WASS
Waste, Society and Sustainability
WASS 2(1): 55–71
ISSN 3062-8202

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Temporal dynamics and geomorphological influences on plastic waste accumulation

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Received Date: January 28, 2025 Revised Date: February 21, 2025 Accepted Date: February 28, 2025

ABSTRACT

Background: Plastic waste is a significant global environmental issue and constitutes the dominant type of marine debris. Its durability, lightness, and stability make plastic widely used in daily life, but its degradation process takes an extremely long time. Teluk Laikang, located in Mangarabombang Subdistrict, Puntondo Hamlet, Takalar Regency, serves as both a coastal tourism destination and a site for seaweed cultivation. This study aims to quantify the amount, weight, and composition of stranded plastic waste at Teluk Laikang Beach over a specific observation period and to analyze the accumulation rates influenced by the geomorphology and oceanographic conditions of the area. **Methods:** The study utilized a shoreline survey method with an accumulation survey type. This method involves regular monitoring of the same stretch of coastline, which was initially cleaned, to record changes in the amount, weight, and composition of plastic waste over time. Direct field measurements were carried out to assess current speed and direction, wave height, and beach slope. **Findings:** The study identified a total of 709 plastic waste items weighing 3,584 grams in Teluk Laikang. Statistical analysis using repeated measures ANOVA revealed significant differences in plastic accumulation rates based on lunar phases. Pairwise comparisons showed that the highest accumulation rates occurred during the full moon phase, with an average of 0.00063 items/m^2/week and 0.00841 grams/m^2/week. Conversely, the lowest rates were recorded during the first-quarter moon phase, with an average of 0.00023 items/m^2/week and 0.00082 grams/m^2/week. The most dominant type of plastic waste during the observation period was drink bottles smaller than 2 liters (PL02). **Novelty/Originality of this Article:** This study provides a detailed analysis of plastic waste accumulation in a semi-enclosed coastal area influenced by geomorphological and oceanographic factors. It is one of the first studies to explore the relationship between lunar phases and plastic waste accumulation rates in Teluk Laikang. By focusing on the temporal variation of waste deposition, the research highlights the critical role of natural cycles in plastic waste distribution.

KEYWORDS: plastic waste; moon phase, laikang bay beach; waste management.

1. Introduction

Plastic waste is one of the significant global environmental problems. Plastic is the dominant type of marine debris. The strong, lightweight and stable nature of plastic makes it widely used in everyday life, but the decomposition process takes a very long time. This is the cause of the accumulation of plastic waste in land and ocean areas, and can have a negative impact on the environment and life of marine ecosystems. Efforts to reduce the use of single-use plastics, one of which is the increase in plastic recycling, is important step in overcoming this problem (Kadir, 2012). The plastics circulating and found in the ocean today are conventional plastics. These plastics are synthetic polymers made from petroleum

Cite This Article:
Al-Munnawwir, M. J., Werorilangi, S., Samad, W. (2025). Temporal dynamics and geomorphological influences on plastic waste accumulation. *Waste, Society and Sustainability, 2*(1), 55-71. https://doi.org/10.61511/wass.v2i1.2025.1733

and have properties that are difficult to decompose in nature. Nowadays, more and more people use plastic because of its economical nature. As a result, more and more waste piles contain plastic in the environment. Based on the results of Yolanda's research (2022) said that the overall total plastic waste on karama beach was 2,402 items weighing 0.010 kg. The plastic category is dominated by food containers, plastic bags and disposable bottles and eating/drinking utensils and the plastic foam category is dominated by cork (refrigeration insulation and packing). Plastic waste stranded in the ocean will continue to float on the surface of the sea and will accumulate on the seabed, shoreline and be carried to the polar regions. The accumulation of such waste in coastal areas is due to the influence of wind, waves and current circulation which acts as a transport medium. In addition, the waste contained in a coastal area is also influenced by the high and low sea level (tides) where it is caused by the influence of the moon phase and the attraction between the earth, moon, and sun (GESAMP, 2019). Based on the results of Yusril's research (2023), the highest rate of plastic waste accumulation was found in the dead moon and full moon phase tides.

Laikang Bay is one of the tourist destinations in Mangarabombang District, Puntondo Hamlet, Takalar Regency where there are many anthropogenic activities, one of which is seaweed cultivation and beach tourism (Dahliati, 2022). In addition, Laikang Bay is a body of water that protrudes into the land or coast so that it is a semi-enclosed area that can cause accumulation of waste in the area. The problem of plastic waste in the waters of Laikang Bay has not been resolved properly, reducing the beauty value of tourism in the Laikang Bay area. About 10% of the waste that is thrown into the waters is generally plastic, clothing, and wood and others. Waste coastal areas and coastal areas is a complex problem that affects all aspects of both marine organisms, terrestrial organisms and health so that it can affect the rate of economic growth (Maulana, 2016) Various waste problems in the waters and coastal areas of Laikang Bay are the cause of the importance of exploring the rate of accumulation of plastic waste that can affect geomorphological and oceanographic conditions in the waters of Laikang Bay, Takalar Regency.

2. Methods

This research was conducted on October 8, 2023 - July 11, 2024. Laikang Bay is located in Puntondo Hamlet, Laikang Village, Mangarabombang District, Takalar Regency, South Sulawesi. The beach is about 50 km from the city of Makassar. The access to the bay is fairly easy and can be accessed using two-wheeled or four-wheeled vehicles. Research location can be seen in Figure 1.

