e-ISSN: 3165-2611

ASHA PUBLISHING

INSPIRE:

Multidisciplinary Journal of Human Development and Wellbeing



Volume 1, Issue 2, 2026
Publisher: ASHA Publishing

INSPIRE:
Multidisciplinary Journal of Human Development and Wellbeing
E-ISSN: 3165-2611
Publisher: ASHA Publishing

Spatial Distribution of Marine Debris at Laguna Beach, Indonesia

Anggun Citra[1], Hartati Tamti[2]*
[1,2]Institut Teknologi dan Bisnis Maritim Balik Diwa
Corresponding author's email: hartati.tamti@gmial.com

ABSTRACT

Marine debris is a persistent environmental problem in coastal areas and is influenced by the interaction of human activities and oceanographic processes. This study aimed to characterize the spatial distribution of marine debris at Laguna Beach, Pao-Pao Village, Barru Regency, South Sulawesi, Indonesia, by comparing its composition, abundance, mass, and density among three sampling stations. The study was conducted in May 2025 at three purposively selected stations representing different activity characteristics: Station 1 (Settlement), Station 2 (Shoreline), and Station 3 (Gazebo). Marine debris was collected using a 100-m line transect divided into five plots measuring 10 m × 10 m. The collected debris was classified by material type, counted, weighed, and analyzed based on abundance, mass, and density. The results identified seven major categories of marine debris: plastic, rubber, foam, glass, wood, coconut husk/sheath, and natural waste. Plastic was the most abundant category at all stations, accounting for 75% of debris at Station 1, 59% at Station 2, and 66% at Station 3. The highest plastic abundance was recorded at Station 1, with 814 items. In terms of mass, plastic was dominant at Station 1 (19.259 kg), whereas wood had the highest mass at Stations 2 (15.079 kg) and 3 (19.092 kg). The spatial distribution varied among stations, with plastic showing the highest density at the settlement area, while wood showed the highest density at the gazebo area. The observed debris was associated primarily with domestic activities, tourism, and natural processes. Ocean currents, wind, and wave conditions potentially contributed to the redistribution and accumulation of debris. These findings indicate that marine debris management at Laguna Beach requires location-specific strategies that address both anthropogenic sources and coastal transport processes.

Keywords: Beach litter; Coastal pollution; Marine debris; Plastic pollution; Spatial distribution

INTRODUCTION

Marine debris has become a persistent environmental problem in coastal and marine ecosystems, with plastic constituting one of the most widely distributed and persistent forms of marine litter. The increasing occurrence of plastic and other anthropogenic debris in marine environments is closely associated with terrestrial activities, river discharge, coastal settlements, fishing, shipping, tourism, and oceanographic processes. Recent studies demonstrate that marine debris can be transported over considerable distances and accumulate in particular locations as a consequence of interactions among human activities, hydrodynamic conditions, coastal morphology, and material characteristics (Cloux et al., 2024; Purba et al., 2024; (Cloux, Pérez, de Pablo, & Pérez-Muñuzuri, 2024; Purba et al., 2024; Zlateva et al., 2024) et al., 2024). Consequently, marine debris should not be considered solely as a local waste-management problem but as a spatially dynamic environmental issue requiring systematic assessment.

The distribution of marine debris is highly heterogeneous across marine and coastal environments (Schreyers et al., 2024) demonstrated that land-use characteristics can influence the distribution of macrolitter, highlighting the importance of surrounding human activities in determining litter patterns. Similarly, (Teng, Chen, Shan, Shi, & Jin, 2024) identified significant temporal and spatial variations in floating marine macro-litter in the Bohai and Yellow Seas. In the North and South Atlantic Ocean, microplastic abundance and distribution were also found to vary considerably across different marine areas (Andersen et al., 2024) . These findings indicate that the occurrence of marine debris is not random but is shaped by the interaction of environmental processes and anthropogenic pressures. Therefore,

Volume 1, Issue 2, 2026, pp: 42-53
DOI: https://doi.org/10.70188/6866gp68

assessments of marine debris distribution need to consider both the quantity and composition of debris as well as its spatial patterns.

Coastal areas and beaches are particularly important locations for marine debris studies because they represent interfaces between terrestrial and marine systems and can function as accumulation zones (Guffogg, Soto-Berelov, Bellman, Jones, & Skidmore, 2024) developed the Beached Plastic Debris Index to facilitate the detection and mapping of plastic accumulation on beaches, emphasizing the importance of spatial information in identifying areas with high concentrations of plastic debris. In the southeastern Baltic Sea, (Sabaliauskaitė, Kataržytė, Rubavičiūtė, Tiškus, & Balčiūnas, 2024) identified beach wrack as a potential hotspot for microplastic accumulation, demonstrating that natural coastal features can contribute to the retention of plastic particles. Similar patterns have been observed in marine sediments, where (Bobchev, Berov, Klayn, & Karamfilov, 2024) reported high microplastic pollution in areas associated with urbanized coastal environments. These studies suggest that beach characteristics, surrounding land use, and coastal processes play important roles in determining the distribution and accumulation of marine debris.

