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Composition and Distribution of Marine Debris during the Transition Season in Bojong Salawe, Pangandaran Regency, West Java, Indonesia

Lintang P. S. Yuliadi^{1,*}, M. F. Zhilalul Haq², P. Auliya Yasmin², N. Zahira²,
N. Shofwatun Nisa², R. Najwa Azkia²

¹ Department of Marine Science, Faculty of Fisheries and Marine Science, Padjadjaran University, Jatinangor, Sumedang Regency 45363, Indonesia

² Faculty of Fisheries and Marine Science, Padjadjaran University, Jatinangor, Sumedang Regency 45363, Indonesia

*E-mail address: elpeesye@gmail.com

ABSTRACT

This study was conducted to determine the composition and distribution of marine debris during the transition season and the factors influencing the distribution of marine debris. The research was conducted in September 2024 at Pangandaran Bojong Salawe Beach, Pangandaran Regency. The results showed that the total waste collected reached 68.056 kg, with plastic waste being the largest contributor at 35.045 kg (51.5%), followed by wood waste at 21,964 kg (32.3%), and other types of waste, such as rubber (2,759 kg or 4.1%), styrofoam (3,395 kg or 5%), and other organic waste (1,990 kg). This shows that plastic dominates pollution in the region, in line with global trends that indicate plastic as one of the main environmental problems. Bathymetry, wind direction, tidal fluctuations, wave height, and the speed and direction of ocean currents are physical factors that play an important role as distribution channels and collection points for marine debris in the Pangandaran coastal area. In addition to physical factors, population and tourist visitation act as point sources, while waste production is the total volume available to pollute the environment. These three non-physical factors work synergistically; population growth in coastal areas and high tourist visitation in areas with high waste production without proper and sustainable management will lead to massive and uncontrolled accumulation of marine debris.

Keywords: Marine debris composition, marine debris distribution, Pangandaran Bojong Salawe Beach, transitional season

1. INTRODUCTION

Marine debris (MD) is a type of pollution that threatens marine ecosystems and has remained an unresolved problem for the past four decades [1]. The increasing amount of slow-degrading marine debris found in the oceans, on the seabed, and along the coastline has become an important issue and has received considerable attention from the global community [2, 3]. Marine debris is transported to the marine environment from land and sea sources carried by wind, currents, and other oceanographic factors [4, 5].

The amount of plastic waste generated in Indonesia tended to increase from 2011 to 2013, from 429,254 m³ to 507,738 m³. The types of plastic found in urban waste include Light Density Polyethylene (LDPE), Polypropylene (PP), High Density Polyethylene (HDPE), Poly Vinyl Chloride (PVC), Polyethylene Terephthalate (PET), and Styrofoam, with PP and HDPE being the most common types (Ministry of Environment and Forestry of the Republic of Indonesia, 2023). Much of the plastic bag waste does not reach the final waste disposal site and only a small amount is recycled, so much of the plastic bag waste ends up in waterways, rivers, and eventually the sea. A study conducted by the Directorate General of Pollution and Environmental Damage Control of the Ministry of Environment and Forestry shows that the types of waste commonly found in Indonesian waters are plastic (42%), wood (24%), and rubber (13%). One of the impacts of plastic pollution in the ocean is on biodiversity.

Plastic that enters river systems will eventually end up in the oceans. A number of studies have shown how highly unidirectional flow of freshwater systems drives the movement of plastic debris into the oceans [6, 7]. Plastic waste has spread in marine ecosystems around the world caused by ocean currents, wind, river flows and currents [1, 8-12]. Plastic debris can be transported over great distances to remote, if not pristine locations, including islands in the middle of the ocean [13], and ocean depths [8].

Pangandaran Regency is a major tourist destination in West Java and is one of the strategic areas for tourism in West Java Province. Pangandaran Regency has a variety of tourist attractions ranging from nature tourism, cultural tourism, and also special interest/artificial tourism. As a tourist destination, Pangandaran is a region that is crowded with tourists, especially during the holiday season, so the tourism sector is one of the sectors that has a significant effect on regional income. An increase in tourists tends to increase informal economic activity in tourist destinations, but ultimately has the potential to reduce tourist appeal due to a decline in environmental quality. One of the causes of the decline in environmental quality in Pangandaran is tourism waste in the form of marine debris generated from tourist activities. In addition, the increase in the population in coastal areas, the habit of littering, marine debris carried from other areas accumulating on the coast, and debris carried from the mainland can directly increase the amount of marine debris in coastal areas. Therefore, sustainable waste management as a result of various anthropogenic activities is expected to improve environmental sustainability and tourist comfort in Pangandaran Regency.

2. METHODOLOGY

Sampling of marine debris was carried out using a systematic approach involving the division of the area (divided into 10 areas) of the 1 km long beach into 100 quadrants. Each quadrant measured 10 meters, which facilitated the management and detailed recording of

marine debris. Marine debris was grouped into four categories, namely organic, non- organic, hazardous, and residue, using the following procedure:

- 1) Draw a quadrant line with dimensions of 10 meters/quadrant, then collect the waste that falls within the line we have drawn.
- 2) Marine debris collection is conducted at a rate of 200 meters per day over five days.
- 3) After completion, the waste is separated based on type and category to facilitate further handling.
- 4) The waste is weighed according to its group and category.
- 5) Enter the weight data of the sorted waste into *the logsheet*