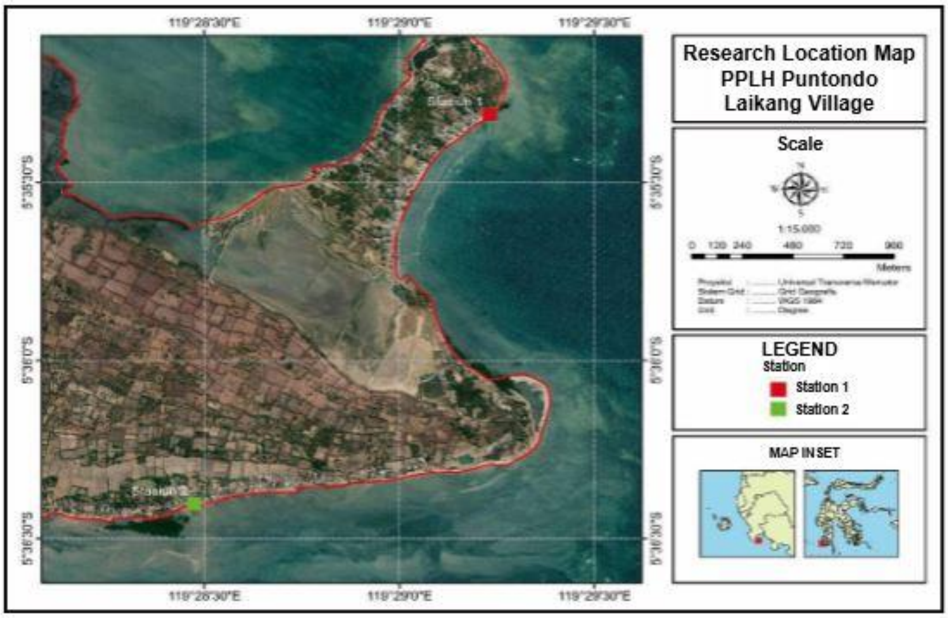

Fig.1. Research location

 https://doi.org/10.61511/wass.v2i1.2025.1733

The preparation stage includes literature study related to the research title, initial survey in the field, determination of research methods, collection of tools and materials that will be used in the research process. Determination of observation stations is based on consideration of the results of preliminary observations in the field. The principle of determining this station is based on the representation of locations where there are 2 stations, station 1 is in the cape area while station 2 is directly adjacent to the open sea. The research method used in this study is the shoreline survey method with the accumulation survey type. The basic objective of shoreline monitoring is to record changes in the amount, weight, and/or composition of litter stranded on the beach over time and can be used to infer changes in litter loading at sea, as well as in adjacent coastal waters. Accumulation surveys are repeated regularly on the same stretch of shoreline that has been previously cleaned (GESAMP, 2019). Direct field measurement methods were used to measure current speed and direction, wave height, and beach slope. The data used in this study include primary data obtained from field surveys, namely data on the amount and weight of plastic waste and physical parameter data (current speed and direction, wave height, and beach slope), as well as secondary data (image of the research location) obtained through image downloads on the SASPlanet application, and tidal data.

Table 1. Tools and materials.

Tools and Materials	Usability
Stationery	Data logger in the field
Camera	Documenting research activities
GPS	Determination of field coordinates
Compass	Directions
Trash Bag	Plastic waste containers
Patok	As a transect laying pole
Roll meter	Measure the length of the transect at each station
Rope	As a transect
Laptop	Primary and secondary data processing
Digital scales	Weighing plastic waste
Current kite	Current speed meter
Geological compass	Beach slope meter
Digital anemometer	Wind speed meter
Measuring signs	Wave height and beach depth gauges
Stopwatch	Measuring time lapse
Plastic waste sample	Objects analyzed
Physical parameter data	Analyzed materials
Abundance of plastic waste	Analyzed materials

The accumulation survey method was used to determine the accumulation of plastic waste deposited on the beach. The plastic waste collected is macro-sized plastic waste, plastic type and plastic foam based on UNEP classification (Chesire et al., 2009). There are 3 sampling units used where one sampling unit will be placed at each station. Placement of sampling units parallel to the shoreline along 100 m and placed at the lowest ebb to the backshore (there is growing vegetation or buildings). Where each unit is divided into 20 transects each with a width of 5 m. After that, in each sampling unit, 4 transects will be randomly selected as plastic waste collection points. The 4 points will continue to be used as sampling points throughout the period. The 4 sampling points will be divided into 2 sampling areas, namely the first area from the lowest tide to the standing line and the second area from the standing line to the backshore (Figure 2). Taking coordinate points on each transect to ensure data collection is carried out at the same point the following week. Data collection on the amount and weight of plastic waste was carried out at the lowest tide for 4 weeks. The selection of data collection time is based on the different moon phases in each week, namely the dead moon phase, 1/4 moon, full moon, and 3/4 moon. Before the study began, the sampling unit was first cleaned of marine debris and then the same thing was done at the beginning of each new phase. A special treatment was given to the research site, namely appealing to the local community not to throw garbage at the research site. All macro-sized plastic waste found at each sampling point was collected and cleaned first, then counted and weighed. From these data, we can calculate the abundance of plastic waste and the weekly accumulation rate of plastic waste at the data collection location. A sketch of the plastic waste sampling unit can be seen in Figure 2.