The movement and accumulation of marine debris are also strongly influenced by ocean currents and other physical processes. (Cloux et al., 2024) used a regional Lagrangian model to investigate the dispersion of floating macroplastics originating from land and river sources, demonstrating the importance of transport pathways in understanding marine plastic distribution. (Purba et al., 2024) similarly emphasized the value of combining particle modelling with in-situ sampling to identify marine debris sources and transport pathways, particularly in archipelagic countries. (Zlateva et al., 2024) demonstrated that terrestrial and riverine sources can contribute substantially to marine plastic pollution, while (Capodici et al., 2024) highlighted the potential of combining in-situ observations with sea-surface current information to identify microplastic hotspots. These findings reinforce the importance of integrating spatial observations and environmental processes when analyzing marine debris distribution.

Marine debris is also found across different environmental compartments, ranging from beaches and surface waters to deep-sea environments. (Fuller et al., 2024) documented the occurrence of marine trash in the deep tropical Atlantic and Caribbean Sea, illustrating that debris can reach offshore and deeper marine environments. (Sánchez-García et al., 2024) identified hotspots of floating macro-debris in the Mediterranean Sea using multiple observation methodologies, further demonstrating that floating debris tends to concentrate in areas. (Cózar et al., 2024) proposed the use of remote sensing technology to monitor marine litter from space, indicating the growing importance of spatially explicit technologies for marine debris assessment. (Sun, Zhang, Xie, Mai, & Zeng, 2024) further showed that low-density plastic debris can be transported and removed from surface waters through interactions with carbonate particles, illustrating the complexity of plastic transport in open-ocean environments.

The ecological implications of marine debris are substantial. Plastic pollution can be ingested by marine organisms and may affect feeding, reproduction, habitat use, and overall ecological functioning. (Pedà et al., 2024) reported evidence of microplastic ingestion by European grayling and highlighted the potential ecological risks associated with plastic contamination. (Lee et al., 2024) documented the ingestion of fishing gear by an Indo-Pacific finless porpoise, demonstrating the consequences of larger marine debris for marine mammals. (Figuerola et al., 2024) found that catsharks altered their substrate selection for oviposition in response to plastic substrates, illustrating that plastic pollution can influence ecological interactions and habitat use. At the same time, (Bajo et al., 2024) demonstrated that some marine bacteria can biodegrade specific plastic materials, although the persistence of plastic remains a major environmental concern. The ecological effects of marine debris therefore extend beyond its physical presence and can influence biological processes within marine ecosystems.

The characteristics and behavior of marine debris also vary according to material type and physical properties. (Stead, de Souza Leite, & Bond, 2024) demonstrated the importance of density measurements in understanding the behavior of microplastics, while (Andersen et al., 2024) documented differences in the abundance, distribution, and characteristics of microplastics across the Atlantic Ocean. These characteristics affect whether debris remains floating, becomes suspended in the water column, or sinks into marine sediments. Consequently, an assessment of marine debris should incorporate not only its abundance but also its material composition, size, and spatial distribution.

Volume 1, Issue 2, 2026, pp: 42-53
DOI: https://doi.org/10.70188/6866gp68

Indonesia, as an archipelagic country with extensive coastlines and numerous coastal communities, is particularly relevant for marine debris research. The complex interaction between land-based sources, river systems, coastal activities, and ocean circulation can create diverse pathways for the transport and accumulation of marine debris. (Purba et al., 2024) specifically emphasized the importance of source identification and transport modelling in archipelagic countries. This context makes site-specific investigation essential for understanding how marine debris is distributed within individual coastal environments.

South Sulawesi contains extensive coastal and marine areas that support fisheries, tourism, aquaculture, mangrove ecosystems, and other socioeconomic activities. Kabupaten Barru, located along the western coast of South Sulawesi, possesses considerable coastal potential, including Laguna Beach in Pao-Pao Village. However, coastal tourism areas may also be exposed to the accumulation of marine debris originating from local activities and transported from surrounding marine and terrestrial environments. Despite the growing body of research on marine debris distribution at international and regional scales, empirical information concerning the quantity, type, composition, and spatial distribution of marine debris at Laguna Beach remains limited.

This study therefore examined the spatial distribution of marine debris at Laguna Beach, Pao-Pao Village, Barru Regency, Indonesia, by comparing debris composition, abundance, mass, and density among settlement, shoreline, and gazebo stations. Potential sources and oceanographic conditions were considered as contextual information for interpreting the observed station-level patterns, rather than as directly tested causes of debris accumulation. The findings are intended to provide a site-specific basis for identifying accumulation areas and developing location-specific coastal waste-management strategies.

METHODS

The study was conducted in May 2025 at Laguna Beach, Pao-Pao Village, Barru Regency, South Sulawesi, Indonesia. The study area was divided into three sampling stations representing different levels and characteristics of human activity: Station 1 (Settlement), Station 2 (Shoreline), and Station 3 (Gazebo). The stations were selected using purposive sampling, considering areas with relatively intensive human activities and a potential for marine debris accumulation. This site-selection approach is consistent with marine litter studies that consider human activities, coastal characteristics, and potential accumulation areas when determining sampling locations (Purba et al., 2024; Velander & Mocogni, 1998). Marine debris was surveyed using a line-transect approach, which is widely applied in beach and coastal litter assessments (Williams, Ashe, & O'Hara, 2011). A 100-m transect was established parallel to the shoreline at each station, following approaches commonly used in marine litter monitoring (Williams et al., 2011). Each transect consisted of five sampling plots measuring 10 m × 10 m. All visible marine debris within the designated plots was collected, counted, weighed, and classified according to material type, including plastic, wood, glass, foam, and other categories. Similar procedures involving the collection, sorting, counting, and weighing of beach litter have been applied in Indonesian and international marine debris assessments (Al Nahian et al., 2022) . The classification of debris by material type enables the composition and abundance of marine litter to be characterized consistently across sampling locations.

