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THE INFLUENCE OF OCEAN CURRENT PATTERNS ON SURFACE MARINE DEBRIS DISTRIBUTION IN MAKASSAR CITY WATERS

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ABSTRACT

A survey of the abundance and distribution of macro debris (>2.5 - <100 cm) and meso-debris (>0.5 – <2.5 cm) has been carried out in Makassar City waters. This research was carried out to map the distribution of surface marine debris following ocean current patterns. The macro debris abundance range is 2222-17222 items/km2 and the meso-debris range is 2222-30556 items/km2, with the dominance of 47,03% plastic debris for macro sizes and 49,74% wood debris for meso-sizes. The highest abundance was found at the Jeneberang estuary, then at the Losari Coastal Waters, and the lowest at the mouth of the Tallo River. The current pattern in Makassar City waters at low or high tide tends to move from north to south towards the Jeneberang River estuary, with the current speed getting southern and slower. This condition causes a high abundance of macro and meso debris at the mouth of the Jeneberang River.

Keywords: Floating, Macro debris, Marine debris, Meso-debris, Pollution

INTRODUCTION

Ocean currents play a significant role in the circulation of water areas. They are patterns of water movement that are driven by winds, tides, and differences in water density. These currents transport heat, marine organisms, nutrients, and dissolved gases such as carbon dioxide and oxygen (Hay, 2017). Ocean currents play an important role in the distribution and accumulation of marine debris (Chassignet et al., 2021; Faizal et al., 2021; NOAA, 2016). Ocean currents control the distribution and accumulation of floating marine debris (Chassignet et al., 2021], carrying it into concentrations known as the Ocean Garbage Patch (Samurovic, 2021). The particles from the model also migrate to the garbage patch due to ocean currents (NOAA, 2016), and its distribution in the ocean is poorly mapped due to the influence of ocean currents on its movement. Once beneath high-pressure systems, the floating debris appears to meander aimlessly, further demonstrating how ocean currents affect its accumulation (van Sebille et al., 2020).

Marine debris is any persistent, manufactured, or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment (Richards & Beger,2011; Jambeck et al., 2015; NOAA, 2016; Agumuthu et al., 2019). Marine debris is the result of waste from anthropogenic activities, which then enters the marine environment through marine hydrodynamic activities (NOAA, 2016) or rivers, disposal canals, (Offer et al., 2012), waste from ships, tourism activities (Van Cauwenberghe & Janssen, 2014) and the movement of waste carried by wind and ocean currents (GESAMP, 2019).

Marine debris accumulation in marine waters may have a bad impact to marine ecosystems, silting of river estuaries, decreasing the aesthetic value of tourism areas, and ultimately reducing the quality of life of the community (Gregory, 2019). Furthermore, Jambeck et al. (2015) reported that the number of marine debris in 2015 in world waters was around 36.5 million metric tons (MMT) and Indonesia contributed 3.22 MMT, which ranks second after China from 192 coastal countries. It is even estimated that if there is no serious handling of marine debris, in 2025 there will be an increase in marine debris of around 52.21% or around 69.9 MMT (Jambeck. et al., 2015; Barboza et al., 2019).

The city of Makassar, which is located in a coastal area, is vulnerable to marine debris threats. Research results show that there is an accumulation of marine debris with quite a high abundance (Asmal et al., 2021; Rafsanjani et al., 2021). This study aims to map the distribution of surface marine debris abundance based on the influence of ocean current patterns and velocity.

MATERIAL AND METHOD

Research site

This research was conducted in October 2020, which is located in the sea waters of Makassar City. Sample analysis was carried out at the Marine Ecotoxicology Laboratory, Faculty of Marine Science and Fisheries, Hasanuddin University. Determination of data collection points using the purposive sampling method, taking into account the observed parameters and the representativeness of the area coverage. The distribution of sampling points is as shown in Figure 1, respectively; Station 1 at the Jeneberang River Estuary (119°22'48.455"E and 5°11'31.361" S), Station 2 at Losari Beach (119°23'50.611" E and 5°7'57.954" S), and station 3 at the Tallo River Estuary (119°26'37.639" E and 5°5'36.493" S).

