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Abundance and spatial distribution of marine debris on the beach of Takalar Regency, South Sulawesi

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Abstract. This study aimed to map the spatial distribution of marine debris abundance in the beach area of Takalar Regency, South Sulawesi Province, Indonesia. This research was conducted during the east monsoon in August-September 2019 and July-August 2020. The data were collected from the beach of Takalar at 2 stations; station 1 in Punaga River Estuary and station 2 in Laikang Bay, with 3 replications per station. Sampling was carried out using the transect method, the length of the transect line is 100 meters parallel to the coastline. Samples were collected within the criteria of macro size (> 2.5 cm - 1 m) and meso size (> 5 mm - 2.5 cm). The results showed that the average total abundance of marine debris in the macro size category was 0.036 items/m^2 and in the meso size was 0.0012 items/m^2; while the average weight abundance of macro and meso marine debris respectively were 0.36 g/m^2 and 0.0013 g/m^2. The spatial distribution showed that the greatest abundance of macro and meso waste was found at station 2 or around Laikang Bay. The semi-enclosed water in Laikang Bay is linked to the high accumulation of debris in the location.

1. Introduction

Debris refers to something that is not used, is disliked, or is discarded, having originated from human activities rather than developing by itself [1]. Marine debris comprises solid anthropogenic materials that are produced, disposed of, or left in the environment, including materials that are created or enter into the sea through hydrodynamic activities [2-5]. Debris that originates on the land, may be carried by the flow of seawater and end up on the land again [6]. Furthermore, the Law on Waste Management Number 18 of 2008 states that waste is the solid residue of human daily activities and/or natural processes.

Humans, directly or indirectly, have long made the sea a place for debris disposal [7,8]. Most of the world's beaches have accumulated marine debris caused by currents, waves and winds [7,9]. Marine debris accumulation in coastal areas has implications for silting, narrowing of river basins and decreasing water quality, which results in decreased quality of public health [10]. In recent years there has been an increase in marine debris in all parts of the world and it is predicted that there will be an increase in marine debris globally by 2025 [11], potentially by as much as 15 to 40% if there is no substantial remediation [3].

Various types of marine debris are often found in coastal and marine areas. These include plastics (nets, ropes, buoys, pipettes, lighters, plastic bags, plastic bottles); styrofoam (sponge, cooler cork, foam floats); cloth (clothes, shoes, hats, towels, backpacks, canvas); glass and ceramics (light bulbs, glass bottles); rubber, paper and cardboard (paper, newspapers, magazines and books); metal (drink cans, bottle caps); and wood [12]. Plastic debris occupies the largest proportion of total waste in coastal and marine areas [13]. Plastic debris is a significant global environmental threat today [14]. Based on the size and distribution area, the characteristics of marine debris are categorised as in Table 1 [15].

Table 1. Classification of debris based on the size and location of distribution.

No	Classification	Size (Length)	Location Distribution
1	Mega	> 1m	Ocean
2	Macro	> 2,5 cm - < 1m	Benthic
3	Meso	> 5mm - < 2,5 cm	Coastline
4	Micro	0,33 mm - < 5mm	Waters/seas
5	Nano	<1 µm	Invisible

Various problems arise due to the presence of marine debris, which can spoil the beauty of coastal areas, cause several kinds of diseases in humans, affect food networks and reduce fisheries productivity [16]. If this happens, it will have an indirect impact on the ecological, economic and community conditions in coastal areas [6].

This waste problem has become a concern for researchers in various parts of the world. In South Sulawesi, several studies on marine debris have been carried out in several locations [17-19]. Furthermore, it was reported that marine debris generally accumulates in coastal areas, with the highest total mass found on the coast of Takalar Regency. Therefore, by looking at the description above, it is very important to map the distribution and abundance of marine debris in Takalar District.

2. Method

Observation and collection of marine debris were carried out between August and September 2019 at the estuary of the Punaga river (769868.1681 mE, 9387466.7616 mS) and Laikang Bay (775590.0290 mE and 9381851.0117 mS) in Takalar Regency, with 3 replications for each location (Figure 1). Flow Modeling was based on measurements in July to August 2020 at the GPS coordinates 767505.0716 mE and 9392433.1408 mS.

