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Marine Macro- and Micro Plastic Litter on Beach Sediment of Northern Peninsular Malaysia

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ABSTRACT

This paper investigates the spatial distribution of small plastic litter on the beach of Kuala Perlis and Pulau Langkawi in the northern region of Peninsular Malaysia. The objectives are to ascertain the categories of macro marine litter and macroplastic types, the amount of microplastic in the sediment layer, and the relationship between macroplastic and microplastic. Macro marine litter was collected in 100-meter transects at six different locations. Sediment samples for microplastic identification were collected using a quadrat measuring 0.5 m × 0.5 m with a depth of 0.05 m. Plastic accounts up most of the macro marine litter collected (73.8%), followed by glass (12%), fabric (7.8%), rubber (4.4%), wood (2%), and metal (0.07%). Between 2018 and 2020, the overall weight of macroplastic (>5 mm) litter and the amount of microplastic (<5 mm) litter on northern beaches were 80.371 g/m^2 and 11.094 g/m^3, respectively. In this investigation, macroplastic collected on the beach surface ranged from 0.02 g to 14.09 g/m^2, while microplastic in the beach sediment ranged from 0 to 1.192 g/m^3. The packaging category seems to have the highest percentage of collected macroplastic. At the 95% confidence level, the calculated R^2 of 0.7444 indicates a substantial association between macroplastic and microplastic. The linear regression equation is $y = 0.1927x + 0.0226$, with y representing microplastic (g/m^3) and x being macroplastic (g/m^2). This strong link demonstrates that the presence of microplastic in sediment is strongly related to the abundance of macroplastic on the beach. This finding provides a good approximation of actual microplastic occurrence to macroplastic abundance, which will be useful in environmental evaluation and management approaches.

1. Introduction

Plastic is a broad category of synthetic or semi-synthetic materials that are widely used today and whose growing number of applications has resulted in an increase in their production [1]. Plastics are an extremely versatile material that can be used for a variety of consumer and industrial applications. Plastic products' light weight plays a significant role in all applications due to their low density [2]. According to an OECD report, global plastic leakage to the environment is expected to be well over 44 Mt per year, while plastic build-up in lakes, rivers, and oceans is anticipated to more than triple,

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as plastic waste increases from 353 Mt in 2019 to 1,014 Mt in 2060 [3]. The vast bulk of pollution comes from larger debris known as macroplastics, but leakage of microplastics (synthetic polymers 5 mm in diameter) from items such as industrial plastic pellets, textiles, and tyre wear is also a significant problem [3].

Plastics make up most of the polluting litter found in the world's oceans and are commonly found in surface water, water column, seabed, beaches, sediments, and organisms. The coastal zone is a fascinating ecosystem and a highly productive environment. This has become a critical concern in Malaysia's coastal area because beach activities are popular among both local and foreign tourists. Rapid development and urbanization have also had a significant impact on disturbing this exclusive region, putting a large number of flora and fauna at risk.

Microplastics are plastic particles with a diameter <5 mm and are classified as primary or secondary microplastics. Primary microplastics are microscopic plastics that are purposefully manufactured, such as microbeads, capsules, fibres, and pellets. Secondary microplastics are the result of larger plastic fragmentation into smaller pieces. This is due to sun radiation exposure, physical abrasion from wave action [4], and biological processes [5].

Small plastic fragments in the ocean were first discovered in the 1970s [6], and a resurgence of scientific interest in microplastics over the last decade has revealed that these contaminants are pervasive and common in the coastal environment and have the potential to harm animals [7]. Because of their small size, microplastics are thought to be bioavailable to species all along the food chain, and they are also thought to be hazardous plastics leaching and attaching to waterborne organic contaminants. As a result, consuming microplastics may introduce toxins to the base of the food chain, where bioaccumulation is possible [8,9].