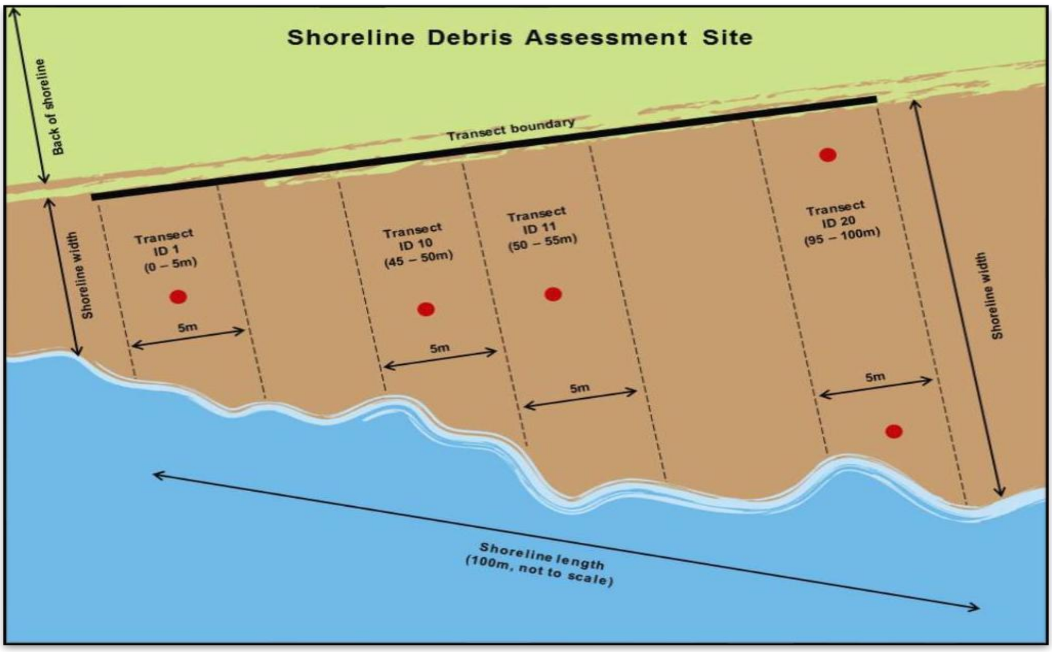

Fig. 2. Sketch of plastic waste sampling unit
(Lippiat et al., 2013)

The current speed was measured using a current kite and the direction of the current was determined using a compass, which determines the starting point of the current kite when it is released until it reaches its final distance. Current measurements were taken at each station with 3 repetitions to obtain more accurate data. Wave measurements aim to determine the movement up (peaks) and down (valleys) of the sea surface using a scaled pole, wave measurements were taken at each predetermined station 51 times with a repetition of 3 times. The difference in value between the peak and valley of the measured wave is the wave height value. Wave period measurements were taken using a stopwatch. The direction of incoming waves was determined using a compass. Tidal measurements are not carried out directly in the field, but tidal data is secondary data obtained from observation data.

3. Results and Discussion

3.1 General condition of the research location

Laikang Bay is located in Puntondo Hamlet, Laikang Village, Mangarabombang District, Takalar Regency, South Sulawesi. The beach is about 50 km from the city of Makassar. The access to the bay is fairly easy and can be accessed using two-wheeled or four-wheeled vehicles. The research location was carried out at 2 stations on the beach of Laikang Bay, Takalar Regency, namely Station 1 located in the inner part Laikang Bay, and Station 2 located in the outer part of Laikang Bay. Station 1 is located in the inner part of Laikang Bay at the end of Laikang Bay adjacent to tourist destinations which are thought to have the potential for the distribution of plastic waste from tourist activities. Station 2 is located in the outer part of Laikang Bay adjacent to residential areas, and also at this location there is seaweed cultivation which allows the distribution of plastic waste that accumulates at this location. Sampling location of station 1 and station 2 can be seen in Figure 3

a

b


Fig. 3. (a) Sampling location of station 1; (b) Sampling location of station 2

3.2 Abundance of marine debris on beaches

Presidential Regulation No. 83/2018 on Marine Debris Handling, explains that marine debris is waste originating from land, water bodies, and coastal areas that flows into the sea or waste originating from activities at sea. Meanwhile, plastic waste is waste that contains polymer compounds. addition, GESAMP (2019) defines marine debris as persistent solid material that is produced or processed directly or indirectly, intentionally or unintentionally, dumped or abandoned into the marine environment. UNEP (2009) defines marine debris as solid materials that are difficult to decompose, are factory and processed products that are disposed of or left in the marine and coastal environment. The level of coastal and marine pollution is increasing due to the entry of remnants of human activities such as residual materials carried by water from agricultural areas, household waste, garbage, waste materials from ships, offshore oil spills and many other waste materials that are wasted and end up in the sea (Johan et al., 2020). Marine debris can be carried by ocean currents and winds from one place to another and can even cover long distances very far from the source (Djaguna et al., 2019).

Unmanaged garbage and the number of people who often throw garbage in rivers or coastal areas are contributing factors to the presence of garbage in the ocean. Flowing and stagnant surface water (such as lakes, reservoirs and swamps) and some groundwater (rivers) merge with each other to form large rivers, carrying all surface water to the surrounding sea. Indonesia's coastal areas include oceans that occupy 50% of the land and 70% of the population. This is why waste accumulates in the ocean. In general, marine debris can be classified into several sizes as shown in Table 2.

Table 2. Characteristics of marine debris by size

Type	Scale
Mega	>1 m
Macro	>2.5 cm - 1 m
Meso	>5 mm - 2.5 cm
Micro	1 µm- 5.5 mm
Nano	<1 µm

Marine debris can be divided into organic waste and inorganic waste based on its nature. Organic waste can be decomposed by microorganisms, while inorganic waste is difficult or even cannot be decomposed by microorganisms (Bangun et al., 2019). Plastic packaging and household appliances are the most common types of waste in daily life and have properties that are difficult degrade in nature. In addition, this type of waste is also categorized as the largest contributor to waste that causes damage to the balance of nature. The use of plastic in very large quantities will certainly have a significant impact on human health and the environment. To be completely decomposed (decomposed), plastic waste is estimated to take around 100 to 500 years (Johan et al., 2020). The method used in sampling marine debris data is the shoreline survey method. Opfer et al. (2012) mentioned that there are 2 types of shoreline survey methods that can be done, namely the standing stock and accumulation survey methods.

Pawar et al., 2016 argued that seas around the world have been contaminated by plastic waste from the poles to the equator, and from coastlines to small islands and even to uninhabited remote islands. Marine plastic waste has become one of the main problems at the national and even global levels and is a major threat to marine and coastal biodiversity (Kemenko Maritim, 2017). Coastal areas are transitional areas between land and sea that have great resource potential. This potential includes non-biological and biological potential. In line with that, the potential for pollution of coastal and marine areas is also quite large. This is due to the dense population of Indonesia, high coastal and marine tourism activities including transportation, and large development (Djaguna et al., 2019).