2. 1. Study area

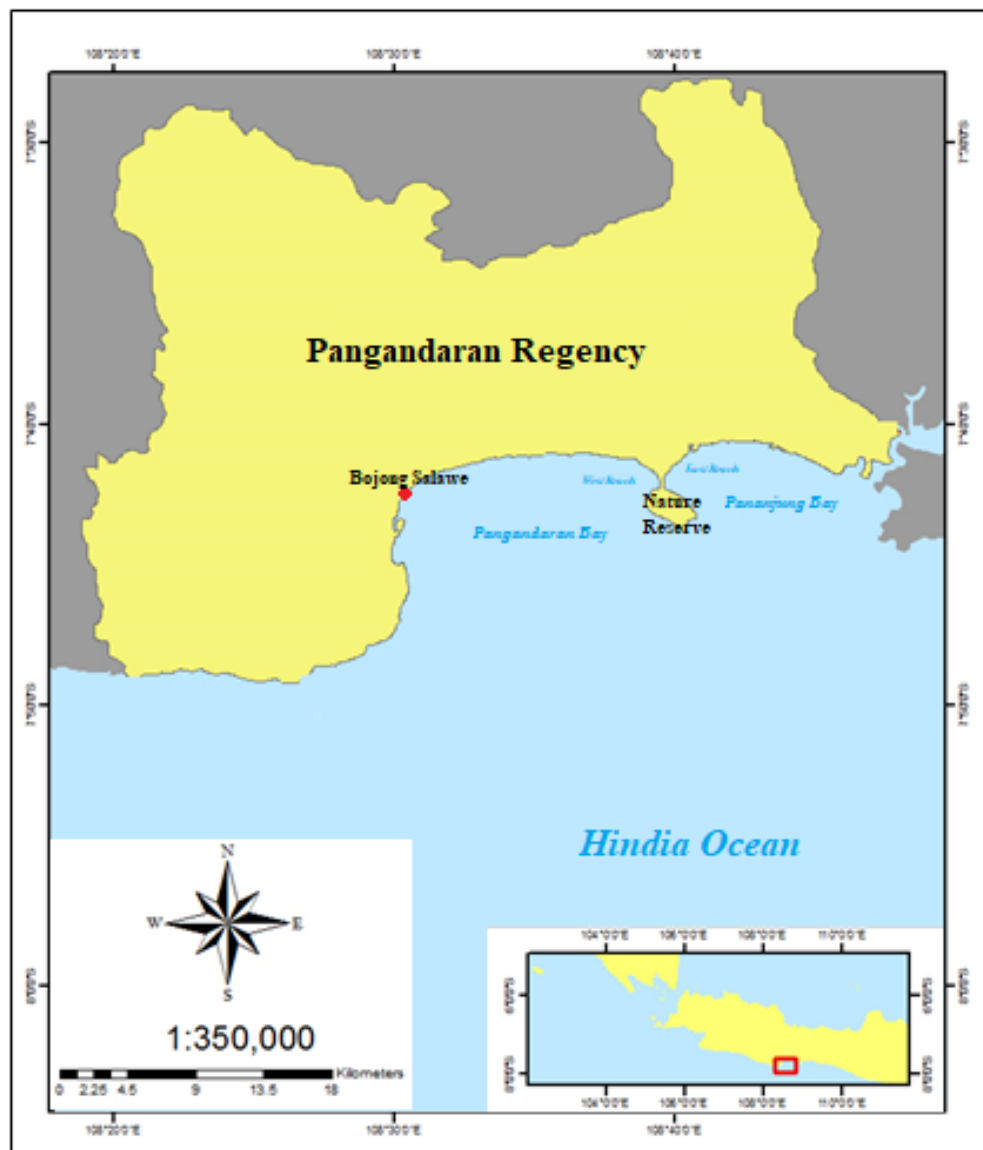


Figure 1. Study Area.

Location of Pangandaran between longitude 108°40' E and latitude 07°43' S. The total area of Pangandaran Regency is 168,509 Ha with an area of sea of 67,340 Ha. Pangandaran Regency has a coastal length of 91 Km. The study was conducted in September 2024.

3. RESULTS AND DISCUSSION

3. 1. Tourist Visits, Population, and Waste Production in Pangandaran District

The number of tourist visits to this district shows a long-term upward trend, despite being hampered by the pandemic. The gradual recovery after the pandemic is a positive sign that the tourism sector is growing again, with projections reaching more than 3 million visits in 2024. The government and tourism industry players can take advantage of this momentum to strengthen promotion, improve facilities, and maintain service quality. Presented data on tourist visits, population, and amount of waste production in Pangandaran Regency between 2020 and 2023.

Table 1. Tourist Visits, Population, and Waste Production in Pangandaran District.

	2020	2021	2022	2023
Number of Tourist Visits ¹	3,939,992	3,604,128	4,310,097	3,898,575
Population (People) ²	423.67	425.59	428.60	431.46
Amount of Waste Production (tons/day) ³	183.63	29.7	63.28	87.87

Source: 1. Department of Tourism and Culture of West Java Province;

2. <https://tasikmalayakota.bps.go.id/>;

3. <https://opendata.jabarprov.go.id/>;

The number of tourist visits and population affect the amount of waste production (Table 1). The increase in population is closely related to the waste produced, as well as tourism activities. Marine debris is generally the result of anthropogenic (human) activities, one of which is tourism. The amount of anthropogenic waste in the sea or washed up on the shore is directly proportional to the number of people living on the island [10, 14-18]. Anthropogenic waste is associated with various human activities that occur around the coast itself or float in the sea as debris. The amount of anthropogenic waste has increased today[19].

From 2020 to early 2022, the tourism sector experienced fluctuations in tourist visits due to policies restricting community activities. Fluctuations in tourist visits to Pangandaran have an impact on waste production, considering that the main source of waste in Pangandaran comes from tourism services (hotels, restaurants, and traders), in addition to restrictions on activities during the pandemic, changes in community consumption patterns, and the strengthening of waste management systems at the local level.

