) will be more challenging to return to the sea when it settles; hence, beaches with pocket beach typologies tend to have a higher abundance of macro-sized marine debris [51, 78].

The coastal typological characteristics of Gunungkidul are affected by morphological and oceanographic processes on the coast and are connected or more popularly known as coastal morphodynamics [15, 47]. In the Gunungkidul coastal area, oceanographic processes can take the shape of currents, waves, and tides [55]. The beach's topography will impact how the waves behave as they approach the shore [59]. In Gunungkidul, the type of pocket beach that creates a bay and includes cliffs that are present naturally increases wave energy and can aid in sediment movement [50]. Infragravity

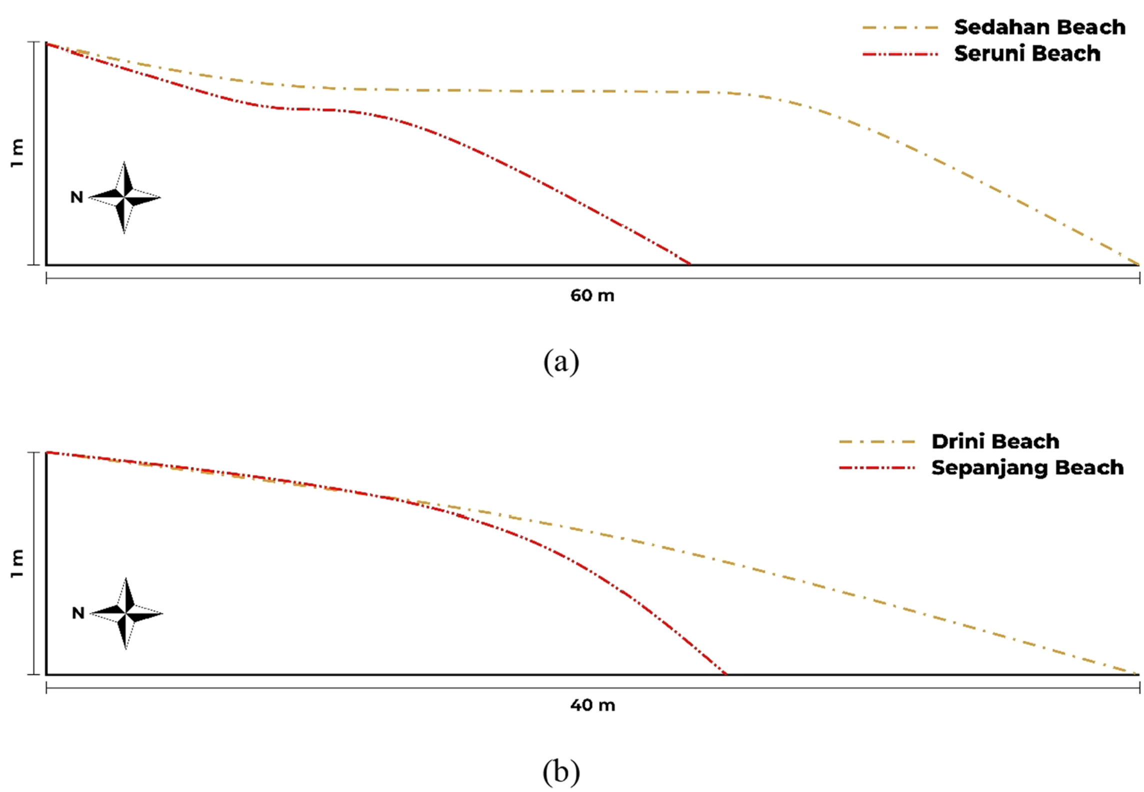


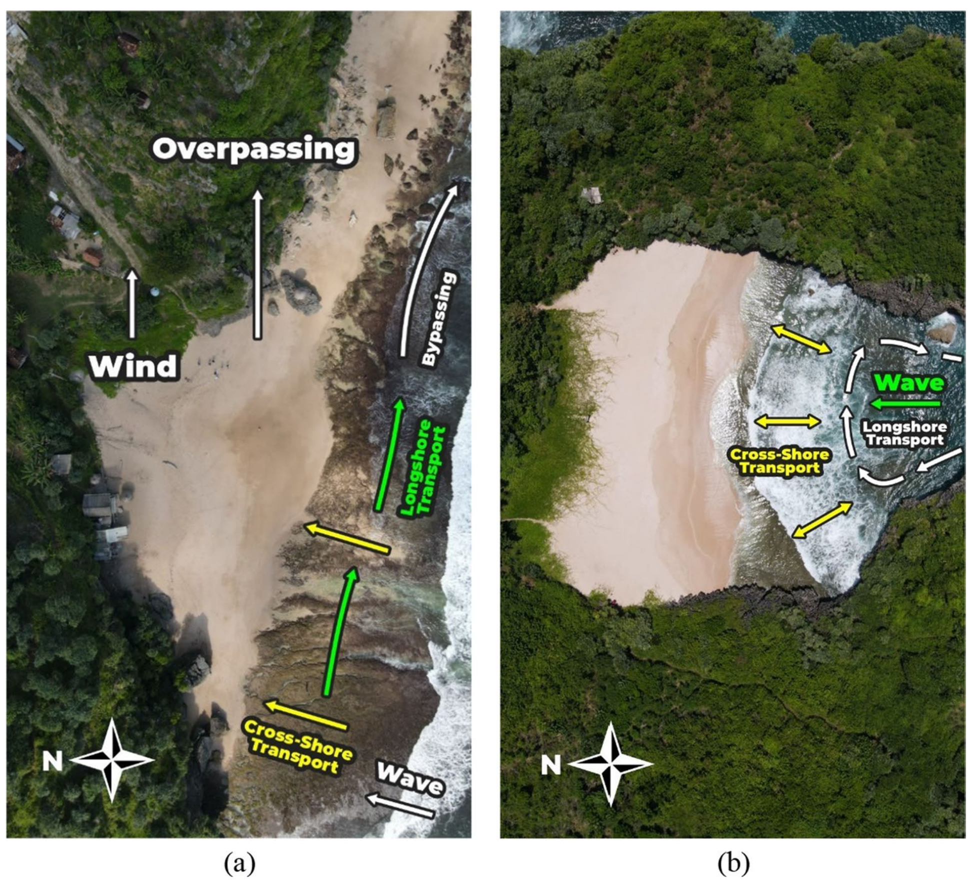
Fig. 4 Cross-sectional beach-slope of (**a**) Sedahan—Seruni and (**b**) Drini–Sepanjang