The collected data were analyzed descriptively by calculating the total abundance, total weight, and mean abundance and weight of each marine debris category across the three sampling transects. Total abundance and total weight were calculated as:

$$\text{Jn tot} = \text{Jn transek 1} + \text{Jn transek 2} + \text{Jn transek 3}$$

$$\text{Bn tot} = \text{Bn transek 1} + \text{Bn transek 2} + \text{Bn transek 3}$$

$$\dot{Jn} = \frac{Jn\ transek\ 1 + Jn\ transek\ 2 + Jn\ transek\ 3}{Jn\ transek\ total}$$

$$\dot{Bn} = \frac{Bn\ transek\ 1 + Bn\ transek\ 2 + Bn\ transek\ 3}{Bn\ transek\ total}$$

Volume 1, Issue 2, 2026, pp: 42-53
DOI: https://doi.org/10.70188/6866gp68

Information:

J*n* Tot	:	Total quantity of waste type n (units)
B*n* Tot	:	Total weight of waste type n (grams)
J*n* $\dot{X}$	:	Average number of waste items of type n (units)
J*n*	:	Quantity of waste type n (units)
B*n*	:	Weight of waste type n (grams)

Next, the distribution data will be measured using the following formula (Kungskulniti, Charoenca, Hamann, Pitayarangsarit, & Mock, 2018).

$$S=\frac{W(kg)}{A}$$

S	average waste (kg/m²)
W	weight of waste obtained, in kilograms
A	waste collection area in square meters

Respectively, while mean abundance and mean weight were calculated by dividing the corresponding total values by the number of transects. Marine debris density was subsequently calculated by dividing the total quantity or weight of debris by the corresponding sampling area, an approach widely used in beach-litter assessments (Al Nahian et al., 2022) . For the present study, debris weight density was calculated using (S=W/A), where (S) is marine debris density (kg/m²), (W) is the total weight of collected debris (kg), and (A) is the total sampling area (m²). The use of area-normalized abundance and weight facilitates comparison among sampling locations and is consistent with recent marine litter studies that express debris density as items or weight per unit area (Williams et al., 2011) . The resulting values were compared among the three stations to identify differences in debris abundance, composition, and density and to determine areas with relatively greater accumulation. This approach provides a quantitative basis for describing the spatial distribution of marine debris at Laguna Beach.

RESULT AND DISCUSSION

1. Oceanographic Parameters

Ocean currents, wind, and wave height were considered to provide a physical context for interpreting the spatial distribution of marine debris at Laguna Beach. These parameters may help explain transport and retention processes, but their effects on station-level debris patterns were not directly tested in this descriptive study.

Table 1. Ocean current direction and velocity at Laguna Beach in May 2025

Date	Current Direction	Current Velocity (cm/s)
14 May 2025	East–Northwest	5.3–32.3
15 May 2025	East–Northwest	5.3–32.3
20 May 2025	East–Northwest	5.3–32.3

Source: BMKG Makassar (2025)

The BMKG data show that the ocean current around Barru Regency during the observation period generally moved from east toward northwest, with velocities ranging from 5.3 to 32.3 cm/s. This current condition provides an important mechanism for transporting floating and semi-floating debris along the coastline. The role of currents in transporting marine debris is consistent with recent modelling and observational studies showing that debris distribution is strongly associated with transport pathways generated by hydrodynamic processes. (Cloux et al., 2024) demonstrated that floating macroplastics can be transported over considerable distances from terrestrial and riverine sources through ocean circulation, while (Purba et al., 2024) emphasized the importance of combining in-situ observations with particle modelling to identify marine debris pathways in archipelagic environments. Similarly, (Teng et al., 2024) reported significant spatial and temporal variation in floating marine macro-litter associated with environmental transport processes.

Volume 1, Issue 2, 2026, pp: 42-53
DOI: https://doi.org/10.70188/6866gp68

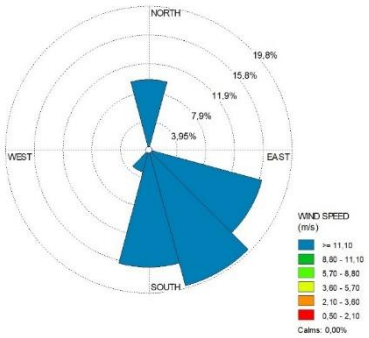


Figure 2. Wind rose at Laguna Beach in May 2025
Source: Processed from BMKG data (2025)

The wind data processed using WRPLOT indicate that the dominant winds originated from the south and southeast, each contributing approximately 19.8% of the total observation period, while northerly winds accounted for approximately 7.9%. The recorded wind speeds were predominantly in the ≥11.10 m/s category. These relatively strong and persistent winds may contribute to the redistribution of lightweight marine debris, particularly plastics, foam, and other floating materials. The interaction between wind and surface currents can cause floating debris to move away from its initial source and accumulate in areas where transport energy decreases. Such processes are consistent with the findings of (Sánchez-García et al., 2024) , who identified distinct accumulation hotspots of floating macro-debris through multiplatform observations, and (Capodici et al., 2024) , who demonstrated the relevance of surface-current information in identifying microplastic hotspots.