The Pangandaran Regency Government has begun shifting its paradigm from transporting waste to reducing it at the source. The activation of *Reduce, Reuse, Recycle* Waste Processing Sites (TPS3R) in tourist villages is beginning to show results. Organic waste is now

being managed into compost or maggot feed at the village level, so that not all waste ends up in landfills. In addition, Pangandaran has become one of the most progressive regions in utilizing BSF (Black Soldier Fly) maggots to decompose household and market organic waste, which significantly reduces the tonnage of waste officially measured in landfills.

The decline in waste production in Pangandaran Regency recorded by the Environmental Agency often reflects the amount of waste entering the landfill. This means that this decline could mean two things: the amount of waste produced has indeed decreased, or the sorting system at the village level (upstream) has improved so that less waste is disposed of at the landfill.

3. 2. Composition of Marine Waste Collected at Pangandaran Beach

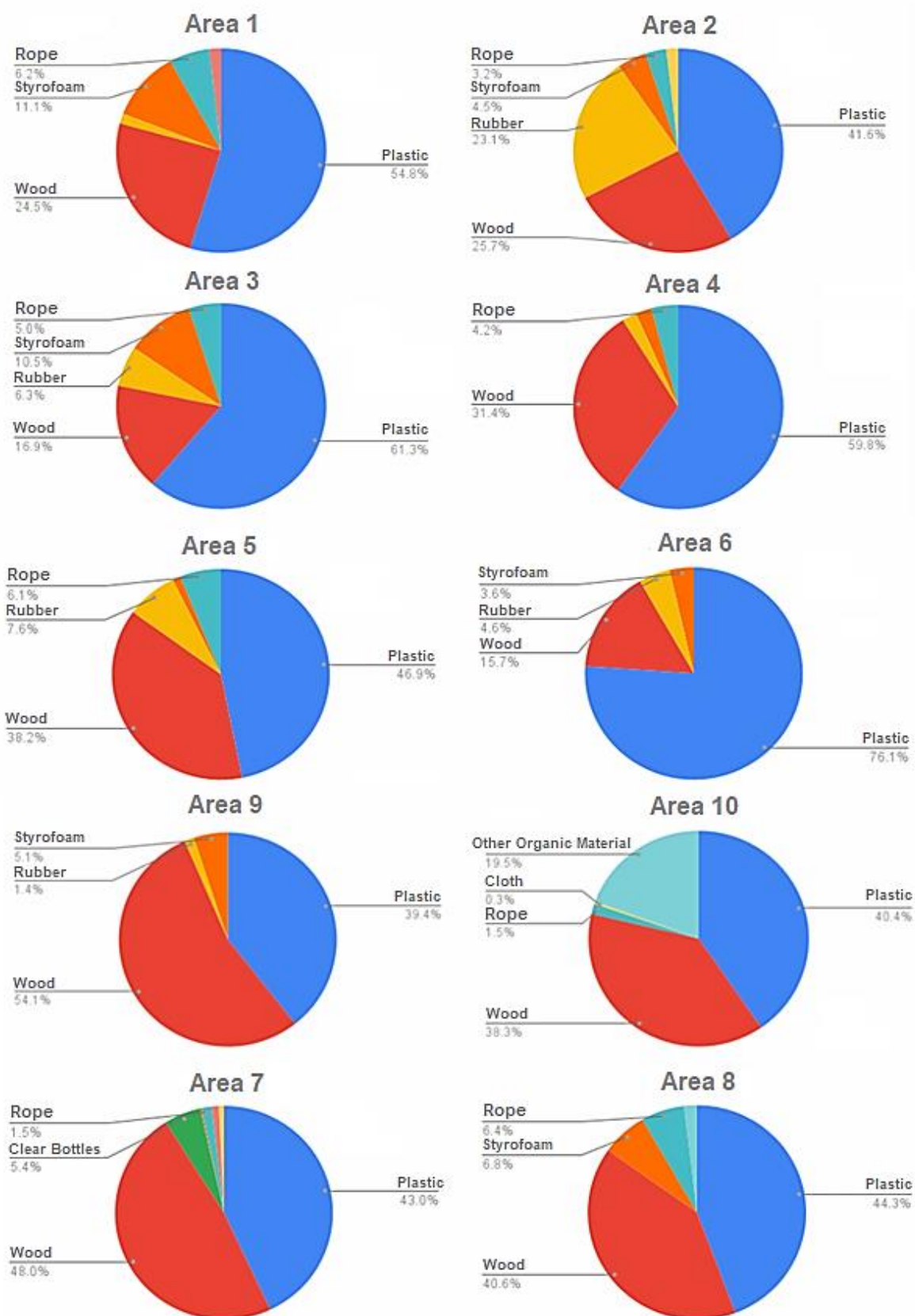
The diagram below (Figure 2) presents data on the composition of waste collected at Pangandaran Bojong Salawe Beach in kilograms. Plastic waste dominates, accounting for 51.5% of the total waste collected. This dominance of plastic shows that non-biodegradable materials are one of the biggest threats to coastal ecosystems. Plastic is known to be difficult to break down naturally, and its presence in large quantities on beaches shows the seriousness of the problem of plastic pollution in the region. Plastic waste can damage marine habitats, threaten animals that often mistake it for food, and damage the aesthetics of beaches.

Wood is the second largest type of waste, contributing 32.3%. Although wood is more easily decomposed than plastic, its significant amount still poses its own challenges. Wood washed up on beaches can come from various sources, such as human activities around the coast, building materials carried by currents, or from nearby forests and land. Although wood is generally more environmentally friendly, the presence of poorly managed wood can still cause disturbances on beaches, especially in terms of cleanliness and visitor comfort, as well as risks to local ecosystems.