waves, shear waves, long-shore currents, and cross-shore currents also impact how much energy is transferred from waves [37]. Therefore, this will affect the near-shore current, which circulates close to the shoreline in Gunungkidul.

Factors affecting oceanographic processes may also impact how much marine debris is collected. There are oceanographic processes that have an impact on how waves and currents behave. A complicated series of coastal activities, including deposition, which can alter the volume and distribution of marine debris, is caused by the movement of ocean currents close to the shore and the morphological layout of the pocket beach, like in Sepanjang and Sedahan beaches [71]. Currents and waves in Gunungkidul waters act as carriers of sediment to the shore. Long-shore currents and cross-shore currents in Gunungkidul waters are two types of currents that make up the primary oceanographic process. According to Erlangga et al. [25], long-shore currents flow parallel to the shore due to wave fluctuations caused by wind. Cross-shore currents, meantime, are a type of near-shore water circulation that can carry sediments to the beach [51]. Currents that carry sediment may flow towards the sea or the coast. Based on these existing circumstances and further influenced by the typological features of the coastal area in Gunungkidul, which has cliffs as natural barriers, therefore overpassing and bypassing may be caused (Fig. 5). Sediment transport processes known as overpassing and bypassing occur in bays or on beaches resembling bays [40].

According to Gunungkidul's coastal typology, bypassing pocket beaches will be more challenging because sediment transport will become trapped on the beach, it will be difficult to experience offshore transportation, and pocket beaches have a greater distance between cross-shore currents and long-shore currents than non-pocket beaches [40]. While bypassing is more likely to happen on non-pocket beaches due to the proximity of cross-shore and long-shore currents, making it more straightforward for sediment to be transported and a cliff as a barrier. When a shoreline joins behind the cliff, overpassing may take place. As a result, pocket beaches have a higher spread of marine debris than non-pocket beaches. When compared to Java's northern region [65], Gunungkidul's beach faces south, is situated face to the Indian Ocean, and is part of the open ocean current circulation system, all of which have an impact on the movement of sea currents down the shore [55, 58]. The circulation of ocean currents along the coast of Gunungkidul is now more complicated because of this phenomenon.

Fig. 5 Visual representation and illustration of the occurrence of overpassing and bypassing in (**a**) Seruni and (**b**) Sedahan beaches



5 Conclusions

Coastal typology in Gunungkidul can be classified as pocket or non-pocket beaches, and cliffs surround both types. A pocket beach characterizes by a pocket- or bay-shaped shape and is surrounded by cliffs. Meanwhile, a non-pocket beach does not resemble a bay and has a predominant straight shoreline. Furthermore, cliffs in Gunungkidul can be defined as coastal landforms that border the shore and are close to the water. The geomorphological processes that result from the raising of the Gunungkidul karst hills and the resulting wave action shape the characteristics of the coastal type. The morphodynamics that takes place in this area is thus highly dynamic.

The size, mass, and quantity of marine debris vary among Seruni, Drini, Sepanjang, and Sedahan beaches. Sepanjang and Sedahan beaches were classified as pocket beaches, while Seruni and Drini as non-pocket beaches. Furthermore, Seruni and Sedahan beaches are classified as non-tourist beaches, while Drini and Sepanjang beaches are classified as tourist beaches with higher touristic activity than Seruni and Sedahan. Compared to non-pocket beaches (i.e., Drini and Seruni beaches), pocket beaches (i.e., Sepanjang and Sedahan beaches) contain more marine debris. The higher slopes of the pocket beach typology will trap marine debris and make it challenging to reenter the water. On pocket beaches, oceanographic processes concentrate marine debris in one location. Still, on non-pocket beaches, marine debris can disperse and return to the sea more readily due to the cycling of currents near the coast. Marine debris is also more prevalent on famous beaches following tourism-related activities.

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Data availability All data generated or analyzed during this study are included in this published article.

Declarations

Ethical approval and consent to participate Our paper does not have negative societal impacts. There is no humans or animals were used in this research. The authors were compliant with the ethical standards.

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