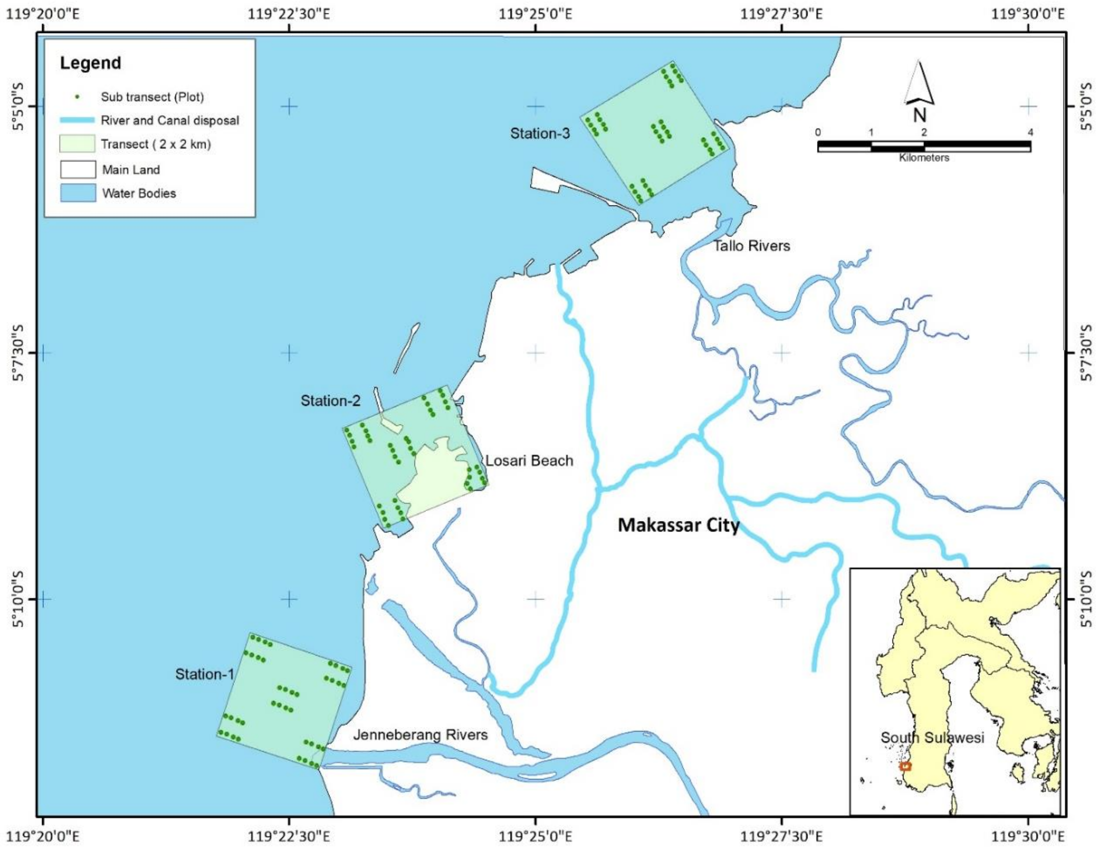

Figure 1. Location of research data collection

Method

The size of marine debris in the waters is based on the criteria of Lippiat et al. (2013) and is divided into several classifications; mega (>100 cm), macro (>2.5 - <100 cm), meso (>0.5 – <2.5 cm), micro (>0.033 – <0.5 cm) and nano (<1 µm), in this study the categories measured are macro and meso. The transect technique used in this study was modified from (Lippiatt et al. 2013). Each station is made of a transect with a size of 2000 x 2000 m, where each station has five substations with a size of 400 m x 400 m, then each substation has four tracks with a length of 300 m each. Sampling method using Neuston Net (neuston net specifications; mesh size 0.5 mm, net size 1.5 x 0.50 m). The nets attached to the boats are towed at each substation with a maximum speed of 5 knots.

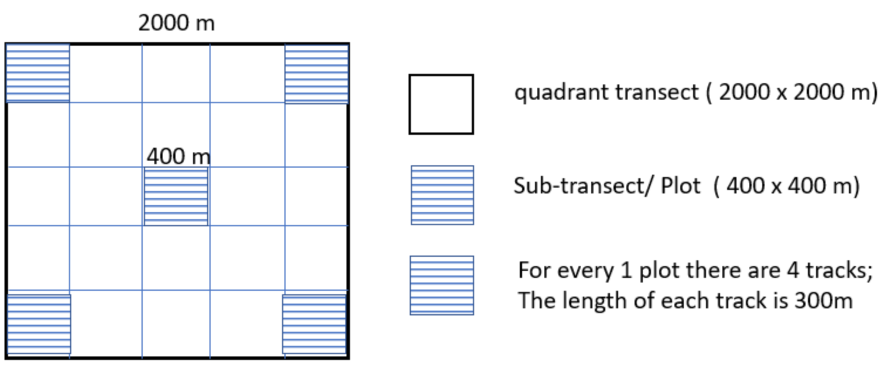

Figure 2. Sampling scheme at each station

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The waste collected from each transect is separated based on the size of the waste (macro and meso), Then calculated the amount of waste and the weight of marine debris for each category. The current measurement uses an Electric Current Meter (ECM) at the highest tide conditions until near low tide.

Data analysis

The density of beach waste based on the amount and weight is calculated by equation 1 (Lippiatt et al. 2013)

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

Where n = amount of marine debris (item); p = transect length (km) and l = net width (km)

The spatial distribution of marine debris was mapped based on the abundance at each sub-station. Analysis of the distribution of current direction and speed data for seasonal periods, using the RMA-2 module. (equations 2, 3, and 4) (U.S. Army Corps of Engineers, 2003).