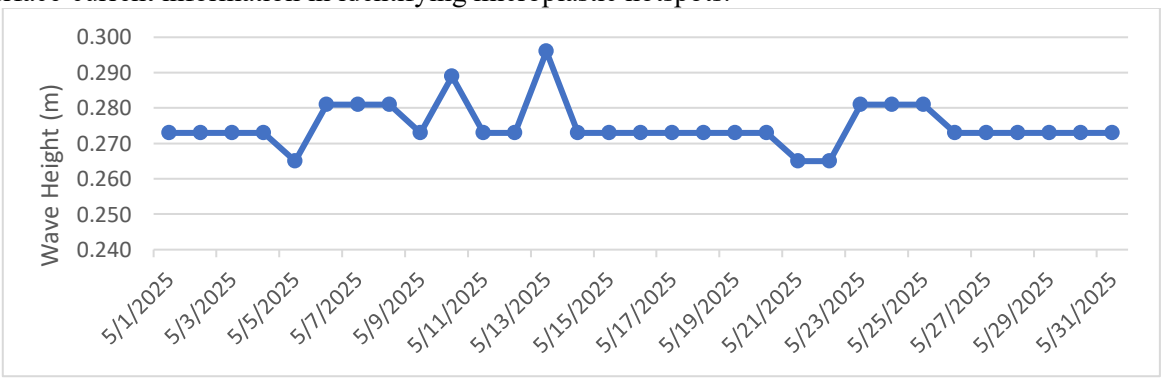


Figure 3. Wave height at Laguna Beach in May 2025
Source: BMKG Makassar (2025)

Wave height during May 2025 showed relatively limited variation, ranging from approximately 0.265 to 0.296 m. The highest wave height was recorded on 13 May at 0.296 m, whereas the lowest values, approximately 0.265 m, occurred on 5, 21, and 22 May. The relatively low wave conditions indicate comparatively calm coastal waters during the observation period. Such conditions may facilitate the retention of debris along the shoreline rather than continuously transporting it offshore. The combined influence of current, wind, and wave conditions may therefore explain why certain debris categories were concentrated at specific stations. The spatial distribution of marine litter is generally not determined by hydrodynamic conditions alone; surrounding land use and human activities may also contribute substantially to accumulation patterns (Schreyers et al., 2024) .

2. Marine Debris Composition and Abundance

Marine debris collected from the three sampling stations consisted of seven major categories: plastic, rubber, foam, glass, wood, coconut husk/sheath, and natural waste. Plastic was the dominant category at all three stations.

Volume 1, Issue 2, 2026, pp: 42-53
DOI: https://doi.org/10.70188/6866gp68

Table 2. Abundance and composition of marine debris at each sampling station

Marine debris type	Station 1 (Settlement)	Station 2 (Shoreline)	Station 3 (Gazebo)
Plastic	814 (75%)	594 (59%)	627 (66%)
Foam	95 (9%)	154 (15%)	95 (11%)
Rubber	38 (4%)	79 (8%)	40 (4%)
Glass	27 (2%)	78 (8%)	33 (3%)
Wood	46 (4%)	38 (4%)	69 (7%)
Coconut husk/sheath	30 (3%)	33 (3%)	16 (2%)
Natural waste	35 (3%)	31 (3%)	72 (8%)
Total	1,085	1,007	952

Source: Research findings, 2025

The results show that plastic accounted for the largest proportion of marine debris at all stations, reaching 75% at Station 1, 59% at Station 2, and 66% at Station 3. In absolute terms, Station 1 contained the highest number of plastic items (814 items), followed by Station 3 (627 items) and Station 2 (594 items). The predominance of plastic is consistent with the persistent nature and widespread mobility of plastic debris in coastal environments. (Guffogg et al., 2024) demonstrated the importance of monitoring plastic accumulation on beaches, while (Andersen et al., 2024) reported the widespread distribution of microplastics across different areas of the North and South Atlantic Ocean.

The particularly high proportion of plastic at Station 1 (Settlement) suggests a strong relationship between marine debris composition and nearby human activities. Plastic packaging, straws, food wrappers, and other single-use materials are commonly associated with domestic consumption. This interpretation is also supported by (Schreyers et al., 2024) , who found that land-use characteristics influence macrolitter distribution. Therefore, the high plastic abundance at the settlement station may reflect both direct waste generation and the subsequent movement of debris through coastal processes.

At Station 2 (Shoreline), plastic remained dominant but its proportion decreased to 59%, while foam reached 15%, rubber 8%, and glass 8%. This comparatively diverse composition suggests that the shoreline functions as an accumulation interface where materials originating from both land and marine sources can be retained. (Sabaliauskaitė et al., 2024) similarly identified coastal accumulation zones where natural shoreline characteristics contribute to the retention of microplastics. The relatively high occurrence of foam, glass, and rubber at Station 2 may therefore reflect the combined influence of local activities and the physical retention of debris along the shoreline.

At Station 3 (Gazebo), plastic accounted for 66% of all debris, followed by foam (11%) and natural waste (8%). The relatively high abundance of natural waste and wood at this location may be associated with activities undertaken by visitors, as well as the retention of naturally derived materials. The ecological and physical characteristics of coastal environments can create localized accumulation zones, as also demonstrated by studies of beach wrack and marine litter hotspots (Sabaliauskaitė et al., 2024; Sánchez-García et al., 2024) .