Since the first appearance of microplastics more than 40 years ago, there has been a significant increase in public awareness of the issue, as it now poses a serious threat to human health via food chains. Until now, the occurrence of microplastics in the coastal environment has been increasing. Tackling this issue is difficult due to the unknown toxicity and potential to transport bioavailable pollutants across the tropic level. The critical issue is the ambiguity of the chemical amounts that are leached out into the environment and pose a threat to humans and organisms. The ambiguities and distribution of microplastics after weathering in terms of time for degradation and fragmentation into smaller and smaller pieces, the evolution of particle morphology and properties, and the deleterious effects of chemicals released during weathering remain unresolved. According to [10], the degradation rate of macroplastic may vary depending on its composition (size and density) and environmental factors (sunlight, wave, and temperature).

As a result, it is critical to investigate the relationship between the abundance of macroplastic litter on the beach and microplastic in the beach sediment. Future research on the effects of pollution on the ecosystem, biodiversity, and human health will be heavily reliant on this relationship, which has yet to be proven in the local context. Understanding the relationship between macro- and microplastic is critical for managing the overall problem of plastic pollution.

2. Methodology

2.1 Study Area

This study focuses on the coast of Peninsular Malaysia's northern region, which lies within the Malacca Strait. It includes the coastlines of Perlis and Pulau Langkawi in Kedah, with an approximate study area of 5,000 km^2. The coastal region of Kuala Perlis' socioeconomic activity is primarily comprised of fishing, and it has naturally become a popular seafood destination for locals. The Kuala Perlis jetty is also a major route for northern Malaysia's tourism industry, as many locals and foreigners travel by sea to Pulau Langkawi. The Perlis coastal area will be the primary sampling location in this study. Pantai Pasir Tengkorak and Teluk Datai, on the other hand, are popular tourist attractions in Pulau Langkawi. Even though Teluk Datai area is densely packed with tourism activities and small-scale development, it is well maintained and considered pristine and undisturbed. No development has also occurred in Pantai Pasir Tengkorak, an area considered untouched and is surrounded by Gunung Machinchang's natural environment. Therefore, these sites in Pulau Langkawi are deemed appropriate as control sites. Figure 1 shows four sampling stations in the Kuala Perlis (S1, S2, S3, and S4) and two sampling stations in northwest Pulau Langkawi (S5 at Pantai Pasir Tengkorak and S6 at Teluk Datai). S1 and S2 are in recreational areas, S3 is near a restaurant area, S4 is near a residential area, and S5 and S6 are considered pristine and undisturbed, with a very small scale of development and a highly reserved area that is well maintained.

Fig. 1. Location of sampling sites in the coastal area of Kuala Perlis and Pulau Langkawi

2.2 Data Collection

The transects method is used to collect marine macro litter (>5 mm) and microplastic (>5 mm). The samples of marine macro litter collected along the transect line are then classified into six categories: plastic, rubber, metal, glass, wood, and fabric [11-13]. Each category's dry mass is determined by weight and measured in gram per unit area (g/m^2). Microplastic in beach sediment is collected using a 50 cm x 50 cm quadrat with a depth of 5 cm. In each section, two additional replicate samples are collected. Beach sediment samples are dry sieved through a 5 mm sieve to collect macroplastics (>5 mm) while separating microplastics (5 mm). To obtain microplastic for further analysis, wet peroxide oxidation and density separation of floating from settled materials are used [12]. The collected microplastics are then weighed and calculated in grams per cubic metre (g/m^3). Figure 2 depicts the sampling design used in this study for marine macro litter and microplastics.