In addition to plastic and wood, other waste such as rubber, styrofoam, rope, and organic material was also found on this beach. Rubber accounted for 5% of the total waste, indicating the presence of this material in quantities that cannot be ignored. Rubber, like plastic, has a long decomposition time and can threaten marine ecosystems if not managed properly. Styrofoam, which accounts for 3.5% of the total, is also a major environmental problem because it easily breaks down into small particles (microplastics) that then enter the marine food chain. Meanwhile, rope (4.1%) and other organic waste (2.9%) also contribute, albeit in smaller amounts.

Overall, this data shows that pollution on Pangandaran Bojong Salawe Beach is very diverse, with the majority consisting of plastic and wood. This variety of waste types indicates that there are various sources of pollution, ranging from human activities to natural processes that bring materials to the beach. This condition highlights the importance of comprehensive and integrated waste management efforts, including regular cleanup programs, public education to reduce single-use plastic consumption, and wood waste management. Without concrete action, pollution at this beach may continue to increase, threatening the sustainability of the surrounding coastal and marine environment.

Based on the data above, the total waste collected reached 68,056 kg, with plastic waste being the largest contributor, namely 35,045 kg or around 51.5% of the total. This shows that plastic dominates pollution in the region, in line with global trends that indicate plastic as one of the main environmental problems.



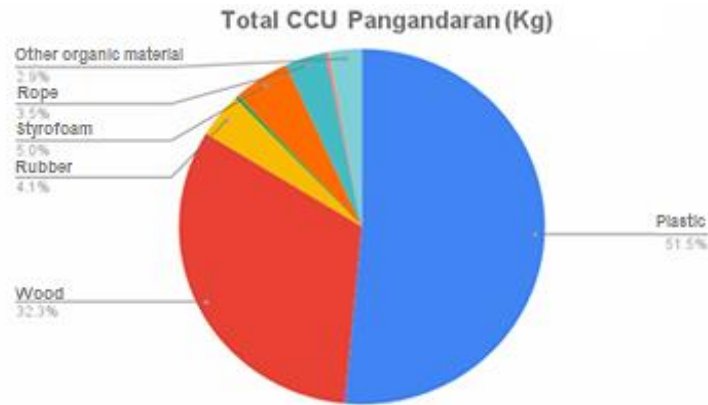


Figure 2. Coastal Clean Up Pangandaran.

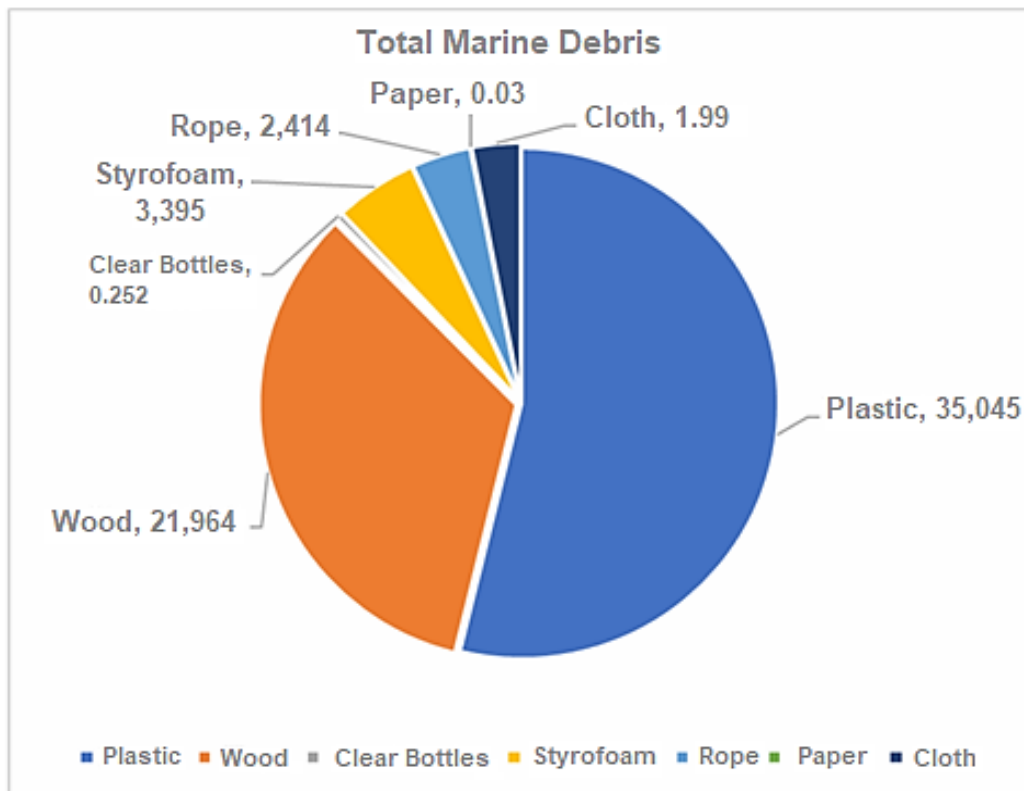


Figure 3. Total Marine Debris.

In addition, wood waste ranked second with a weight of 21,964 kg (32.3%), which likely came from construction waste, furniture, or organic materials such as twigs. Other types of waste, such as rubber (2,759 kg or 4.1%), styrofoam (3,395 kg or 5%), and other organic materials (1,990 kg), although lower in quantity, still contribute to environmental pollution.

The smallest weight categories include cans (0.205 kg), paper (0.205 kg), cloth (0.03 kg), and diapers, indicating potential for further management, even though the volume of this waste is relatively small. There was no record of hazardous and toxic waste, but attention still needs to be paid to the possibility of its unidentified presence. Given these conditions, recommended management measures include reducing the use of single-use plastics, educational campaigns on recycling, and the reuse of wood waste. In addition, the processing of styrofoam and rubber waste also needs to be prioritized due to its non-biodegradable nature. This data provides an important overview to support the evaluation and monitoring of cleanliness activities and encourage sustainable waste management.