Indonesia has mega-biodiversity and is dubbed as the "Amazon of the Ocean". Unfortunately, the vast ecosystems of coral reefs, mangroves and seagrasses are currently in danger due to the accumulation of plastic waste that can be easily found along the coastline. The UN estimates that 45-70% of all marine debris is persistent plastics and hazardous pollutants (Kemenko Maritim, 2017). Barboza et al., (2019) estimate that the peak of the global increase in marine debris will occur in 2025 if not taken seriously. Because the impacts caused by marine debris can threaten the survival and sustainability of aquatic biota, making the issue of marine debris a very critical problem today, Isman (2016).

Plastic waste is one of the easiest and most common categories of marine debris found at the bottom of the water, in the water column and even in coastal areas. The size and mass of plastic waste that is light so that it easily floats and is carried by ocean currents is one of the factors. This is supported by the results of research conducted by Isman (2016) in the Makassar City Waters area which shows that the most common type of marine debris found both in high and low tide conditions is plastic waste. In line with the results of research conducted by Yolanda (2022) at Karama Beach and also Yusril (2023) located on Salissingan island using the accumulation survey method, it shows that the abundance of plastic marine debris ranks top compared to other types of marine debris. The same thing was also found by Kneefel (2021) at Mallasoro Bay Beach, Jeneponto Regency. The results showed that macro-sized plastic waste dominated marine debris in the area. The average abundance of plastic waste amounted to 0.75 items/m^2 and the average abundance of plastic waste weight reached 19.22 gr/m^2.

3.3 Waste accumulation rate

According to the Kamus Besar Bahasa Indonesia (KBBI) rate is speed, while accumulation is the collection or addition (both in quantity and weight) of something. The rate of plastic waste accumulation is the addition (both in quantity and weight) of plastic waste at a certain speed (time span). One of the drastic changes in the last half-century on our planet is the abundance and accumulation of waste that can easily be found everywhere, including in the oceans. The accumulation of marine debris from human activities at sea and on land has been a conservation issue related to water pollution since the 1970s (Thiel et al., 2021). Studies show the accumulation of marine debris has been found in shallow waters, deep waters and even in water areas far human activities (Barnes, 2009). Research conducted by Eriksson et al., 2013 in the coastal areas of Sub-Antarctic islands showed that plastic marine debris is the most dominating type of marine debris in the ocean. The accumulation of both macro- and micro-sized plastic waste in the last four decades has increased consistently in coastal areas and sediments. Barnes (2009) suggested that 40-80% of the total accumulated marine debris is plastic debris. Studies conducted by Ivar and Costa (2007) in Central and South America also show that plastic waste due to human activities on land dominates marine debris in the region. Whereas in remote islands, fishing-related debris is more common.

The rate of marine debris accumulation is influenced by many factors. One factor that plays a major role is the physical oceanographic conditions that occur in these waters. Accumulation rate studies conducted in certain time intervals such as in certain seasons, annually, monthly, weekly and even daily show significant differences in accumulation rates. This is caused by differences in oceanographic conditions that occur within a certain period of time. One of them is the speed and direction of current and wind movements that allow waste transportation (Eriksson et al., 2013). Purba et al., (2018) conducted a study to see the accumulation of waste in the Pangandaran Beach area, West Java in 2016 and 2017. The study showed that the highest accumulation of waste occurred in October with a total weight of 44.3 kg and 33% of which was plastic waste while the lowest accumulation occurred in May at 38 kg. This very significant difference was influenced by the physical oceanographic conditions that occurred at that time. In October (Western season), the rainfall was very high, resulting in the overflow of rivers around the Pangandaran Beach area so that the debris was washed away and ended up on the beach. In addition, high current and wind speed also had a major influence on the accumulation of garbage.

3.4 Plastic waste abundance and composition

During data collection in the field, there were two categories of plastic waste found with different amounts and weights, namely the plastic waste (PL) and plastic foam (FP) categories. Overall, the highest amount and weight of waste was found in the plastic waste (PL) category and the lowest waste category was found in the plastic foam (FP) category. The highest total amount of plastic waste is in the full moon phase and the lowest total amount of waste is in the 1/4 moon phase, while the highest weight of waste is in the 3/4 moon phase and the lowest total weight of waste is in the 1/4 moon phase. Total amount and weight of waste by month phase can be seen in Figure 4.

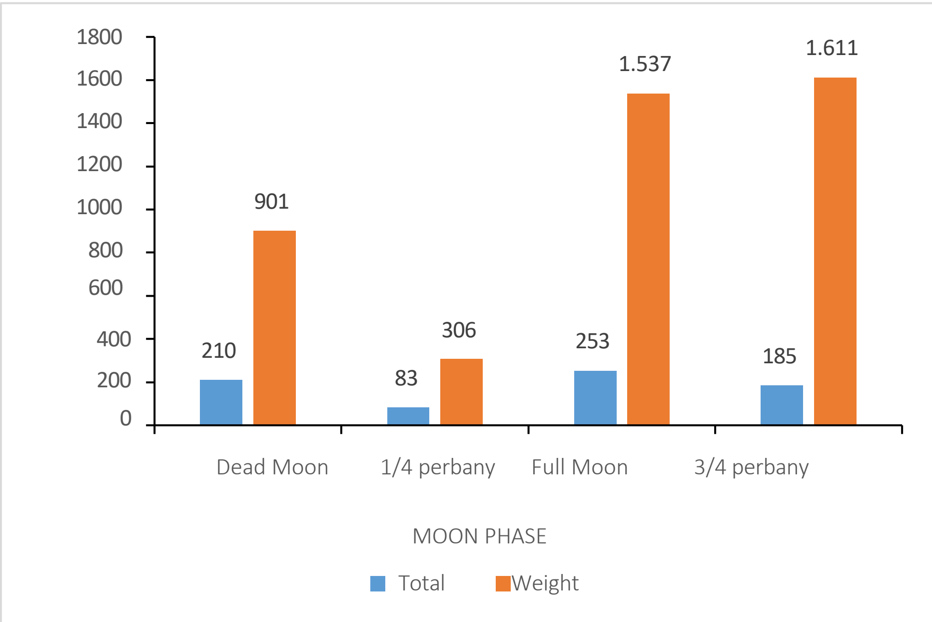

Fig. 4. Total amount and weight of waste by month phase

In the dead moon phase, the amount of waste at station 1 reached 132 items with a weight of 571.9 grams while station 2 reached 78 items and a weight of 329.5 grams. In the 1/4-moon phase there was a decrease in the amount and weight of waste at both stations, then in the full moon phase there was an increase in the amount and weight of waste from both stations, until in the 3/4-moon phase there was a decrease in the amount of waste at two stations while the weight at station 1 increased to reach 1,202 grams and station 2 decreased to 409 grams. Total waste by plastic waste category can be seen in Figure 5.