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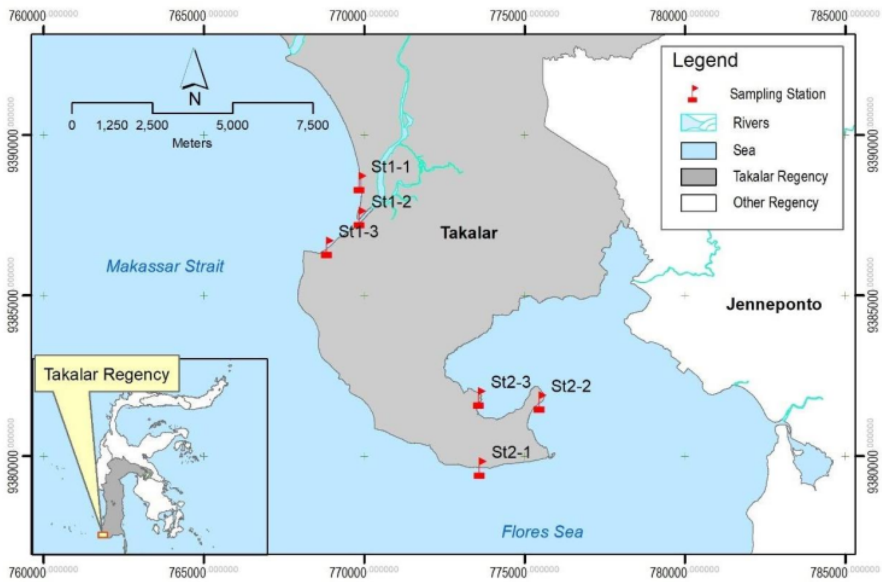

Figure 1. Sampling location at Takalar District.

The samples were categorised as macro debris (> 2.5 cm - 1 m) or meso debris (> 5 mm - 2.5 cm) (Lippiatt et al., 2013). Plot installation for sampling at the beach on P2KP-KLHK [9] was modified from [12] and [15], with the following procedure: marine debris sampling was carried out in coastal areas by laying transect lines of 100 m parallel to the coastline. The transect was then divided into 5 sections with a length of 20 m each. Quadrat transects measuring 5 x 5 m were then laid out in each section. Debris collection was carried out at low tide. Debris samples were taken randomly on 5 sub-transects (1x1m) from a 5x5 m quadrat transect using a 2.5-cm sieve for macro debris and a 0.5-cm sieve for meso debris (Figure 2). The types of debris taken was then identified within 8 categories of plastic debris, based on the Guidelines for Monitoring Coastal Debris by the Ministry of Environment and Forestry [9] and UNEP [12]. Furthermore, the weight of dry debris was recorded using a digital scale. Current measurement was taken using an Electric Current Meter (ECM) at the highest tide conditions until it began to recede.

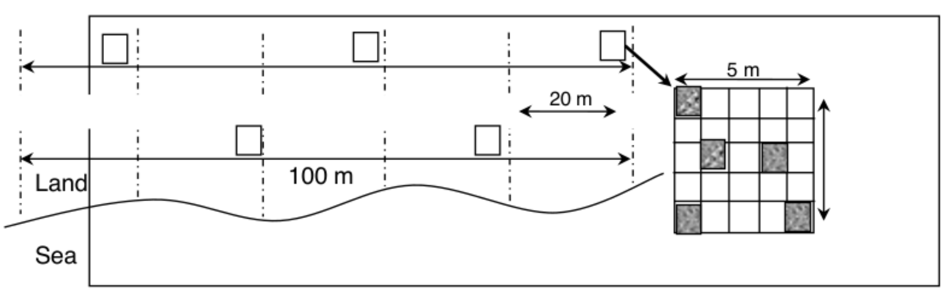

Figure 2. Illustration of marine debris sampling method conducted at each station.