3. 3. Bathymetry

The bathymetry of the Pangandaran coastal area plays an important role as a distribution route and collection point for marine debris because the underwater topography can determine where the currents carry marine debris and where it is eventually deposited. The Pangandaran region has a bathymetry that tends to be gentle in the coastal area (ranging from 5 to 15 m) and gradually increases in depth towards the open sea. These conditions can cause the current speed to slow down when approaching land, so that marine debris carried by currents from the open sea tends to get trapped and deposited on the coastline. Shallow bathymetry near the coast can also direct longshore currents to the coast, so that debris originating from one place (such as a river mouth) will be carried along the coast and eventually deposited in areas with depressions or changes in depth. Bathymetry conditions with gentler contours and areas that are open to incoming currents are more prone to accumulation, while areas with complex bathymetry conditions (rocky or coral reefs) tend to have more marine debris at the bottom of the water due to their ability to trap material.

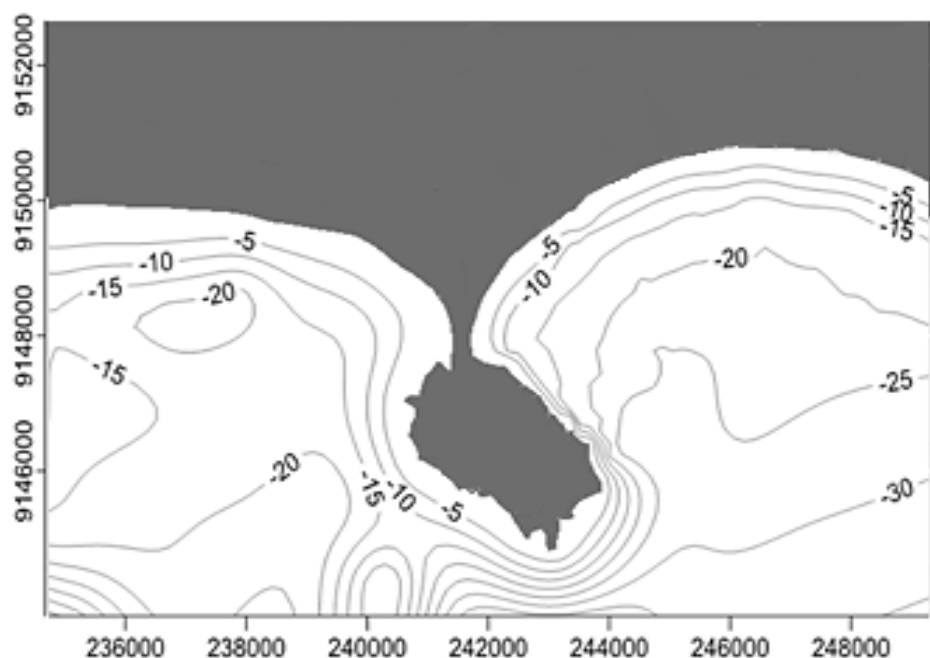


Figure 4. Pangandaran Bathymetry.

3. 4. Wind Speed and Direction

The wind rose plot presented (Figure 5) provides an overview of wind characteristics in Pangandaran in September 2024. The analysis shows that the dominant wind direction is from the south-southeast, with an average wind speed of 2.83 m/s. The wind speed distribution shows that the wind blows at speeds between 3.60 and 5.70 m/s. Other wind speed frequencies are distributed between 2.10 and 3.60 m/s and 5.70 and 8.80 m/s, while calm winds are only recorded at 3.11% of the total observation time.