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/m^3); *g*= gravity acceleration (m^2/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)

RESULTS AND DISCUSSION

General Condition

Makassar city is located in the south of Sulawesi Island, administratively included in South Sulawesi Province. Geographically, it is directly opposite the Makassar Strait. Makassar City waters are strongly influenced by current movements, both east monsoon and west monsoon currents. The research was carried out in the sea waters of Makassar City, Station 1 at the estuary of the Jeneberang with outlet characteristics from the mainland, tourism activities, and sea transportation. Station 2 is in the vicinity of Losari coastal waters, at this station, there are three canals for city debris disposal and tourism activities. Station 3 is around the estuary of the Tallo River which is close to the harbour and fish auction.

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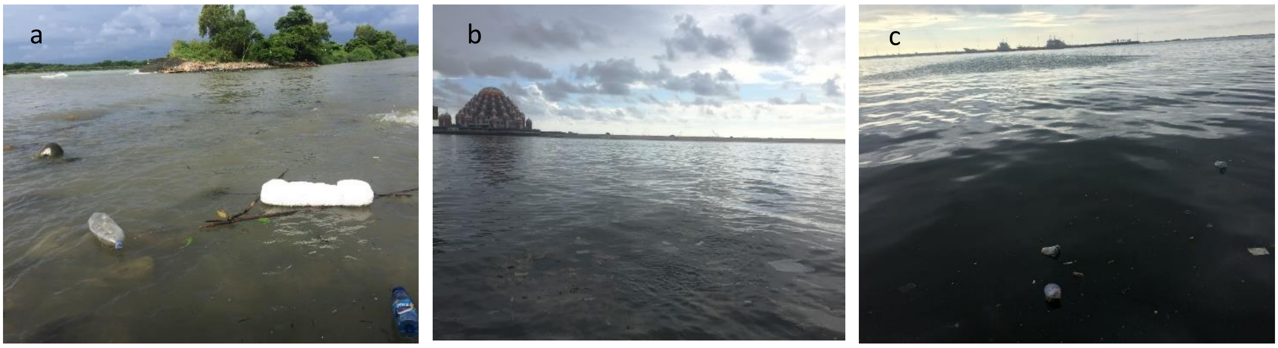

Figure 3. General condition of sampling locations in Makassar City Waters (a) Jeneberang River Estuary (b) Losari Beach Waters and (c) Tallo Estuary.

Ocean current patterns

Ocean currents greatly influence the movement of marine debris, based on the results of modelling and field tests, the current conditions in the observation period for each station are shown in Figure 4.