The abundance of marine debris based on amount and weight was calculated using equation-1 [9]. To distinguish the abundance of marine debris at each station, a one-way ANOVA test was used. The spatial distribution of marine debris was mapped based on the abundance at each sub-station.

$$Abundance = (K)\frac{x}{p \times l} \quad (1)$$

Where x = amount / weight of debris per type; p = transect length (m) and l = transect width (m). Analysis of the distribution of data flows, direction and velocity for the season period, was conducted using the RMA-2 module (equations-2, 3, and 4) [20].
The mass equation as below:

$$\frac{\partial h}{\partial t} + h\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} = 0 \quad (2)$$

Momentum equation:
In the x-direction:

$$h\frac{\partial u}{\partial t} + hu\frac{\partial u}{\partial x} + hv\frac{\partial u}{\partial y} - \frac{h}{p}\left(E_{xx}\frac{\partial^2 u}{\partial x^2} + E_{xy}\frac{\partial^2 u}{\partial y^2}\right) + gh\left(\frac{\partial \alpha}{\partial x} + \frac{\partial h}{\partial x}\right) + \frac{gun^2}{\left(1.486h^{1/6}\right)^2} + \left(u^2 + v^2\right)^{1/2} - \zeta V_a^2 \cos\psi - 2h\omega v \sin\phi = 0 \quad (3)$$

In the y-direction:

$$h\frac{\partial v}{\partial t} + hu\frac{\partial v}{\partial x} + hv\frac{\partial v}{\partial y} - \frac{h}{p}\left(E_{yx}\frac{\partial^2 v}{\partial x^2} + E_{yy}\frac{\partial^2 v}{\partial y^2}\right) + gh\left(\frac{\partial \alpha}{\partial y} + \frac{\partial h}{\partial y}\right) + \frac{gun^2}{\left(1.486h^{1/6}\right)^2} + \left(u^2 + v^2\right)^{1/2} - \zeta V_a^2 \sin\psi - 2h\omega v \sin\phi = 0 \quad (4)$$

Where: h= water depth [m], t = time [sec], u,v = velocity component in X and Y axis [vector], ρ = fluid density [kg/m3], g= gravity acceleration [m2/sec.], E = viscosity coefficient of turbulence (xx, of in the normal towards X axis, yy, in the normal towards Y axis. xy and yx, of coincides in X and Y direction, respectively), a= bottom water elevation, n= Manning coefficient, ζ = wind shear coefficient, Va= wind speed [m/sec], ψ = wind direction [deg.], ω = angular velocity [rad/sec] and ϕ = latitude [deg.]

3. Results

3.1. General Conditions

Takalar Regency is located in the south of Sulawesi Island, administratively included in South Sulawesi Province. Geographically, it is directly opposite the Makassar Strait on the west side and the Flores Sea on the south side. Takalar Regency is flanked by two different ocean regions and has a direct impact on the movement of ocean currents in the region: the west monsoon currents and the east monsoon currents [22].

The research stations are located in the southern part of Takalar Regency. The two research stations are strongly influenced by the hydrodynamic action of the Makassar Strait and the Flores Sea. Station 1

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at the Punaga River Estuary is directly opposite the Makassar Strait and Station 2 at Telak Laikang is directly opposite the Flores Sea. Another characteristic that distinguishes the two stations is the openness of the waters: station 1 is adjacent to open water and station 2 to semi-enclosed water.

3.2. Macro Debris

The total amount of macro debris found the two observation stations was 585 items, with a weight of 11163.14 g. The macro debris category was dominated by plastic debris (83%) with a total of 490 items and a weight of 8272.12 g (74%), the next-most dominant type of debris being wood (3.25%) with a total of 19 items and a weight of 385.69 g (3.46%).

Table 2. Total Amount and Composition of Macro Debris at Both Stations.

Type of Debris	Station 1		Station 2		Total		Composition	
	Amount (items)	Mass (g)	Amount (items)	Mass (g)	Amount (items)	Mass (g)	Amount (%)	Mass (%)
Plastic	133	105.92	357	8166.2	490	8272.12	83.76	74.10
Styrofoam	4	2.12	3	13.0	7	15.12	1.20	0.14
Cloth	6	3.91	11	426.0	17	429.91	2.91	3.85
Glass and Ceramic	1	3.20	17	386.9	18	390.15	3.08	3.49
Metal	1	2.80	5	324.0	6	326.80	1.03	2.93
Paper	1	1.00	1	30.0	2	31.00	0.34	0.28
Rubber	3	13.53	12	695.2	15	708.76	2.56	6.35
Wood	7	43.60	12	342.1	19	385.69	3.25	3.46
Other	0	30.60	11	573.0	11	603.60	1.88	5.41
Total					585	11163.145	100	100

The spatial distribution of the abundance of debris in the macro debris category in each sub-station, in terms of both amount and weight, is shown in Figure 3. The results of the analysis show that the greatest abundance based on the number of items/m^2 was found at Station 2, especially in substation S2-2 (0.009 items/m^2) and substation S2-3 (0.005 Items/m^2). Based on the debris mass, the greatest abundance was found at Station 2, especially at substation S2-2 (1.23g/m^2) and substation S2-3 (0.55 g/m^2).