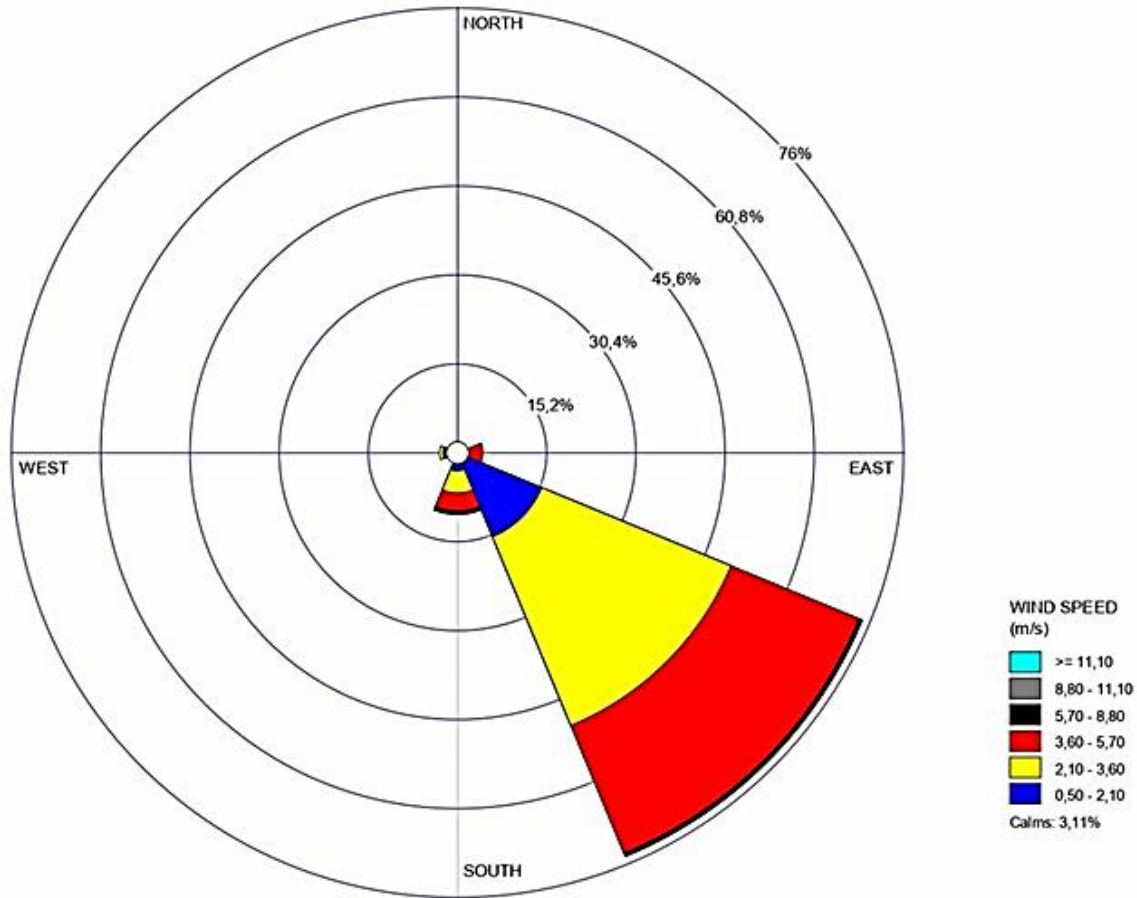


Figure 5. Wind Rose in the Pangandaran Region.

The percentage of wind occurrence shows that 45.6% of winds blow at high speeds, while 30.4% blow at moderate speeds, and 15.2% blow at low speeds. From the total data that has been input, it can be seen that 3.11% of the data is calm winds. Calm Wind refers to conditions where wind speeds are very low or almost non-existent. The wind speed distribution shows that winds in the area are often high speed, with 45.6% of winds recorded as high speed, 30.4% as moderate speed, and 15.2% as low speed. Lower wind frequencies are distributed at speeds between 2.10-3.60 m/s and higher at speeds of 5.70-8.80 m/s.

The dominant wind from the south-southeast will generate surface currents that tend to deviate to the left from the direction of the wind in the east season. However, because

Pangandaran faces the Indian Ocean directly, the dominant surface currents will move towards the northwest. The average surface current speed in Pangandaran during this season ranges from 0.18 to 0.20 knots (approximately 0.1 m/s). Stronger winds from the southeast can increase the speed of these currents, but they usually remain below 0.5 knots due to friction and depth. In addition to wind, currents in Pangandaran are also greatly influenced by tides (tidal currents). Tidal currents here often move back and forth (southeast to northwest), but consistent south-southeast winds provide a push toward the northwest.

Wind direction has a significant impact on where marine debris will accumulate. The east coast of Pangandaran is the area most affected by marine debris. This is because the wind and currents move from the south or southeast towards the mainland (onshore), pushing debris from the middle of the ocean directly to the east coast. Meanwhile, the West Coast of Pangandaran tends to be more protected from the direct push of the southeast wind by the peninsula (Nature Reserve). However, the longshore current can carry some of the debris towards the western end of the coast.

Strong winds from the south-southeast will trigger high waves that come almost perpendicular to the Pangandaran coastline. This condition increases the potential for very strong rip currents at certain points. These rip currents work in the opposite direction, dragging debris from the shoreline back out to sea through narrow gaps in the seabed. Because Pangandaran is located in the Southern Hemisphere, the currents do not move in a straight line with the wind. The surface current will deviate to the left of the wind direction. If the wind comes from the southeast, the surface current will tend to move towards the west/northwest. As this current approaches the Pangandaran coastline, its direction will adjust to the coastline, creating a longshore current that moves from east to west around the nature reserve.

3. 5. Tidal Height

The graph of tidal observations in Pangandaran over two weeks shows a regular pattern of water level fluctuations with observations at 15-minute intervals from 06:00 to 18:00 and 1-hour intervals from 18:00 to 06:00. The data shows a semi-diurnal pattern, where each day there are two cycles of high tide (rise) and two cycles of low tide (fall) within a period of approximately 12 hours. The water level varies from around 50 cm to almost 200 cm at high tide, with a stable change from one peak to the next.

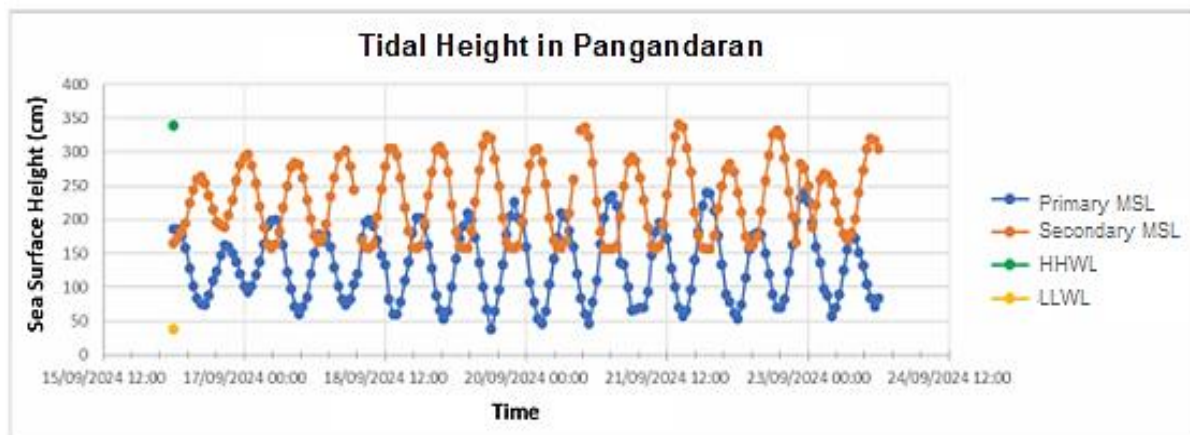


Figure 6. Tidal Height in Pangandaran

Tide are a majoring factor determining the dynamics of waste distribution on the Pangandaran coast. The Pangandaran region has a semi-diurnal tides, meaning that twice a day there is a high tide and twice a day there is a low tide, which creates an active cycle of waste transportation between land and sea. During flood tide, seawater moves toward the mainland, pushing debris in the middle of the sea toward the coast. As a result, debris often washes up on coastal vegetation or the outer edge of the highest spring tide settlement. Conversely, during the ebb tide, seawater moves towards the mainland, so that waste originating from the mainland, including , which is transported by river currents, is carried out to the open sea. If the waste is not cleaned up immediately during the ebb tide, it will become floating *debris* or sink to the bottom.