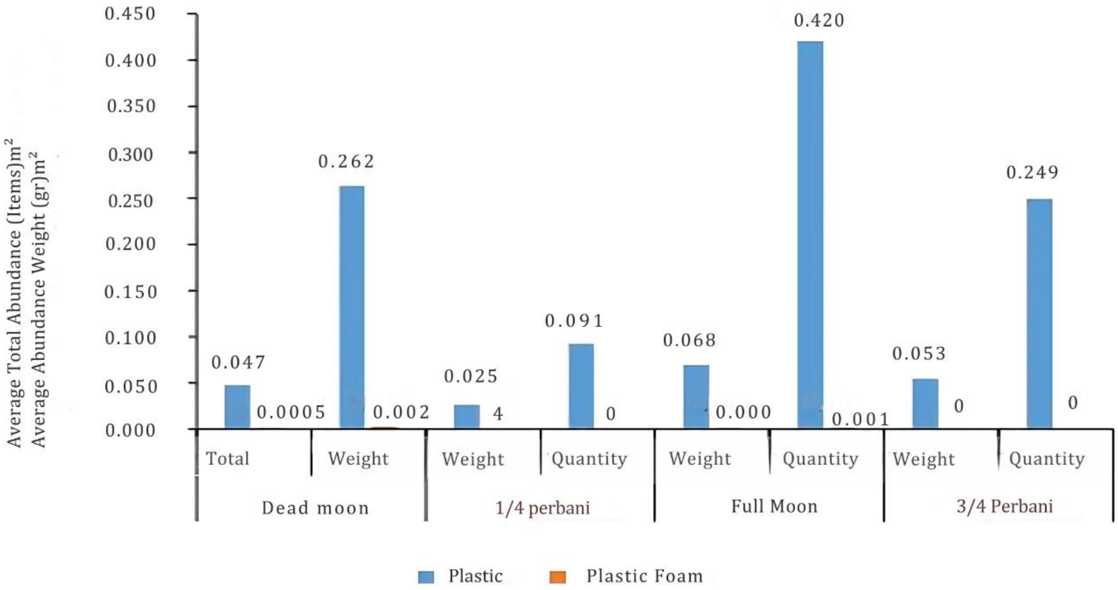

Fig. 5. Total waste by plastic waste category

Total waste by category of plastic and plastic foam can be seen in Figure 8. Total waste by category of plastic was 718 items weighing 3,521 g. While plastic foam was 15 items weighing 62.5 g. The average abundance of the number and weight of waste was highest during the Full Moon phase (October 29, 2023) with a number of 0.07 items/m^2 and an average weight of 0.42 gr/m^2. In the dead moon phase, the average abundance of garbage at station 1 reached 0.015 items with a weight of 0.095 grams while station 2 the number of garbage was 0.015 items with a weight of 0.095 grams waste reached 0.009 items and weight reached 0.038 grams. In the 1/4-moon phase there was a decrease in the amount and weight of waste at both stations, then in the full moon phase there was an increase in the amount and weight of waste from both stations, until in the 3/4-moon phase there was a decrease in the weight of waste at two stations. The highest average abundance of the number and weight of waste in the plastic category occurred in the Full Moon phase. Meanwhile, the average number and weight of abundance in the plastic foam category was highest during the dead moon. Average waste abundance by category can be seen in Figure 6.

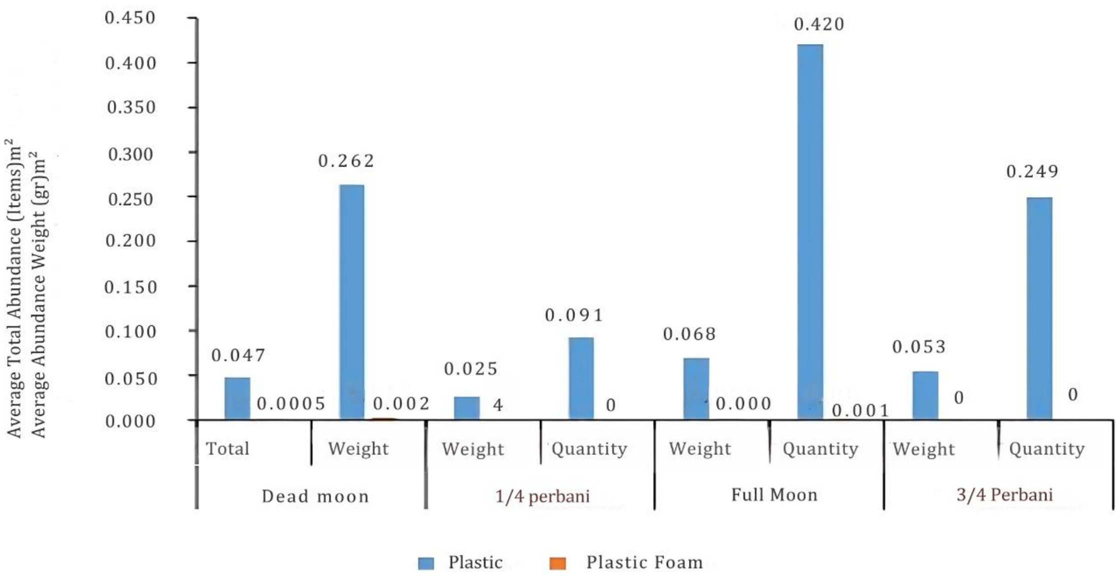

Fig. 6. Average waste abundance by category

3.5 Oceanographic parameters

Based on the measurement data in the field, the highest average wave is in the full moon phase of station 2 while the lowest average wave is in the 1/4 moon phase of station 1. Wave data between stations in Laikang Bay can be seen in Table 3.