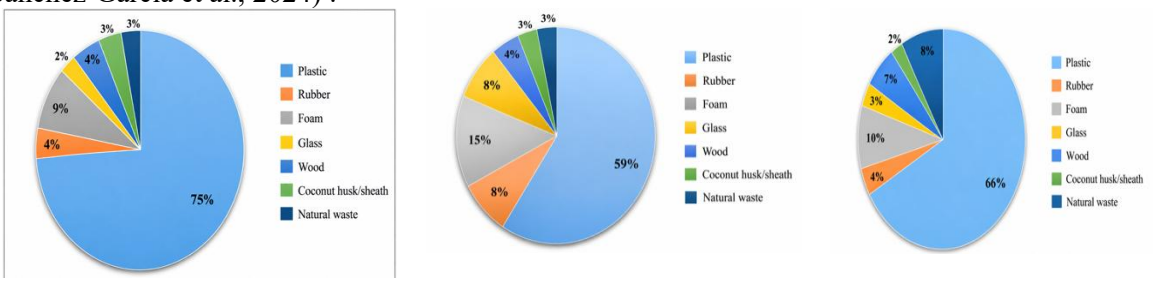


Figure 4. Percentage composition of marine debris at Station

Source: Research findings, 2025

Volume 1, Issue 2, 2026, pp: 42-53
DOI: https://doi.org/10.70188/6866gp68

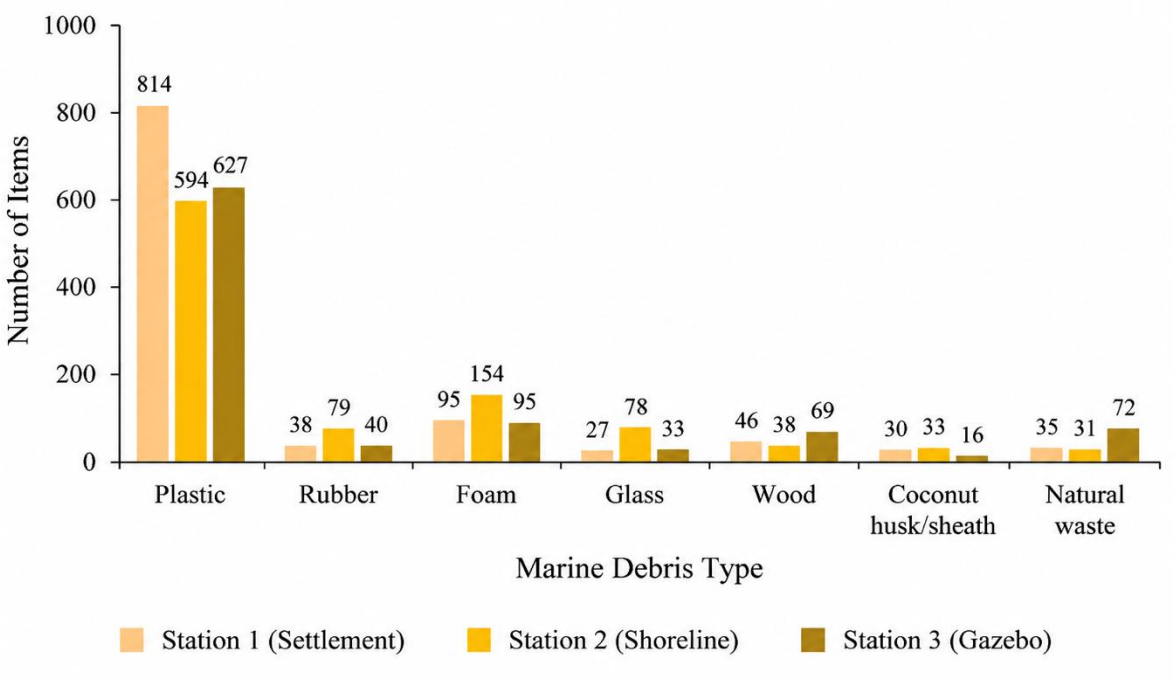


Figure 5. Comparison of marine debris abundance among sampling stations
Source: Research findings, 2025

Overall, plastic was the most abundant marine debris category at Laguna Beach, while the relative contributions of other materials differed among the three stations. These differences characterize the observed spatial distribution and may be associated with local activities and environmental transport processes, although those relationships were not directly tested.

3. Marine Debris Mass

In addition to abundance, the mass of marine debris provides information about the physical contribution of different material categories to the waste load at each station.