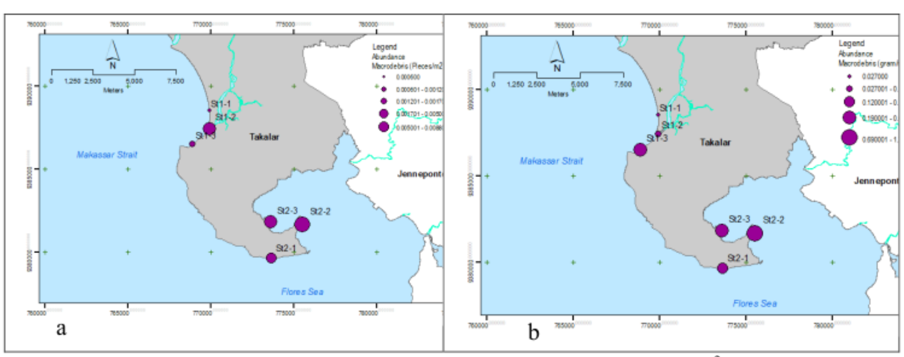

Figure 3. Abundance distribution of macro debris (a) by amount (items/m^2) and (b) mass (g/m^2).

The statistical test results for the abundance of macro debris (Figure 4) were based on the Kruskal-Wallis test because the data variance was not homogeneous. The value was significant p <0.05, or there was a significant difference between stations. Based on the results of further tests (*Mann-Whitney*), it is known that there was a significant difference in the average abundance of macro debris between Station 1 and Station 2. There was also a significant difference between each sub-station, except for the substations S12-S23 and S13-S21. The abundance of macro debris weight between stations 1 and 2 was shown to have a significant difference (p<0.05) using a One-Way Anova test. Meanwhile, for the loyal substation data, it can be seen that the abundance of macro debris at station 1 was not significantly different from station 2 but was significantly different between substation S21 and substation S22-S23.

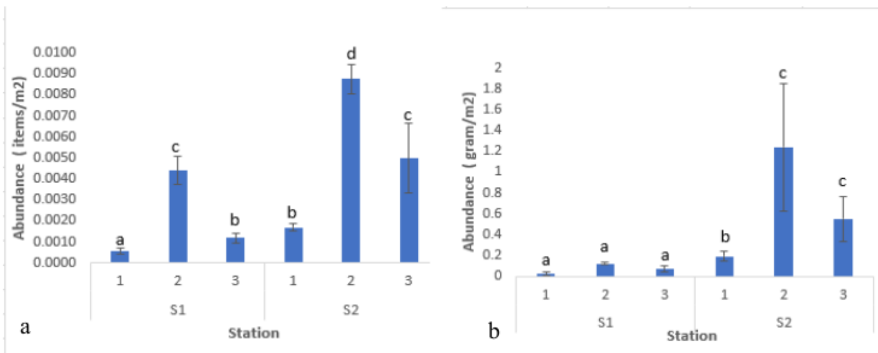

Figure 4. The abundance of macro debris based on (a) number of items and (b) mass.

3.3. Meso Debris

The total amount of meso debris found at the two observation stations was 167 items, with a weight of 54.5 g. The categories and composition of meso debris based on amount and weight can be seen in Table 3. Based on amount, meso debris is still dominated by 113 items (68%) of plastic debris, followed by 38 items (23%) of styrofoam, while other types of debris consisted of <10 items (9%). Based on weight, meso debris was dominated by wood weighing 40 g (73.48%), followed by rubber weighing 8.7 g (15.97%).

Table 3. Total Amount and Composition of Meso Debris at Both Stations.