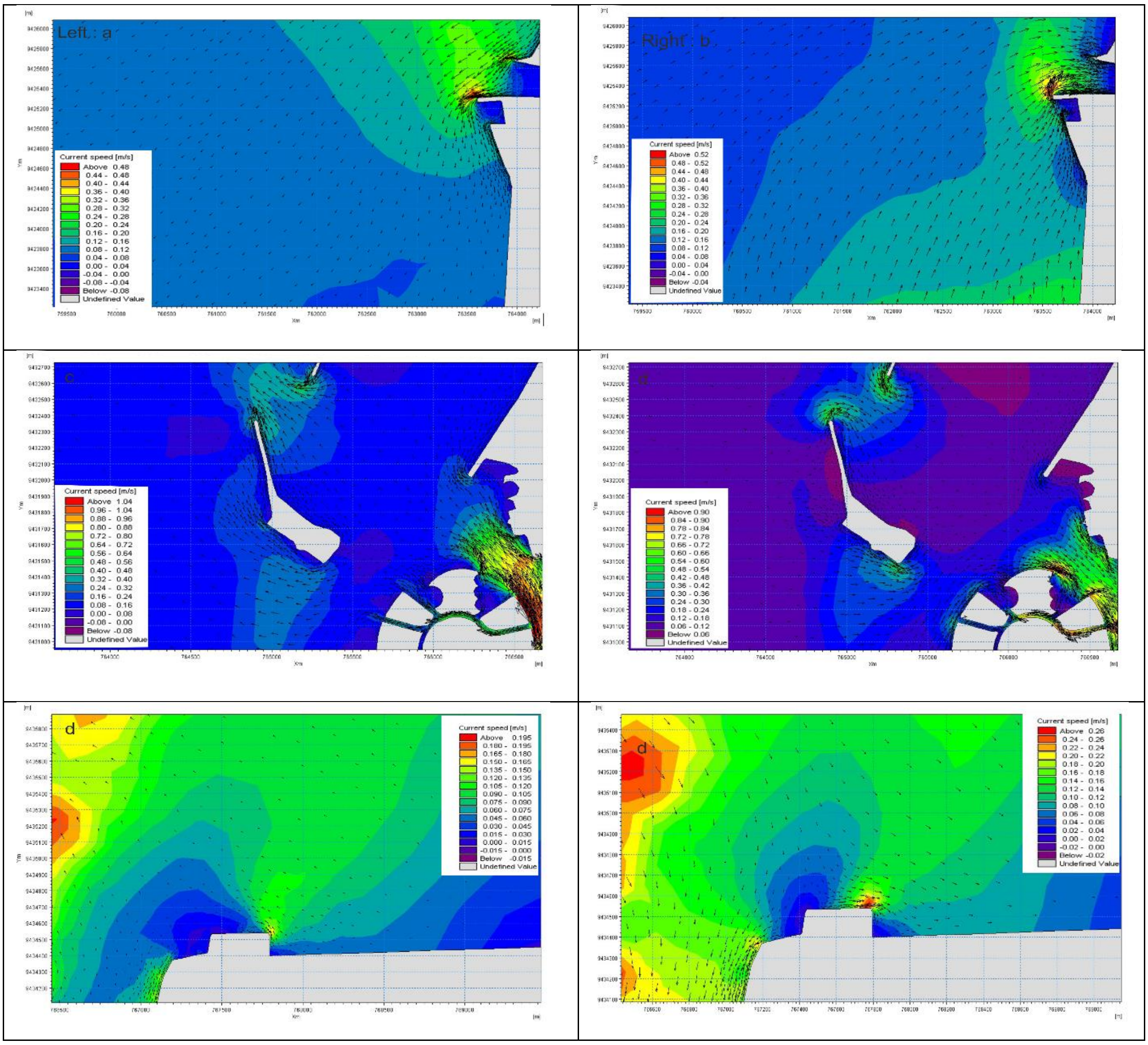

Figure 4. The pattern of ocean currents at the time of observation, (left = low tide condition) and (right = high tide condition) at each station (a,b) Jeneberang River Estuary (c,d) Losari Beach Waters, and (e,f) Tallo River Estuary

The current modelling results are in Figure 4(a). shows that in low tide conditions, the current in the Jeneberang River estuary moves predominantly south-westward away from Makassar mainland and then turns southward with an average speed of 0.04-0.08 m/s, while the maximum speed in the estuary area is 0.28-0.33 m/s. In high tide conditions, the current moves northward and then turn eastward towards the mainland. Furthermore, the current speed increases at high tide in the estuary and coastal areas with a dominant speed of 0.8-0.12 m/s and a maximum speed of 0.48-0.52 m/s at the mouth of the river.

Figure 4(b) shows that the sea currents in the waters of Losari Beach are in low tide, the dominant currents move westward away from Makassar mainland with an average current speed of 0.08-0.16 m/s while the maximum speed is around the coast. Losari in the range of 0.48-1.04 m/s. Whereas in the conditions towards the tide the current moves from open water towards the mainland, with an average speed of 0.8-0.12 m/s.

Figure 4 (c) shows the movement of currents in the Tallo Estuary in low tide conditions, the currents move away from the mainland with an average speed of 0.12-0.13 m/s, in high tide conditions the current moves from east to west. the west direction is then diverted to the north by existing current drag such as reclamation and river estuaries. The average current speed is 0.14-0.16 m/s with a maximum current speed around the reclamation area with a speed range of 0.20-0.26 m/s.

The difference in the current pattern of each station is caused by the dominance of the local current pattern more dominant than the regular current pattern. Based on the observations, the average current speed at each observation station is shown in Figure 5. The average current speed at the Jeneberang River Estuary is 0.34 m/s, Losari Beach is 0.37 m/s and Tallo River Estuary is 0.48 m/s.

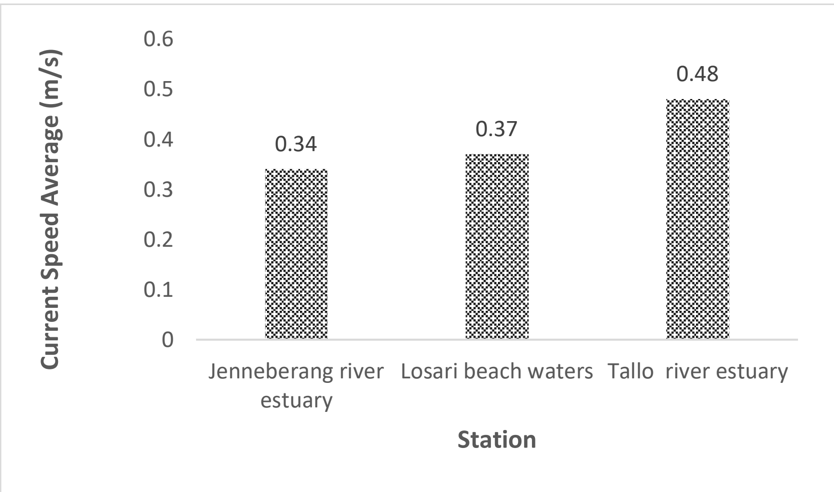

Figure 5. Average current velocity from field measurements at each station

The characteristics of ocean currents in Makassar City waters are influenced by wind and tides. At low tide, the current will move from the mainland toward open water (Sugianti and ADS, 2007; Galgani et al., 2015a)

Abundance and Distribution of Surface Marine Debris

The total amount of macro debris found at the three stations was 219 items. The macro debris category was dominated by plastic debris (47.03%), respectively; The Jeneberang River estuary has plastic 35.64%, Losari Beach Waters 56.92%, and the Tallo River Estuary 56.60%, shown in Table 1. As for Meso-debris, based on observations at the three stations, the amount of marine debris found was 191 items, with a dominance of types of wood waste (49.74%). The largest percentage of wood-type waste was found in the Jeneberang Estuary at 58.59%, then Losari Beach Waters at 41.3%, and Tallo River Estuary at 39.13%, as shown in Table 2.