The tides do not eliminate the debris, but only change its location. Without human intervention (manual cleanup), the tides will continue to pull debris from land into the sea and return it to the shore in a more fragmented state (as microplastics). At the high tide line, piles of marine debris often form long lines along the coast. This occurs because this is the furthest point that the water can reach at high tide, and it is in this area that lightweight plastic debris such as bottles, plastic food wrappers, and styrofoam are most commonly found.

3. 6. Wave Height

Wave height on the Pangandaran coast plays a major role in determining how far marine debris can be pushed onto land. Wave height determines run-up; the higher the waves, the wider the area affected by marine debris. As an area directly facing the Indian Ocean, Pangandaran has varying wave characteristics. During periods of high waves, wave heights in Pangandaran can reach 2–4 meters.

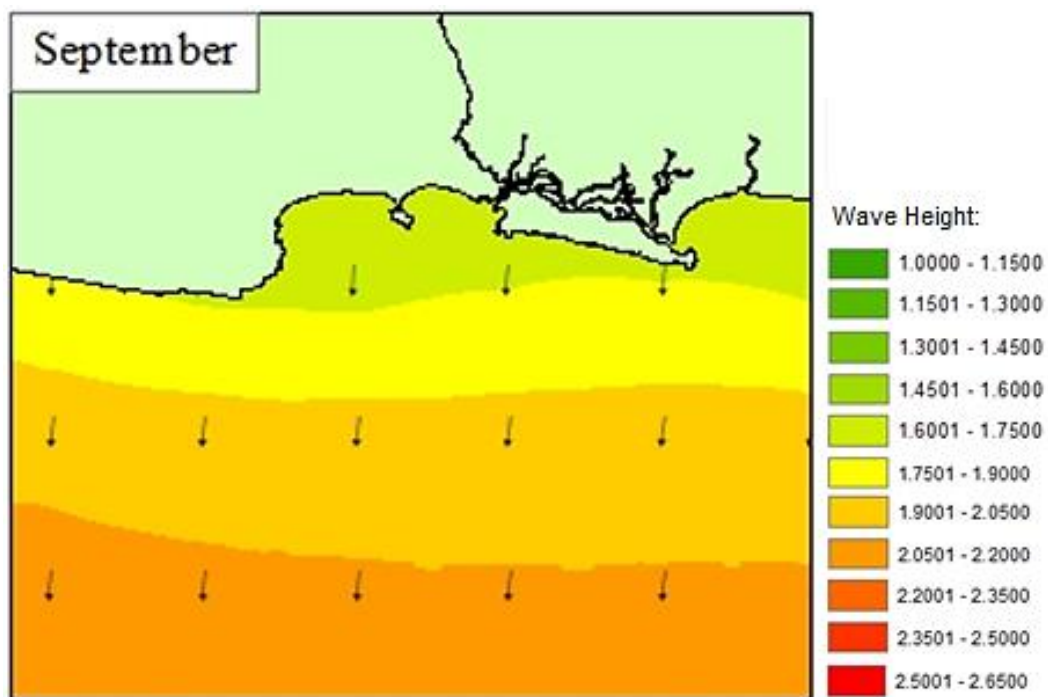


Figure 7. Wave Height in Pangandaran

Conditions during transition II (September–November) tend to be more dynamic and increase as the rainy season approaches. In September, the average height ranges from 1.25 to 2.0 meters, with the remnants of high waves from the East Season (June–August) usually still being felt. Entering October and November, waves begin to fluctuate as westerly winds start to blow. Sudden weather changes (heavy rain accompanied by strong winds) often occur, which can trigger shorter, sharper, and more random waves near the coast.

Wave height is directly proportional to the energy generated. During periods of high waves in Pangandaran, this enormous energy is capable of lifting debris that has settled on the shallow seabed and pushing it far beyond the normal coastline, even to the highways and residential areas along the West Coast. Conversely, when the sea is calm, the debris tends to concentrate in *the surf zone*. This plastic debris often just drifts around in this area or is carried out to sea. When high waves occur, Pangandaran often receives debris from other areas. This debris does not come from local residents, but is carried by *swells* and deposited on the coast. High waves on Pangandaran Beach often bring back debris that was previously discarded through river estuaries. These waves act as a reverse current, preventing the waste from drifting into the open sea and instead returning it to the tourist area. High waves expand the radius of the waste's spread to land, but also accelerate the process of breaking down plastic into microplastics, which are more harmful to the marine ecosystem.

3. 7. Direction and Speed of Ocean Currents

Marine debris can be transported by ocean currents from one place and accumulate in the middle of the ocean [20-22]. The waste will be carried by currents and wind, before eventually accumulating on the coast or disappearing and sinking [23]. The speed and direction of ocean currents are one of the main determining factors in the distribution of marine debris, whether it will accumulate in tourist areas, get trapped in sensitive coastal ecosystems, or be carried out to the open sea.