Type of Debris	Station 1		Station 2		Total		Composition	
	Amount (items)	Mass (g)	Amount (items)	Mass (g)	Jumlah (items)	Amount (items)	Mass (g)	Amount (items)
Plastic	31	1.486	82	3.238	113	4.72	67.66	8.67
Styrofoam	14	0.0242	24	0.071	38	0.10	22.75	0.17
Cloth	0	0	0	0	0	0.00	0.00	0.00
Glass and Ceramic	1	0.1218	3	0.752	4	0.87	2.40	1.60
Metal	0	0	0	0	0	0.00	0.00	0.00
Paper	1	0.0576	0	0	1	0.06	0.60	0.11
Rubber	3	8.6408	1	0.06	4	8.70	2.40	15.97
Wood	3	40.0148	1	0.026	4	40.04	2.40	73.48
Other	0	0	3	0.003	3	0.00	1.80	0.01
Total					167	54.50	100	100

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The spatial distribution of the abundance of the amount and composition of marine debris in the meso debris category in each station and substation can be seen in Figure 5 (a, b). Based on the category of the number of items/m^2, the largest abundance was found at Station 2, especially at substation S2-2 (0.002 items/m^2). and substation S23 (0.0019 Based on the mass/m^2 category, the greatest abundance was found at Station 1, especially at Station S1-2 (0.007 g/m^2).

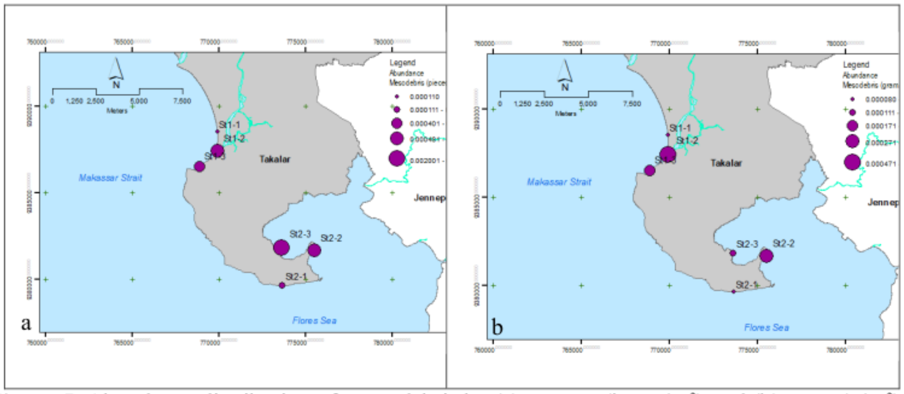

Figure 5. Abundance distribution of meso debris by (a) amount (items/m^2) and (b) mass (g/m^2).

The results of statistical tests for the abundance of meso debris (Figure 6) using the Kruskal-Wallis Anova test with a significant value of $p < 0.05$, showed a significant difference between stations. The average abundance of meso debris was significantly different between substations at Station 1 and Station 2. For the abundance of meso debris weight using a One-Way Anova test, there was a significant difference between stations with a value of $p < 0.05$. Based on the advanced test (LSD), it is known that there were significant differences in the average abundance of meso debris weight between Station 1 and Station 2, especially between the S12 substation and other substations.

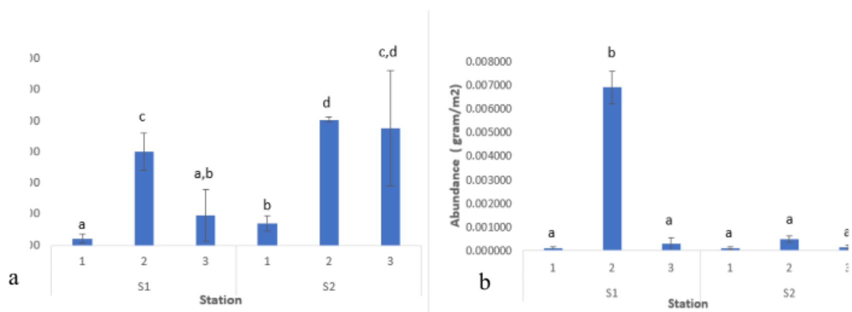

Figure 6. The abundance of meso debris based on (a) number of items and (b) mass.

4. Discussion

The amount and total weight of macro debris found at the research location are shown in Table 2, indicating that macro debris is dominated by plastic types, both in the quantity and mass categories. The phenomenon of the dominance of plastic debris in the macro debris category was also found by other researchers on the island of Sulawesi, such as at Tasik Ria Minahasa Beach [22], Boddia Takalar Beach [23], Estuary River Birringkassi Maros [24], Tanjung Bunga Makassar [17] and the Labuange Barru beach [25]. Research from outside the Sulawesi region also produced the same results,, including in Sungsang North Sumatra [26], the Korean coast [27], and globally throughout the world [3,5].