Tabel 1. Total Amount and Composition of Macro Debris at Three Stations

Type of Debris	Jennerberang River Estuary			Losari Beach Waters			Tallo River Estuary			Total	Percentage (%)
	Amount (items)	Abundance (items/km2)	Percentage (%)	Amount (items)	Abundance (items/km2)	Percentage (%)	Amount (items)	Abundance (items/km2)	Percentage (%)		
Plastic	36	20000	35.64	37	20556	56.92	30	16667	56.60	103	47.03
Styrofoam	33	18333	32.67	5	2778	7.69	15	8333	28.30	53	24.20
Cloth	1	556	0.99	3	1667	4.62	2	1111	3.77	6	2.74
Glass and Ceramic	0	0	0.00	0	0	0.00	1	556	1.89	1	0.46
Metal	5	2778	4.95	3	1667	4.62	1	556	1.89	9	4.11
Paper	0	0	0.00	8	4444	12.31	0	0	0.00	8	3.65
Rubber	0	0	0.00	1	556	1.54	0	0	0.00	1	0.46
Wood	26	14444	25.74	8	4444	12.31	4	2222	7.55	38	17.35
Other	0	0	0.00	0	0	0.00	0	0	0.00	0	0.00
Total	**101**	**56111**	**100**	**65**	**36111**	**100**	**53**	**29444**	**100**	**219**	**100**

Tabel 2. Total Amount and Composition of Meso-Debris at Three Stations

Type of Debris	Jennerberang River Estuary			Losari Beach Waters			Tallo River Estuary			Total	Percentage (%)
	Amount (items)	Abundance (items/km2)	Percentage (%)	Amount (items)	Abundance (items/km2)	Percentage (%)	Amount (items)	Abundance (items/km2)	Percentage (%)		
Plastic	10	5556	10.10	13	7222	28.26	16	8889	34.78	39	20.42
Styrofoam	25	13889	25.25	12	6667	26.09	12	6667	26.09	49	25.65
Cloth	0	0	0.00	0	0	0.00	0	0	0.00	0	0.00
Glass and Ceramic	0	0	0.00	0	0	0.00	0	0	0.00	0	0.00
Metal	0	0	0.00	0	0	0.00	0	0	0.00	0	0.00
Paper	6	3333	6.06	2	1111	4.35	0	0	0.00	8	4.19
Rubber	0	0	0.00	0	0	0.00	0	0	0.00	0	0.00
Wood	58	32222	58.59	19	10556	41.30	18	10000	39.13	95	49.74
Other	0	0	0.00	0	0	0.00	0	0	0.00	0	0.00
Total	**99**	**55000**	**100**	**46**	**25556**	**100**	**46**	**25556**	**100**	**191**	**100**

The total abundance of marine debris for macro and meso-sizes in each plot at each station are shown in Figure 6 and the spatial analysis of macro and meso-debris distribution on the surface sea is shown in Figure 7. The range of macro debris abundance for all stations is 2222-1722 items/km^2 and the meso-debris abundance range for all stations is 2222-30556 items/km^2.

The highest average abundance of macro debris was found at the Jeneberang River Estuary and the lowest at the Tallo River Estuary. The highest average abundance was found in plot 3 in the Jeneberang Estuary (17222 items/km^2) and the lowest average abundance was found in plot 4 in the Tallo River estuary (2222 items/km^2). Likewise, for meso-size marine debris the highest average abundance was also found in the Jeneberang River estuary and the lowest was in the Tallo River estuary where the highest abundance was in plot 1 Jeneberang River (30556 items/km^2), while the lowest average abundance of meso-debris was found in plots 5 River mouths of 2222 30556 items/km^2.