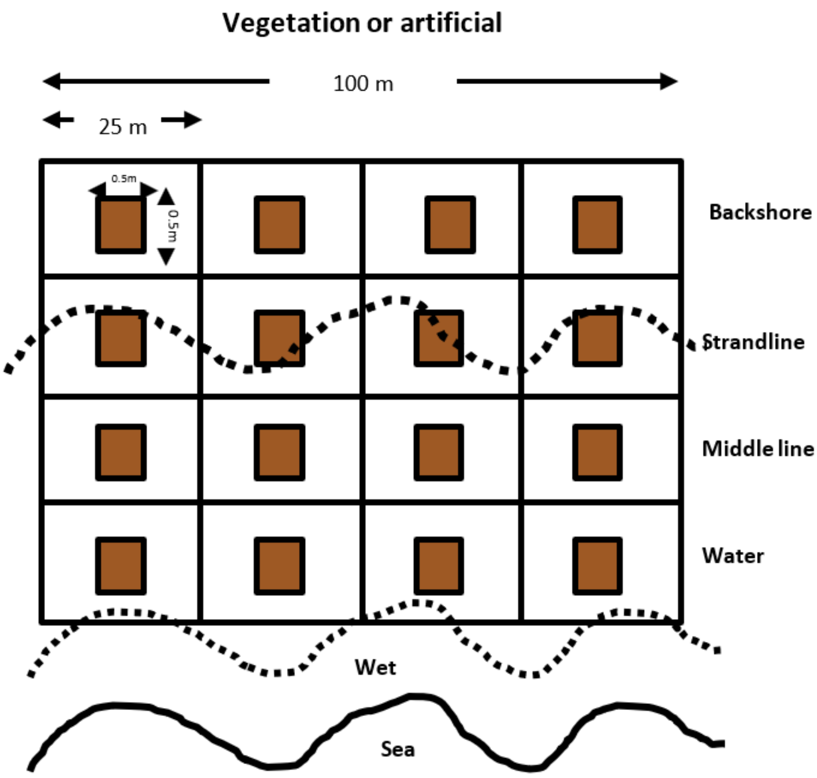

Fig. 2. Marine macro litter and microplastic sampling design

2.3 Macroplastic and Microplastic Correlation

Statistical analysis is used to identify the possible significant relationship between macro- and microplastic. Linear Regression was used in SPSS software to determine this relationship. The hypothesis is that there is a relationship between macroplastic abundance on the beach and the amount of microplastic in beach sediments.

3. Results

3.1 Marine Litter Categories

Six types of marine litter were collected in the study area: plastic, fabric, rubber, wood, glass, and metal. Figure 3 shows the total average weight of six categories for all stations discovered in the study area, which totaled 228 kg of macro marine litter. The heaviest category is macroplastic, which accounts for 73.8 % litter. Plastic pieces, food containers and wrappers, plastic bags, cigarette filters, drinking straws, and plastic bottles are examples of macroplastic found in this category. Glass was found to be 12 %, fabric 7.8 %, rubber measuring 4.4 %, wood 2 %, and metal 0.07 %. The fabric in this study area is made up of old bags and clothes, while the glass is mostly made up of drinking glass bottles and ketchup bottles. Plastics are the heaviest measuring marine litter because they are light, durable, and can last for a long time in the environment. Plastics degrade into smaller and smaller pieces over time and eventually become buried within the sand itself or in sediment. The third heaviest weight of macro marine litter collected is fabric, which has a lower density, is lighter, and can be fragmented into smaller sizes. This facilitates the movement of fabric by water to the coastal area [14].