Table 3. Mass of marine debris by type and sampling station

Marine debris type	Station 1 (kg)	Station 2 (kg)	Station 3 (kg)
Plastic	19.259	12.029	12.454
Wood	17.797	15.079	19.092
Coconut husk/sheath	12.504	12.592	5.886
Natural waste	9.446	9.119	12.047
Rubber	6.350	11.957	6.659
Foam	5.885	11.522	8.408
Glass	6.580	Not reported	5.495

Note: The original dataset provided for Station 2 does not report the mass of glass
Source: Research findings, 2025

At Station 1, plastic had the highest mass at 19.259 kg, followed by wood at 17.797 kg and coconut husk/sheath at 12.504 kg. The high mass of plastic corresponds with its high abundance and reinforces the importance of domestic activities as a potential contributor to marine debris at this station. However, the relatively high mass of wood indicates that abundance alone does not determine the contribution of a particular material to the total waste load. At Station 2, wood had the highest recorded mass (15.079 kg), followed by coconut husk/sheath (12.592 kg), plastic (12.029 kg), rubber (11.957 kg), and foam (11.522 kg). The relatively balanced mass distribution among several categories indicates that the shoreline receives or retains debris from multiple sources. This pattern is consistent with the concept of

Volume 1, Issue 2, 2026, pp: 42-53
DOI: https://doi.org/10.70188/6866gp68

coastal zones acting as transition areas where terrestrial and marine debris pathways intersect (Purba et al., 2024; Zlateva et al., 2024) .

At Station 3, wood recorded the highest mass at 19.092 kg, followed by plastic (12.454 kg) and natural waste (12.047 kg). The high mass of wood and natural materials suggests that this area may function as a retention zone for larger organic materials. In addition to naturally transported materials, some wood may originate from human activities around the recreational area.

The comparison demonstrates that the material with the highest mass differs from the material with the highest abundance. Plastic dominates in terms of number of items, particularly at Station 1, whereas wood contributes substantially to total mass, especially at Station 3. This distinction is important because abundance and mass describe different characteristics of marine debris. A large number of lightweight plastic items may coexist with a smaller number of heavier wood materials. Consequently, both metrics should be reported when characterizing marine debris.

4. Potential Sources in Relation to Spatial Distribution

Based on the physical characteristics, locations, and types of debris observed, the marine debris at Laguna Beach can be associated with three broad source categories: domestic activities, natural/ecological processes, and tourism or visitor activities.

Table 4. Potential sources of marine debris based on material type

No.	Marine debris type	Examples	Potential source
1	Plastic	Straws, bags, food wrappers	Domestic activities, tourism
2	Rubber	Sandals, shoes, rubber fragments	Domestic activities
3	Foam	Food containers, Styrofoam	Tourism, domestic activities
4	Glass	Bottles, fragments	Domestic activities, tourism
5	Wood	Wood pieces, branches	Natural processes, tourism
6	Coconut husk/sheath	Coconut fibers, coconut husks	Natural processes, tourism
7	Natural waste	Leaves, food residues, corn husks, banana peels	Natural processes, tourism

Source: Research findings, 2025

The composition of debris suggests that domestic and tourism-related activities are important potential sources, particularly for plastic, rubber, foam, and glass. The high abundance of plastic at the settlement station provides additional evidence that proximity to human activity is associated with marine debris accumulation. However, source attribution based solely on debris type should be interpreted as an indication rather than definitive proof of origin. Identifying actual sources would require additional approaches such as interviews, land-use analysis, hydrodynamic modelling, or particle tracking, as recommended by (Purba et al., 2024; Zlateva et al., 2024) .

Natural materials such as leaves, branches, and coconut-derived materials may originate from coastal vegetation and may subsequently be transported by wind and currents. The presence of burned coconut material and wood also indicates a possible contribution from visitor activities. Thus, the observed marine debris pattern reflects a combination of anthropogenic inputs and natural transport processes, rather than a single source.

5. Spatial Distribution of Marine Debris

The spatial distribution of marine debris was characterized by comparing mass density, calculated as debris mass per unit sampling area, among the three stations. Differences among stations and material categories were used to describe station-level accumulation patterns.

Volume 1, Issue 2, 2026, pp: 42-53
DOI: https://doi.org/10.70188/6866gp68

Table 5. Marine debris density at Station 1

Marine debris type	Density (kg/m²)
Plastic	0.0128
Coconut husk/sheath	0.0083
Natural waste	0.0062
Glass	0.0043
Rubber	0.0042
Foam	0.0039
Wood	0.0011

Source: Research findings, 2025

At Station 1, plastic exhibited the highest density (0.0128 kg/m²), followed by coconut husk/sheath (0.0083 kg/m²) and natural waste (0.0062 kg/m²). The dominance of plastic in this area corresponds with the high number of plastic items recorded at the settlement station and indicates that the area represents an important zone of plastic accumulation.

Table 6. Marine debris density at Station 2

Marine debris type	Density (kg/m²)
Wood	0.0100
Glass	0.0083
Coconut husk/sheath	0.0081
Plastic	0.0080
Rubber	0.0079
Foam	0.0076
Natural waste	0.0060

Source: Research findings, 2025

Station 2 displayed a relatively more balanced distribution among the seven debris categories. Wood had the highest density (0.0100 kg/m²), followed by glass (0.0083 kg/m²), coconut husk/sheath (0.0081 kg/m²), and plastic (0.0080 kg/m²). The relatively even distribution suggests that the shoreline may act as an accumulation interface for materials transported from different directions. Similar spatial concentration patterns have been documented in studies identifying marine litter hotspots and coastal accumulation areas (Capodici et al., 2024; Sánchez-García et al., 2024) .