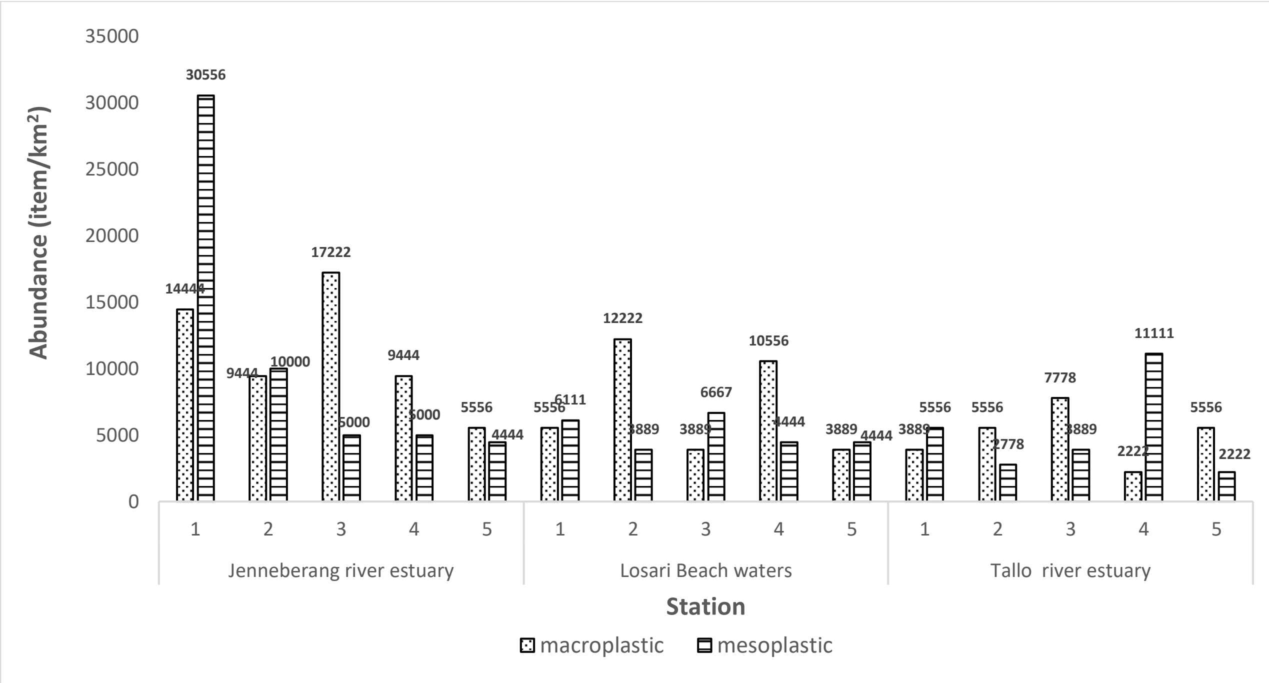

Figure 6. Total abundance of macro and meso-debris in Marine waters of Makassar City.

The research data shows that spatially the abundance of macro debris and meso-debris in the marine waters of Makassar City is highest around the Jeneberang River estuary. The high abundance of marine debris in the Jeneberang River estuary is thought to originate from river runoff (Allopps, 2006) and the accumulation of transportation processes from the river mouth to the waters (Willis et al., 2017), wind and drainage canals (Lee et al., 2017). Other sources of marine debris are thought to be from tourism activities in the surrounding area, one of which is Tanjung Bayang Beach. The results of research by Fadhlin et al., (2016) explain that the number of tourists in Tanjung Bayang is around 5738 people/day, which of course will be a contributor to waste in the surrounding waters if there is no proper marine debris management.

In line with that, Cheshire et al. (2009) explained that most debris found in the waters is in the form of household waste. The Jeneberang River basin passes through several cities such as Makassar, Malino, Bili-Bili, and Sungguminasa. The percentage of use of the downstream part of the Jeneberang River basin consists of forests (69%), paddy fields (5%), agriculture (12%), urban areas (14%), and urban land covering 101.78 km located in the estuary area of the Jeneberang River (Fahmi, 2015)