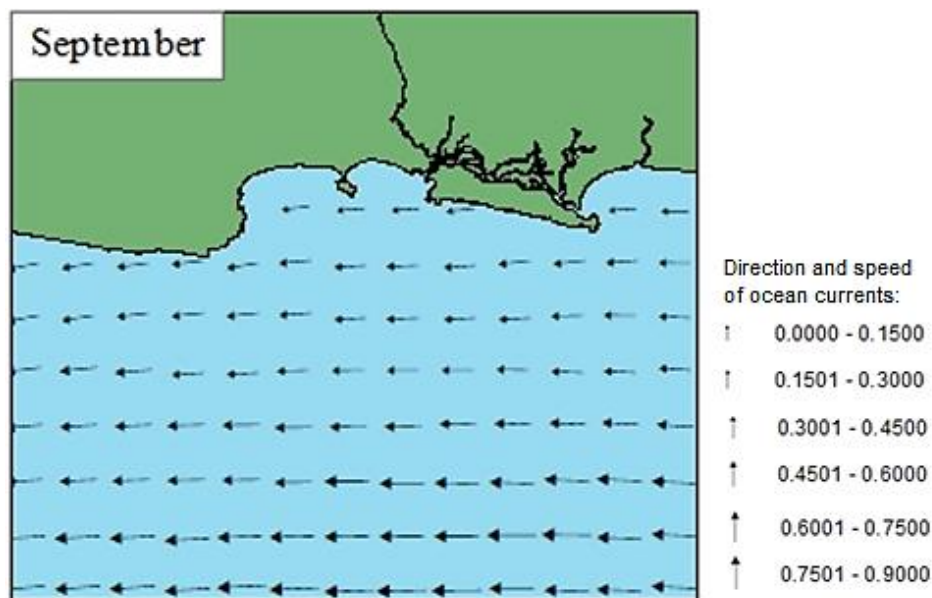


Figure 8. Direction and Speed of Ocean Currents

The direction of currents in Pangandaran is greatly influenced by monsoon winds. During the east monsoon (June–August), currents tend to move from east to west. During this period, debris in the estuary on the east side or from the open sea will be carried towards the west coast of Pangandaran. This is why the west coast often receives a higher load of debris during these months. During the west monsoon (December–February), currents move east or southeast. Debris from the Pangandaran mainland is more easily carried away from the coast toward the open sea. Transitional season II (September–November) is a transition period from the east monsoon to the west monsoon. Conditions during this period are often more dynamic than in transitional season I. During this season, there are changes in the direction and speed of the currents.

The currents begin to shift from east/southeast to west/northwest. Current patterns often change or swirl (eddy) due to the influence of the wind. Current speeds can increase suddenly in November as the west winds strengthen. Current speeds in Transition Season II tend to be lower than in other seasons (West or East Seasons). The average surface current speed ranges from 0.14 knots to 0.18 knots (approximately 0.07 - 0.09 m/s). Although the average is low, under certain conditions (such as during peak tide or spring tide), the current speed can increase, but it is still not as strong as during the peak of the West Season.

By mapping the direction of the currents, we can trace the origin of marine debris in Pangandaran. Debris from tourist activities on the beach and domestic waste from residential areas is carried by longshore currents. These currents move parallel to the coastline. If the current speed is low, the debris will only move from one point on the beach to another (for example, from the hotel area to the conservation area). The waste found in Pangandaran does not always originate from local residents. Surface currents driven by global winds carry plastic waste from other countries or from large ships sailing the Indian Ocean. This waste is usually distinctive: it has many barnacles/marine organisms attached to it because it has been in the water for a long time.

The speed of the currents determines how far the waste travels, while the direction of the currents determines where it goes. In Pangandaran, the interaction between coastal currents and the peninsula's structure creates conditions where the West Coast becomes the point that receives the most waste during certain seasons, making it a major challenge for tourism managers to maintain the aesthetics of the beach.

4. CONCLUSIONS

The total waste collected reached 68,056 kg, with plastic waste being the largest contributor at 35,045 kg or about 51.5% of the total. Wood waste ranked second with a weight of 21,964 kg (32.3%), which likely came from construction waste, furniture, or organic materials such as twigs. Other types of waste, such as rubber (2,759 kg or 4.1%), styrofoam (3,395 kg or 5%), and other organic waste (1,990 kg), cans (0.205 kg), paper (0.205 kg), cloth (0.03 kg), and diapers, indicate the potential for further management, even though the volume of this waste is relatively small. There was no record of hazardous and toxic waste, but attention still needs to be paid to the possibility of its unidentified existence.

The Pangandaran region has a relatively flat bathymetry in the coastal area (ranging from 5 to 15 m) and its depth gradually increases towards the open sea. The dominant wind direction is from the south-southeast, with an average wind speed of 2.83 m/s. Wind speed distribution

shows winds blowing at speeds between 3.60 and 5.70 m/s. Other wind speed frequencies are distributed between 2.10 and 3.60 m/s and 5.70 and 8.80 m/s, while calm winds are only recorded at 3.11% of the total observation time. The tidal type in Pangandaran is semi-diurnal, with two tidal cycles and two ebb cycles occurring every day. Water levels vary between 50 cm (lowest ebb) and 200 cm (highest tide).

The current speed in Transition Season II tends to be lower than in other seasons (West or East Season). The average surface current speed ranges from 0.14 knots to 0.18 knots (approximately 0.07 - 0.09 m/s). In Transition Season II, there are changes in the direction and speed of the current. The currents begin to shift from east/southeast to west/northwest. Current patterns often change or swirl (eddy) due to the influence of wind. Bathymetry, wind direction, tidal fluctuations, wave height, and ocean current speed and direction are physical factors that play an important role as distribution pathways and collection points for marine debris in the Pangandaran coastal area.

In addition to physical factors, population and tourist visitation act as point sources, while waste production is the total volume available to pollute the environment. These three non-physical factors work synergistically; population growth in coastal areas and high tourist visitation in areas with high waste production without proper and sustainable management will lead to massive and uncontrolled accumulation of marine debris.

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