Table 7. Marine debris density at Station 3

Marine debris type	**Density (kg/m²)**
Wood	0.0127
Plastic	0.0083
Natural waste	0.0080
Foam	0.0056
Rubber	0.0044
Coconut husk/sheath	0.0039
Glass	0.0036

Source: Research findings, 2025

Station 3 was characterized by the highest density of wood (0.0127 kg/m²), followed by plastic (0.0083 kg/m²) and natural waste (0.0080 kg/m²). The concentration of wood and natural materials in the gazebo area may reflect both the accumulation of naturally transported organic material and local recreational activities. The comparison among the three stations demonstrates clear differences in the spatial distribution of individual debris categories. Plastic had the highest density at Station 1, while wood had the highest density at Station 3. Station 2 showed a relatively balanced distribution across several categories, suggesting that the shoreline may function as a transition and retention zone.

The observed station-level differences suggest that several factors may contribute to marine debris distribution at Laguna Beach, including human activity, coastal location, wind, currents, and material characteristics. Their relative contributions cannot be determined from the present descriptive survey. Lightweight floating materials such as plastic and foam have greater potential for transport by wind and surface currents, whereas heavier materials may remain closer to their sources or accumulate in areas where local hydrodynamic energy is reduced. This interpretation is consistent with studies demonstrating that marine debris pathways and accumulation are influenced by both hydrodynamic processes and the characteristics of surrounding land use (Cloux et al., 2024; Purba et al., 2024; Schreyers et al., 2024) .

Overall, the findings indicate that Station 1 represents the most prominent plastic accumulation area, Station 2 functions as a relatively diverse shoreline accumulation zone, and Station 3 shows a greater concentration of wood and natural materials. The results therefore provide evidence that management interventions should consider the characteristics of each coastal zone rather than applying an identical waste-management strategy across the entire beach.

CONCLUSION

This study characterized the spatial distribution of marine debris at Laguna Beach, Pao-Pao Village, Barru Regency, Indonesia, through comparisons of composition, abundance, mass, and density among three sampling stations. Seven material categories were recorded: plastic, rubber, foam, glass, wood, coconut husk/sheath, and natural waste. Plastic dominated debris abundance at all stations, accounting for 75% at the settlement station, 59% at the shoreline station, and 66% at the gazebo station. The settlement station contained the highest number of plastic items (814), identifying it as a priority area for plastic-waste management within the surveyed locations.

The dominant material by mass differed among stations: plastic had the highest mass at the settlement station (19.259 kg), while wood had the highest recorded mass at the shoreline (15.079 kg) and gazebo (19.092 kg) stations. Reported density patterns likewise identified prominent plastic accumulation at the settlement station and wood accumulation at the gazebo station, whereas the shoreline showed a more balanced distribution across material categories. These station-level differences support location-specific management rather than a uniform approach across the beach. Domestic activities, tourism, and natural processes were identified as potential sources, while currents, wind, and waves provided contextual explanations for transport and retention; these relationships were not directly established by the descriptive survey. The findings are limited to the purposively selected stations surveyed in May 2025. Seasonal monitoring, verification of the density calculations, and source-tracking or hydrodynamic studies are needed to assess the persistence and drivers of the observed spatial patterns.

REFERENCES

Al Nahian, S., Rakib, M. R. J., Haider, S. M. B., Kumar, R., Walker, T. R., Khandaker, M. U., & Idris, A. M. (2022). Baseline marine litter abundance and distribution on Saint Martin Island, Bay of Bengal, Bangladesh. *Marine Pollution Bulletin*, *183*, 114091. https://doi.org/10.1016/j.marpolbul.2022.114091

Andersen, R., Harsaae, A. L., Kellner, A., Smyth, A., Westermann, T. A. R., Green, M., … Lorenz, C. (2024). Abundance, distribution and characteristics of microplastics in the North and South Atlantic Ocean. *Marine Pollution Bulletin*, *209*. https://doi.org/10.1016/j.marpolbul.2024.117217

Bajo, K., Romano, R., Kolvenbach, B., Nazemi, S. A., Shahgaldian, P., Corvini, P. F.-X., … Raddadi, N. (2024). Biodegradation of untreated plasticizers-free linear low-density polyethylene films by marine bacteria. *Marine Pollution Bulletin*, *209*. https://doi.org/10.1016/j.marpolbul.2024.117115

Bobchev, N., Berov, D., Klayn, S., & Karamfilov, V. (2024). High microplastic pollution in marine sediments associated with urbanised areas along the SW Bulgarian Black Sea coast. *Marine Pollution Bulletin*, *209*. https://doi.org/10.1016/j.marpolbul.2024.117150

Capodici, F., Corbari, L., Gauci, A., Basilone, G., Bonanno, A., Campanella, S., … Aronica, S. (2024). Towards microplastic hotspots detection: A comparative analysis of in-situ sampling and sea surface currents derived by HF radars. *Marine Pollution Bulletin*, *209*. https://doi.org/10.1016/j.marpolbul.2024.117237

Cloux, S., Pérez, P., de Pablo, H., & Pérez-Muñuzuri, V. (2024). A regional Lagrangian model to evaluate the dispersion of floating macroplastics in the North Atlantic Ocean from land and river sources in the western coast of Spain. *Marine Pollution Bulletin*, *209*. https://doi.org/10.1016/j.marpolbul.2024.117110

Cózar, A., Arias, M., Suaria, G., Viejo, J., Aliani, S., Koutroulis, A., … Corradi, P. (2024). Proof of concept for a new sensor to monitor marine litter from space. *Nature Communications*, *15*(1). https://doi.org/10.1038/s41467-024-48674-7