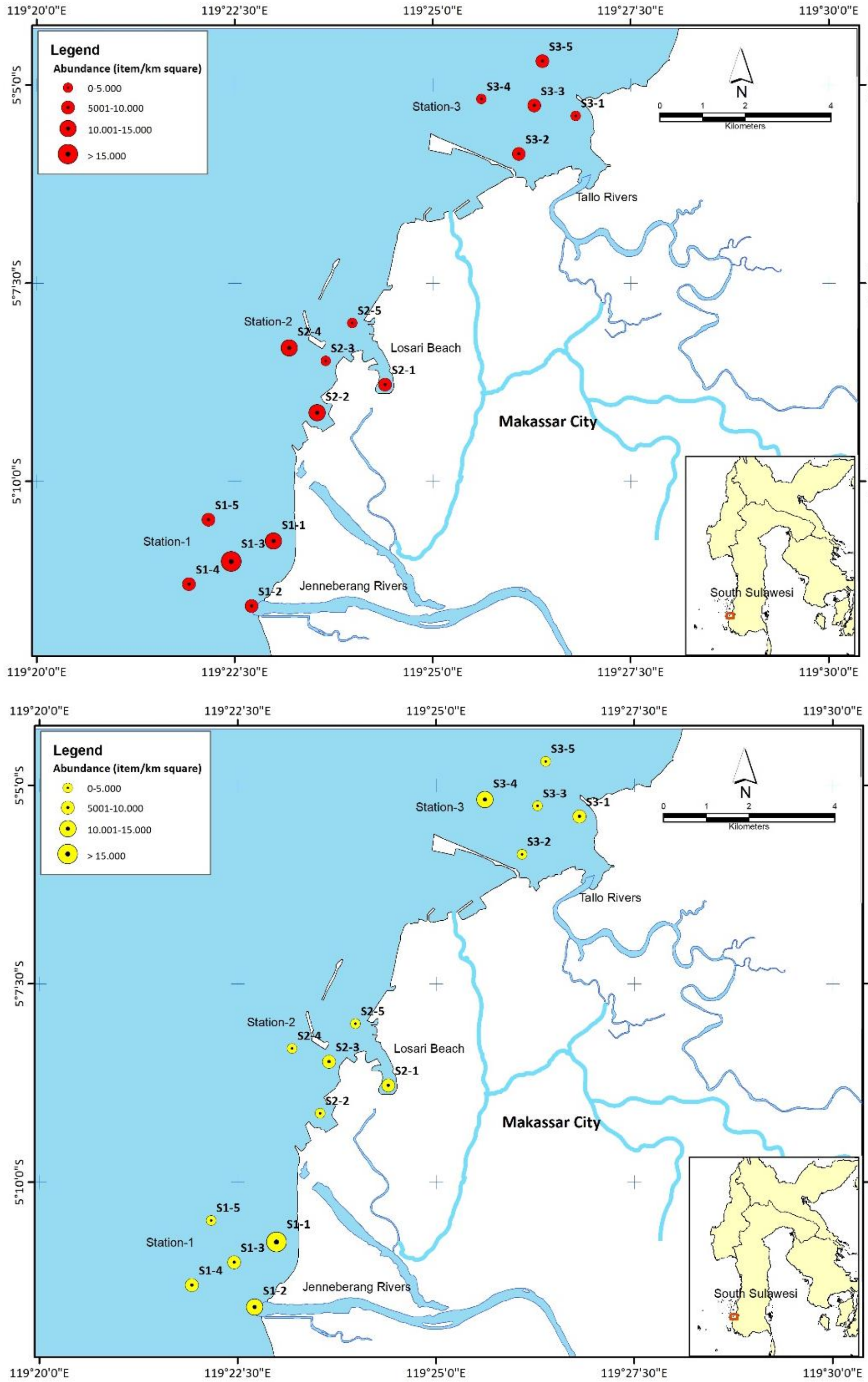

Figure 7. Map of distribution the total abundance of macro debris (above) and meso-debris (below) at each station

In comparison between the amount of macro and meso-debris, meso-debris has a larger amount, this is due to the size of meso-debris, which is the result of the decomposition of mega and macro debris. The cause of the decomposition of marine debris is the length of time the waste is in the sea and the hydrodynamic action of seawater causes the weathering of macro debris to meso-debris (Sebille et al., 2015), physical, chemical, and biological processes which include UV radiation, wave action and degradation by microbes (Lee at al., 2017). Based on the results of field observations that the size of meso-debris is dominated by types of wood, when inundated by seawater the types of wood will easily decompose into smaller forms. The half-life of wood species tends to be faster than plastic (Fendall and Sewell, 2009). The data also shows that the highest amount of meso-debris is 30556 items/km^2, which is similar to the amount of marine debris found by Isman, (2016) in the coastal area of Makassar City with an abundance of 36,450 items/km^2.

The results of the spatial analysis using the interpolation method for the distribution of macro and meso-debris are shown in Figures 8a and 8b. The two figures show that the largest abundance of marine debris is found in the southern part of the Jeneberang River Estuary.

In Losari Beach waters, there are 3 water canals suspected as a source of marine debris supply, namely; Jongaya, Haji Bau, and Rotterdam canals. The abundance of marine debris found in Losari Beach waters ranges from 3889-5556 items/km^2 for macro debris and 4444-12,222 items/km^2 for meso-debris, with the greatest abundance located around Lae-lae Island. This shows the small supply of waste from the disposal canals and the possibility that the high marine debris at the station originates from accumulation due to the movement of ocean currents. Coastal reclamation around station 2 causes a shift in current patterns which causes the accumulation of debris in the southern part of the reclamation area (Station S2-2). This condition is corroborated by the opinion of Jaya, (2012) that reclamation greatly affects the physical and chemical conditions of seawater. Apart from the influence of current patterns, it is suspected that another reason for the high abundance of marine debris around Lae-lae Island (station S2-4) is due to tourism activities. This is in line with the results of Syaktia et al., (2017) using the trawling method, that a large amount of accumulated waste in the intertidal zone along the Cilacap coast comes from beach tourism and runoff from the Donan and Serayu Rivers.