Table 3. Wave data between station in Laikang Bay

Time	Station	Wave (cm)
15-Oct-23	1	11.47
	2	6.06
22-Oct-23	1	4.12
	2	6.53
29-Oct-23	1	6.53
	2	16.53
05-Nov-23	1	6.76
	2	5.65

Based on the results of data processing, the highest tide is 52 cm. While the lowest ebb is -91.2 cm and the value of msl obtained is 0.1 cm and the harmonic constant is obtained Formzhal value of 1.9 which is included in the type of diurnal tide, where in one day there is one tide and one low tide. Tidal graph can be seen in Figure 7.

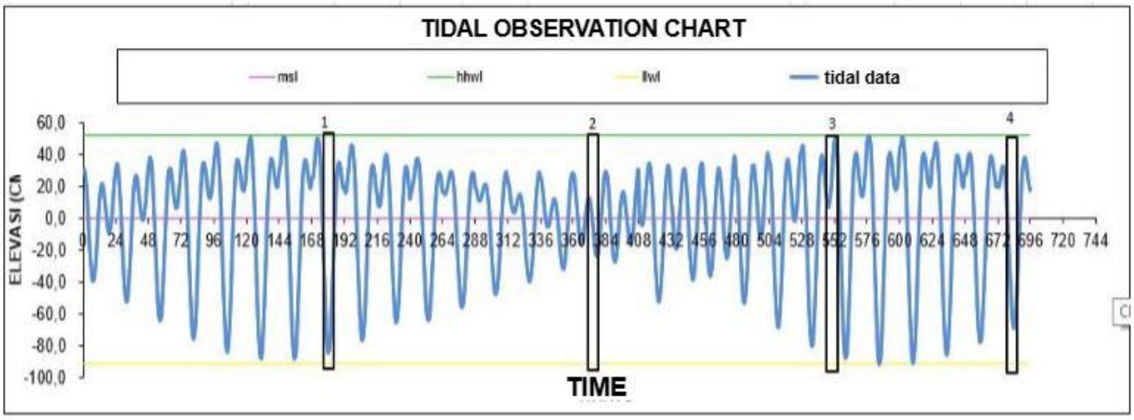

Fig. 7. Tidal graph

Harmonic constants of tidal calculation results using admiralty can be seen in Table 4.

Table 4. Harmonic constants of tidal calculation results using admiralty

	So	M2	S2	N2	K2	K1	O1	P1	M4	MS4
A (cm)	0.1	6.9	8.1	18.8	1.9	20.9	7.5	6.9	0.2	0.1
G		328.5	64.5	36.9	64.5	145.1	15.4	145.1	65.8	259.4

Based on the results of data processing, the highest average wind speed was obtained on October 10, 2023 with a value of 7.0 m/s blowing 115 0 from the southeast. While the lowest average value occurred on October 27, 2023 at 2.5 m/s blowing 1150 from the southeast. During the field data collection period, the wind tends to come from the East. Windrose of Laikang Bay wind direction can be seen in Figure 8.

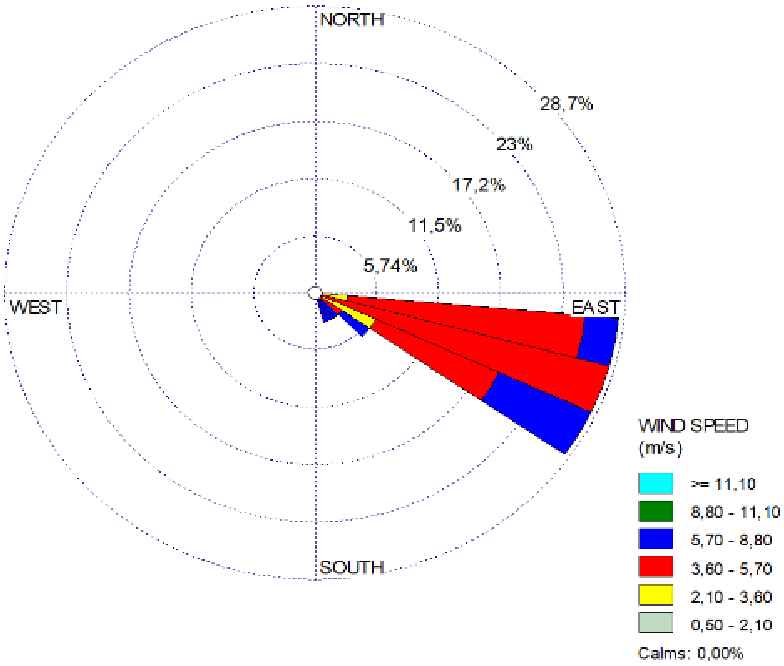

Fig. 8. Windrose of Laikang Bay wind direction

Based on the results of field measurements, the height of the coastal slope and the percentage of coastal slope in Laikang Bay can be seen in Table 9. The highest value of coastal slope and percentage of coastal slope is found at Station 2 with a slope value of 0.020 0 and a percentage of coastal slope of 2.033%. While the value of coastal slope and the lowest percentage of coastal slope is found at Station 1 with a slope value of 0.017 0 and a percentage value of coastal slope of 1.713%. Slope of Laikang Bay Beach can be seen in Table 5.