Likewise, meso-sized marine debris collected at the two observation stations (Table 3) showed that based on category, the amount of waste is dominated by the plastic. The high dominance of plastic-type debris is due to the fact that over long periods of time plastic debris degrades into smaller pieces which are very difficult to decompose. Plastic debris is a synthetic organic polymer [28] and undergoes fragmentation from macro debris to meso debris [29,30] and is very easily transported [23,31]. In terms of debris mass, the category was dominated by wood debris, similar to the results of research at Tongkaina Beach and Talawaan Bajo Minahasa Utara [32].

The abundance of both macro- and meso- marine debris, , was found to be higher at Station 2 (Figures 3 and 5) and based on the statistical tests in Figures 4 and 6, there was a difference between the abundance of macro debris and meso debris at the two stations. Several things make this phenomenon possible: (1) The difference in activities at the two stations. At Station 1, the land is mainly used for cultivation, while at Station 2 the main activity is tourism. Anthropogenic activities such as settlement activities [33,34] and tourism activities [35] greatly influence the high accumulation of marine debris in a place ; (2) The geographical location of Station 2. This station is highly influenced by the interaction between the Flores Sea and the Makassar Strait and the conditions in the bay mean that this location tends to accumulate marine debris; and (3) Ocean currents as a movement of water masses that allows the transport of material including marine debris.

In particular, the distribution of garbage along the coast is strongly influenced by currents and tides, which according to [36] are the main factors in the distribution of debris in coastal waters. The effect of these currents and tides is magnified at low tide, when a large amount of debris is transported and accumulates on the coastline. Marine debris found along the coast of Laikang Bay, Takalar Regency, is assumed to have originated from the high seas (Makassar Strait and the Flores Sea) via transportation on oceanic currents. The concave topography of the Laikang Bay coastline encourages the accumulation of marine debris in the bay, with this assumption being backed up by the research of [37], which found that more debris gathers in water bodies with a concave topography compared to in open water.

The distribution pattern of marine debris is strengthened from the results of the analysis of ocean flow data in the east and west monsoon conditions as shown in Figure 7 and Figure 8. The trend of ocean currents shows that in the west monsoon, the ocean currents originate from the Flores Sea towards Laikang Bay and rotate towards the Makassar Strait. When entering Laikang Bay, the ocean currents reduce speed and head towards the headland (station 2.2) so that at this substation the highest abundance of marine debris is found. This is reinforced by the research of [24] that the current moves from the south to the north with a speed of between 0.13 and 0.25 m / s in the coastal area of Takalar Regency.

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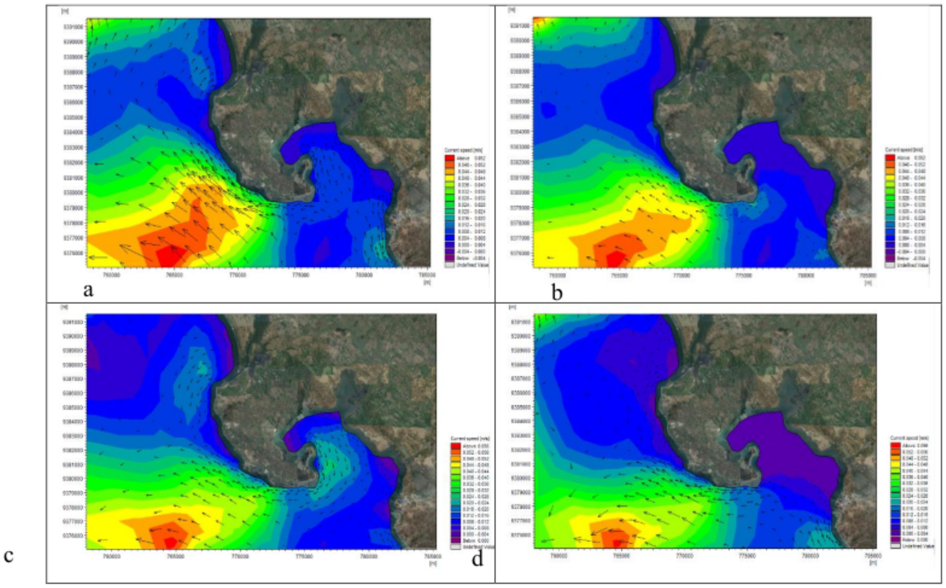
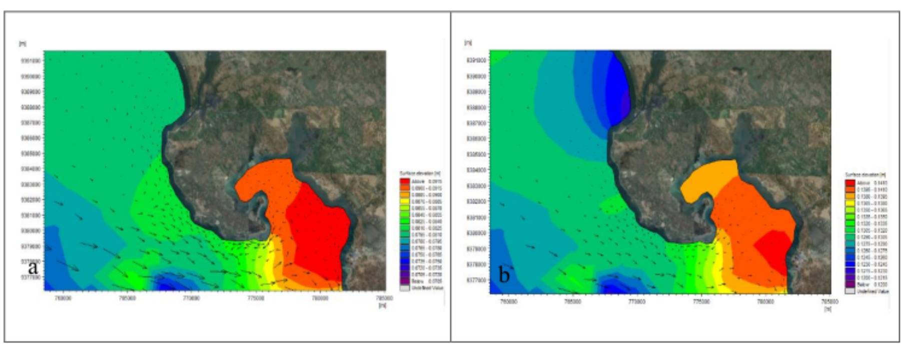