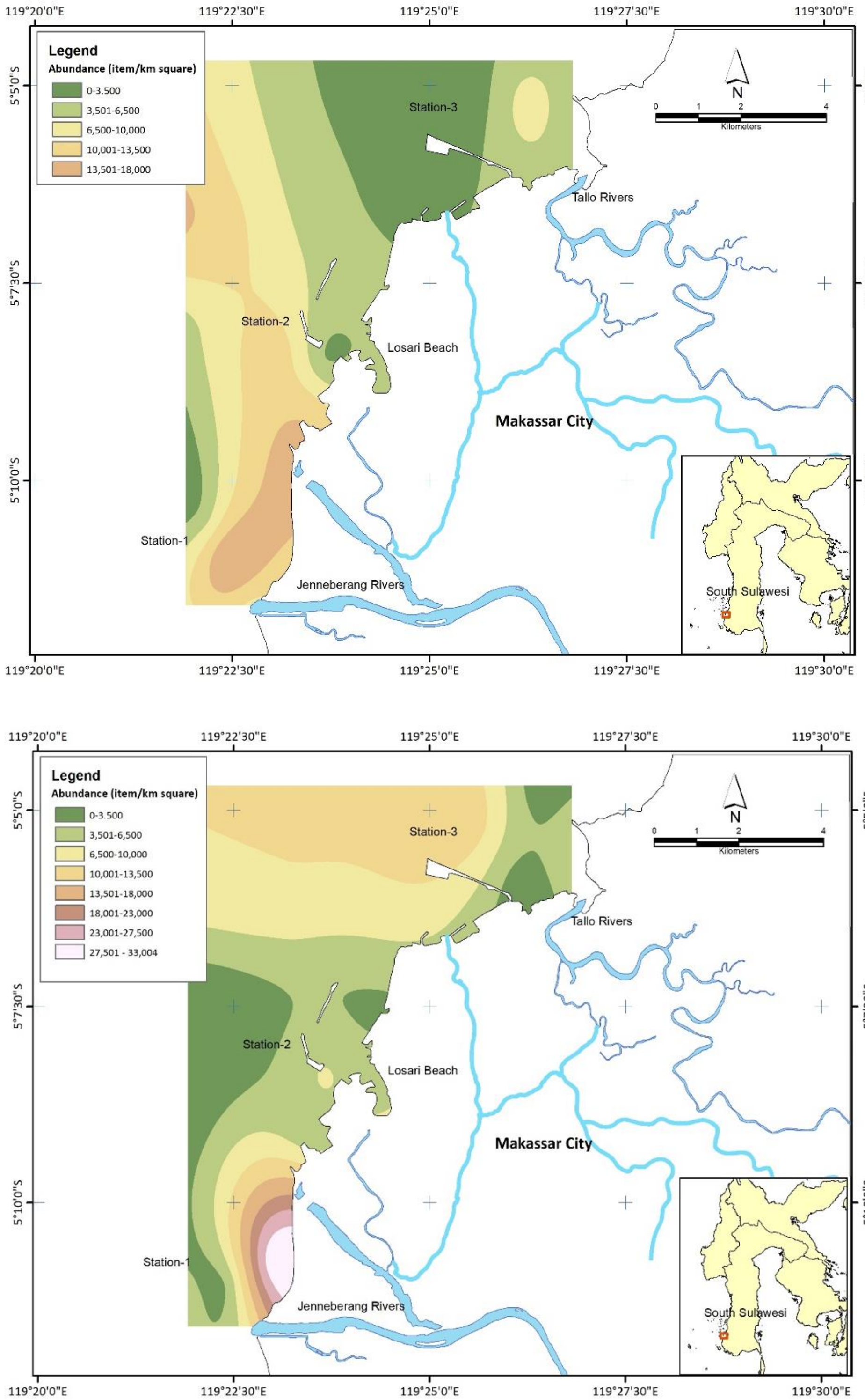

Figure 8. Map of distribution of macro debris (above) and meso-debris (below) abundance in the sea waters of Makassar City.

At the station in the Tallo River estuary, an abundance of macro debris was found in the range of 2222-5556 items/km^2 and an abundance of meso-debris in the range of 2222-11111 items/km^2. Figure 8 shows that the farther from the mouth of the river the abundance of marine debris is higher. The source of marine debris around the Tallo River estuary is thought

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to originate from the Tallo River, the Paotere Fish Auction Site, Industry, and settlements. This is corroborated by Setiawan (2013) that the mouth of the Tallo River is a place for waste disposal originating from the Makassar Industrial Area, and transportation activities. In addition, household waste also greatly influences the high abundance of debris, especially types of plastic in water (Jambeck et al., 2015).

If this is related to the movement of ocean currents in Figures 4 and 5, which tend to move southward and experience a slowdown when in the Jeneberang River Estuary, this causes a high abundance of macro and meso-debris in that location. Tables 1 and 2 also show that the largest percentage of the waste is found in the Jeneberang River Estuary, where for the macro size it is dominated by plastic debris, and for the meso-size it is dominated by wood debris. The results of other studies show that generally trash is rarely found in waters with strong currents and high-water masses, trash will sink when it loses its buoyancy (Galgani et al., 2015b).

CONCLUSION

The The current pattern in Makassar City waters at low or high tide tends to move from north to south towards the mouth of the Jeneberang River, and similarly, the current speed is getting souther and slower. This condition causes a high abundance of macro and meso debris at the mouth of the Jeneberang River. The type of plastic debris dominates the size of the macro-debris, and the type of wood dominates the meso-debris.

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