Table 5. Slope of Laikang Bay beach

Station	X (Width of distance between poles) m	Y (Altitude)	Beach Slope(^{0})	Percentage of Slope Beach(%)
1	50	0.857	0.017	1.713
2	50	1.017	0.020	2.033

3.6 Plastic waste accumulation rate

The accumulation rate based on the amount and weight of waste at the research location can be seen in Figure 15. Based on the results of the repeated measure anova test that has been carried out, there is a difference in the average accumulation rate based on the time or phase of the moon ($p = <0.05$,. The results of the Pairwise Comparisons further test show that the accumulation rate in the full moon phase (week 3) is higher if the accumulation rate in the full moon phase is higher than the accumulation rate in the full moon phase (week 3) compared to the accumulation rate in the quarter-moon phase (week 2). Descriptively, it can be seen that the accumulation rate of waste with the highest number and weight occurred during the full moon phase (October 29, 2023) with a total number of 0.00063 items/m^2/week and a weight of 0.00841 gr/m^2/week. While the accumulation rate with the lowest number and weight occurred during the ¼ moon phase (October 22, 2023) with a weight of 0.00082 gr/m^2/week and a total of 0.00023 items/m^2/. Trends in the average accumulation rate of the amount and weight of plastic waste by month phase can be seen in Figure 9.

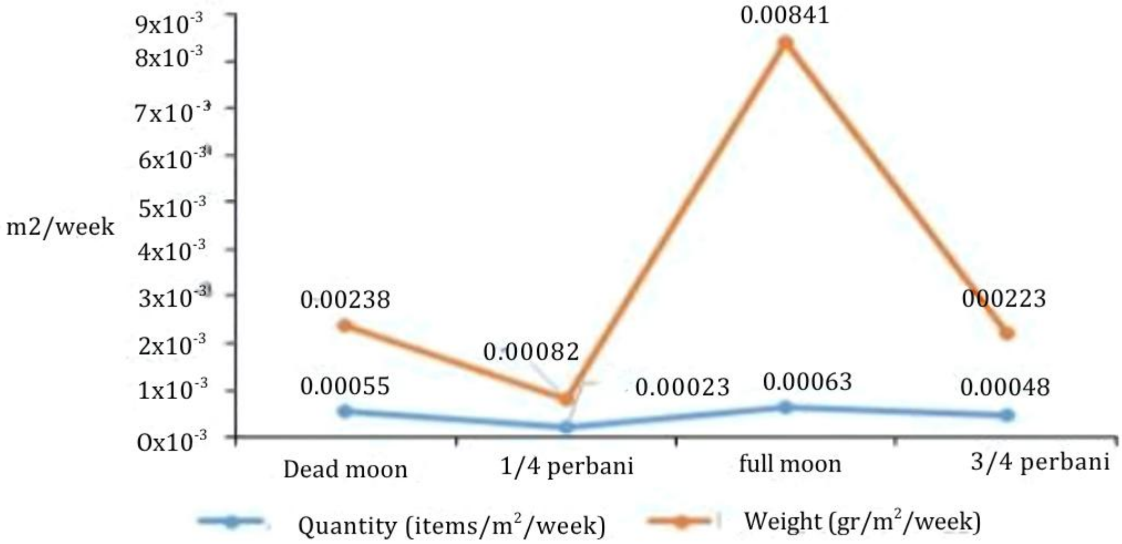

Fig. 9. Trends in the average accumulation rate of the amount and weight of plastic waste by month phase.

Based on the results of data processing, the accumulation rate of plastic waste was found at two stations. The highest accumulation rate at station 1 occurred during the dead moon phase with 0.0008 items/m^2/week while at station 2 the highest accumulation rate occurred during the full moon phase with 0.00055 items/m^2/week.The lowest rate of accumulation at station 1 occurred during the quarter moon phase with 0.0003 items/m^2/week and at station 2 the lowest rate occurred during the quarter moon phase with 0.00017 items/m^2/week which can be seen in Figure 16. The results of the Independent T-test, showed that the average accumulation rate at station 1, at 0.0006 was higher than station 2, at 0.0003 (p =< 0.05).

3.7 Composition and abundance of plastic waste

Based on the results of the research conducted, there are 2 types of plastic waste categories found in Laikang Bay, namely the plastic category (PL) and the plastic foam category (FP). Plastic waste (PL) was dominated by bottles <2 L (PL02) as many as 193 items weighing 1,577.7 grams and food container waste (PL06) as many as 150 items weighing 486.05 grams while the lowest types of waste were knife, fork, spoon, straw, stirrer and food utensils (PL04) as many as 4 items weighing 3.3 grams and plastic bag waste (PL07) as many as 4 items weighing 14.09 grams. Plastic bottle waste <2 L which is the largest amount of waste is influenced by the activities of local people who carry out seaweed cultivation. This is in accordance with Yahya's (2020) statement that seaweed cultivation and tourism activities in PPLH Puntondo produce plastic waste. addition, the conditions around the field collection location are tourist attractions which are thought to be a source of plastic waste. Hidayati et al. (2022) stated that the factors that influence the amount of plastic waste in the waters are waste management, water location, river discharge, and flood events.

As for the plastic foam category found in Laikang Bay, there are only 2 types, namely sponge foam waste (FP01) as many as 6 items weighing 17.1 grams and cork waste (FP04) as many as 9 items weighing 45.4 grams. amount found during the study was less than the amount obtained by Yusril (2023), which was 67 items weighing 554 g. This can occur because at the time of sampling the activity of fishermen was quite less because people tended to cultivate seaweed. Based on the amount and weight, the plastic waste category (PL) has a much higher amount and weight compared to the plastic foam category (FP). The amount and weight of waste for the plastic category has a total of 694 items and a total weight of 3,521.93 grams while the plastic foam category has a total of 15 items and a total weight of 62.5 grams. The highest total amount of waste was found in the full moon phase with 253 items weighing a total of 1,537 grams, including 244 items the plastic (PL) category (1,491.5 grams) and 9 items in the plastic foam (FP) category (45.4 grams). While the lowest amount of waste is found in the ¼ perbani moon phase with 83 items of plastic waste with the plastic category (PL) weighing 306 grams. With the highest abundance of waste found in the full moon phase with an average abundance of 0.07 items/ $m^2$with an average abundance weight of 0.42 gr/m^2, including 0.0685 items/m^2 (0.4206 gr/m^2) plastic category waste (PL) and 0.0002 items/m2 (0.0011 gr/m^2) plastic foam category waste (FP). While the lowest waste abundance was found in the ¼ perbani moon phase with an average abundance of 0.0254 items/m2 with the plastic category (PL) with an average weight abundance of 0.0913 gr/m^2. The results of this study are in line with research conducted by Yolanda (2022) at Karama Beach which shows that the plastic waste category is much more dominant with a percentage of 93.31% with a weight of 9,436.09 grams of total waste.