Figure 7. The west monsoon flow Pattern (a) towards high tide in the west monsoon (b) during the tide peak in the west monsoon, (c) towards low tide in the west monsoon and (d) lowest low tide in the west monsoon.

On the other hand, during the east monsoon, ocean currents tend to originate from the north (the Makassar Strait) in the form of shoreline currents, entering Laikang Bay towards the Flores Sea. These conditions facilitate the transport of marine debris from the Makassar Strait to Laikang Bay (Station 2). According to [38], the source of the arrival of garbage can be determined by tracing the movement of debris particles in the sea. The pattern of this movement will follow the path of major ocean currents, which can be determined through the oceanographic characteristics in the area, such as the speed and direction of currents.



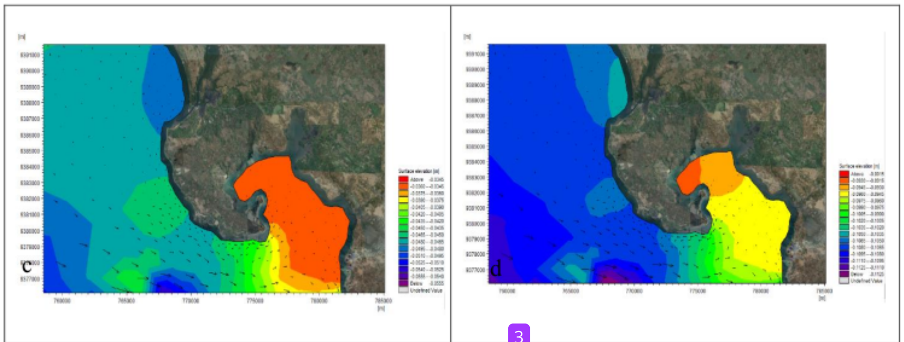


Figure 8. The east monsoon flow pattern (a) towards high tide in the east monsoon (b) during the tide peak in the east monsoon, (c) towards low tide in the east monsoon and (d) lowest low tide in the east monsoon.

The high abundance of both macro and meso marine debris at the beach at Station 2 is strongly supported by three factors: land use, geographic position and the direction and velocity of ocean currents. This is in line with the research of [33], which found that the buoyancy of plastic debris causes it to be easily carried away by winds, ocean currents and tides, and can also accumulate along coastlines - even on the most remote islands - as well as in the open sea and deep sea.

5. Conclusion

Marine debris, in the form of both macro debris and meso debris, was found at all research stations. Plastic debris dominated the amount and weight of marine debris found in Takalar Regency. The average total abundance of macro marine debris was 0.036 items/m^2 and of meso marine debris was 0.0012 items/m^2, while the average weight abundance of macro and meso marine debris were 0.36g/m^2 and 0.0013 g/m^2 respectively. The spatial distribution shows that the greatest abundance of macro and meso debris was found at Station 2, or around Laikang Bay. The semi-enclosed water, current direction and land use in Laikang Bay are linked to the high accumulation of debris in the location.

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