Figuerola, B., Ruiz-García, D., Subías-Baratau, A., Maceda-Veiga, A., Sanchez-Vidal, A., & Barría, C. (2024). Adapting to a pollution hotspot? Catsharks shift to plastic substrates for oviposition. *Science of the Total Environment*, *955*. https://doi.org/10.1016/j.scitotenv.2024.176998

Fuller, N., McMahon, E., North, A., Petty, A. J., Tzetzis, C., Calus, J., … Gerringer, M. E. (2024). Observations of trash in the deep tropical Atlantic and Caribbean Sea. *Marine Pollution Bulletin*, *209*. https://doi.org/10.1016/j.marpolbul.2024.117182

Guffogg, J., Soto-Berelov, M., Bellman, C., Jones, S., & Skidmore, A. (2024). Beached Plastic Debris Index; a modern index for detecting plastics on beaches. *Marine Pollution Bulletin*, *209*. https://doi.org/10.1016/j.marpolbul.2024.117124

Kungskulniti, N., Charoenca, N., Hamann, S. L., Pitayarangsarit, S., & Mock, J. (2018). Cigarette waste in popular beaches in Thailand: high densities that demand environmental action. *International Journal of Environmental Research and Public Health*, *15*(4), 630.

Lee, S. B., Yuen, A. H. L., Kim, S., Jung, W. J., Kim, D.-G., Kim, S. W., … Park, S. C. (2024). Ingestion of fishing gear and Anisakis sp. infection in a beached Indo-Pacific finless porpoise (Neophocaena phocaenoides) in the Jeju Island, Republic of Korea: findings from post-mortem computed tomography and necropsy. *BMC Veterinary Research*, *20*(1). https://doi.org/10.1186/s12917-024-04090-z

Pedà, C., Rizzo, C., Laface, F., Giannarelli, S., Battaglia, P., Romeo, T., & Lo Giudice, A. (2024). First evidence of microplastic ingestion by the European grayling, Thymallus thymallus, in sub-Arctic regions: Insights on plastic pollution and preliminary risk assessment in the Teno River (Finland). *Science of the Total Environment*, *957*. https://doi.org/10.1016/j.scitotenv.2024.177603

Purba, N. P., Faizal, I., Christie, D., Pratama, M. B., Valino, D. A., Martasuganda, M. K., … Pasaribu, B. (2024). Mapping the sources and strands of marine debris via particle modelling and In-situ sampling approaches in archipelagic countries. *Scientific Reports*, *14*(1). https://doi.org/10.1038/s41598-024-73373-0

Sabaliauskaitė, V., Kataržytė, M., Rubavičiūtė, R., Tiškus, E., & Balčiūnas, A. (2024). Beach wrack as a potential microplastic hot spot in the South-Eastern Baltic Sea environment. *Marine Pollution Bulletin*, *209*. https://doi.org/10.1016/j.marpolbul.2024.117139

Sánchez-García, N., Alomar, C., Rios-Fuster, B., Vazquez-Bonales, J. A., Calleja-Setien, E., Ventero, A., … Deudero, S. (2024). Identifying macrofloating debris hotspots in the Mediterranean Sea applying multiplatform methodologies. *Science of the Total Environment*, *955*. https://doi.org/10.1016/j.scitotenv.2024.176860

Schreyers, L. J., Erismann, R., Erismann, S., Ludwig, C., Patel, B., Filella, M., & van Emmerik, T. H. M. (2024). Revealing the role of land-use features on macrolitter distribution in Swiss freshwaters. *Environmental Pollution*, *362*. https://doi.org/10.1016/j.envpol.2024.124911

Stead, J. L., de Souza Leite, L., & Bond, T. (2024). Gradient columns to measure the density of microplastics. *Science of the Total Environment*, *953*. https://doi.org/10.1016/j.scitotenv.2024.176176

Sun, X.-F., Zhang, Y., Xie, M.-Y., Mai, L., & Zeng, E. Y. (2024). Calcite carbonate sinks low-density plastic debris in open oceans. *Nature Communications*, *15*(1). https://doi.org/10.1038/s41467-024-49074-7

Teng, G., Chen, W., Shan, X., Shi, Y., & Jin, X. (2024). Temporal and spatial distribution of floating marine macro litter in the offshore waters of the Bohai Sea and Yellow Sea (BYS). *Marine Pollution Bulletin*, *209*. https://doi.org/10.1016/j.marpolbul.2024.117232

Velander, K. A., & Mocogni, M. (1998). Maritime litter and sewage contamination at Cramond Beach Edinburgh—a comparative study. *Marine Pollution Bulletin*, *36*(5), 385–389. https://doi.org/10.1016/S0025-326X(97)00204-X

Williams, R., Ashe, E., & O'Hara, P. D. (2011). Marine mammals and debris in coastal waters of British Columbia, Canada. *Marine Pollution Bulletin*, *62*(6), 1303–1316. https://doi.org/10.1016/j.marpolbul.2011.02.029

Zlateva, I., Ricker, M., Slabakova, V., Slavova, K., Doncheva, V., Staneva, J., … Raykov, V. (2024). Analysis of terrestrial and riverine sources of plastic litter contributing to plastic pollution in the Western Black Sea using a lagrangian particle tracking model. *Marine Pollution Bulletin*, *209*. https://doi.org/10.1016/j.marpolbul.2024.117108