3.8 Plastic waste accumulation rate

Based on the results of the research conducted in Laikang Bay, it was found that the accumulation rate trend fluctuated as influenced by different moon phases. The highest average accumulation rate was found in the full moon phase while the lowest average was found in the ¼ moon phase. The total accumulation rate in the first week (October 15, 2023) during the dead moon phase reached 0.00055 items/m^2/week with the weight accumulation rate reaching 0.00238 gr/m^2/week. The dead moon phase affects oceanographic factors at the study site such as tides. Accumulation rate in the second week (October 22, 2023) of the lunar phase ¼ perbani decreased and was the lowest accumulation rate value of 0.00023 items/m^2/week with a heavy accumulation rate of 0.00082 gr/m^2/week. The low rate of waste accumulation at this time is due to the tides that occur in the ¼ moon phase where the position of the moon and sun form a right angle (perpendicular) which causes neap tides, namely low rising tides and high tides (Kvale, 2006). The total plastic waste found this week was 83 items with a weight 306.3 grams and was the lowest number and weight of plastic waste during the data collection period with an average wind speed of 3.0 m/s blowing from the Southeast and generating waves with a much lower average significant wave of 5.32 cm.

The accumulation rate of number and weight in the third week (October 29, 2023) in the full moon phase experienced a significant increase and was the highest accumulation rate value of 0.00063 items/m^2/week with a weight accumulation rate of 0.00841 gr/m^2/week. The high rate of waste accumulation at that time was caused by the tides that occurred during the full moon phase. Plastic waste in the water is carried by the current to the land during high tide conditions. The high rate of waste accumulation at that time is caused by spring tides that occur during the full moon phase where the position of the earth, moon and sun is on a straight line so that the resulting drag force will be greater (Rizqi et. al., 2021). The total plastic waste found this week was 253 items with a weight of 1,536.9 grams and was the highest number and weight of plastic waste during the data collection period with an average wind speed of 5.0 m/s blowing from the south and generating waves with a much higher average significant wave of 11.53 cm. The accumulation rate of number and weight in the fourth week (November 5, 2023) in the ¾ moon phase decreased again, namely 0.00048 items/m^2/week and the accumulation rate of weight, namely 0.00223 gr/m^2/week, was the second lowest accumulation rate after the second week.

The waste accumulation rate based on the station with the highest value occurred at station 1 with a value of 0.00061 items/m^2/week with a weight of 0.00411 gr/m^2/week. One of the factors affecting the high rate of waste accumulation at station 1 is due to high community activities, one of which is beach tourism activities. This is in line with the statement of Syakti et. al., (2017) which states that waste in the waters can come from tourism activities. Reinforced by research by Toruan et al. (2021) that research on waste on the coast of Timor Island where plastic waste dominates waste in coastal areas and the high level of plastic category waste shows the dependence of society, especially tourists on the use of various kinds of materials made from plastic. In addition, because the location of station 1 is in Laikang Bay. The bay is a body of water with a concave topography, allowing waste carried by the current to accumulate more easily in the bay (Yahya, 2020). While the lowest accumulation rate occurred at station 2 with a value of 0.00033 with a weight of 0.00281 gr/m^2/week. One of the factors affecting the low accumulation rate at station 2 is because the station is directly facing the open sea which has stronger and more variable currents than in the bay. Strong currents can carry waste away from its source and spread more widely into the open sea. This is reinforced by the statement of that the buoyancy of plastic waste causes it to be easily carried by wind, ocean currents, and tides, and can also accumulate along the coastline, even on the most remote islands as well as in the open sea and deep sea.

4. Conclusions

This research reveals that plastic waste is a significant environmental issue in Teluk Laikang, with beverage bottles smaller than 2 liters being the dominant type of waste during the observation period. The highest accumulation of plastic waste occurs during the full moon phase, while the lowest accumulation is recorded during the first-quarter moon phase. These findings indicate that lunar phases influence the accumulation dynamics of plastic waste, likely due to changes in oceanographic conditions such as tidal movements and wave patterns. The study highlights the urgent need for targeted efforts to manage plastic waste effectively, especially in semi-enclosed coastal areas like Teluk Laikang, where anthropogenic activities and geomorphological characteristics contribute to waste accumulation. Furthermore, the findings emphasize the necessity of developing comprehensive waste management strategies to mitigate the environmental impact of plastic debris on marine ecosystems.

Given the insights provided by this study, further research is essential to understand the broader implications of plastic waste on marine ecosystems and local biodiversity. Future studies should explore the ecological impacts of specific types of plastic waste, such as microplastics, on marine organisms and habitats. Additionally, investigations into the socio-economic consequences of plastic pollution on local communities reliant on tourism and aquaculture are necessary.

Author Contribution

The authors would like to express their sincere gratitude to the anonymous reviewers for their invaluable comments and insightful suggestions, which greatly contributed to improving the quality and clarity of this manuscript.

Funding

This research did not receive funding from anywhere.

Ethical Review Board Statement

Not available.

Informed Consent Statement

Not available.

Data Availability Statement

Not available.

Conflicts of Interest

The authors declare no conflict of interest.

Open Access

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