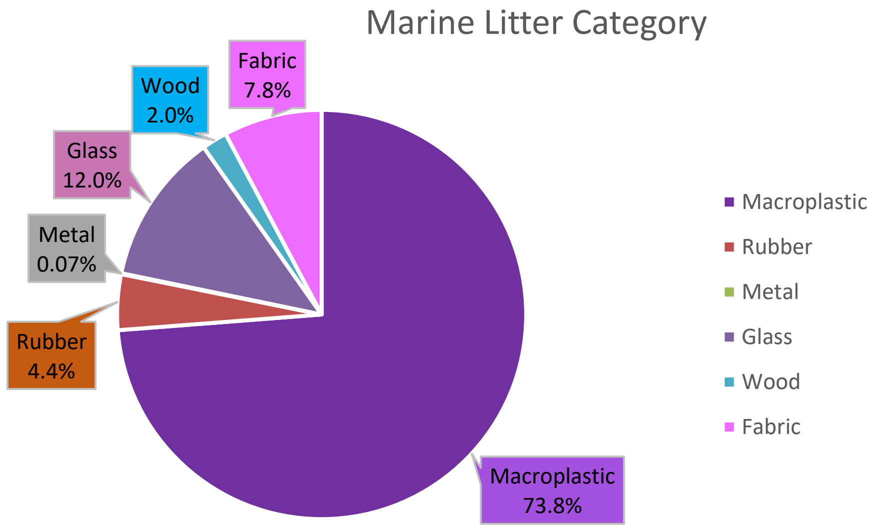

Fig. 3. Percentage of different categories of marine macro litter

Figure 4 clearly shows that macroplastic constitutes most of the marine litter collected at S1, S2, S3, S4 (in the vicinity of Kuala Perlis), S5 (Pantai Pasir Tengkorak), and S6 (Teluk Datai). However, for S6, all the marine litter collected is made of plastic, whereas S1, S3, and S4 contain a small amount of rubber. S1, S2, and S5 contain a small amount of wood. S4 (Kurung Tengar), which is located near a residential area, has a higher percentage of fabric and glass.

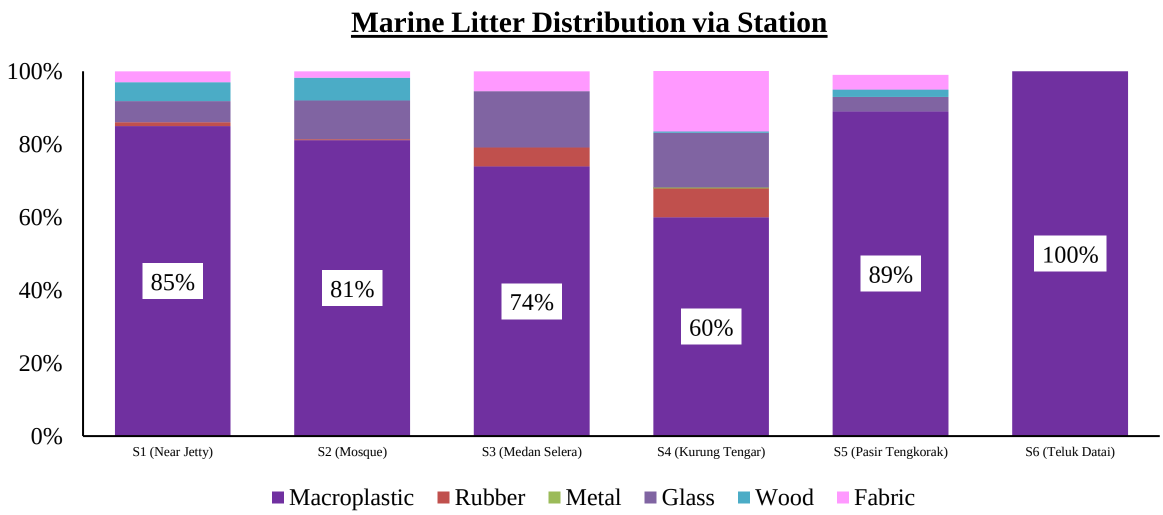

Fig. 4. Comparative marine litter distribution for each sampling location

Table 1 shows the results of marine litter collection for the Kuala Perlis and Langkawi Northwest coastal region in terms of weight per unit area (g/m^2) and percentage. S3 has the highest amount of macroplastic per unit area, 24.7 g/m^2 (Medan Selera). S6 has the lowest amount of macroplastic, with 0.523 g/m^2. S6 is a highly privileged tourist area in Teluk Datai that is untouched by development, pristine, and well-maintained by the local authority. Metal can only be discovered at S4 (Kurung Tengar) (0.1 g/m^2), which is surrounded by residential areas and illegal settlements. Glass can be found at S1 (0.9 g/m^2), S2 (0.19 g/m^2), S3 (5.1 g/m^2), S4 (5.4 g/m^2), and S5 (0.4 g/m^2), whereas fabric litter can be found from S1 to S5, weighing 0.4 g/m^2, 0.3 g/m^2, 1.8 g/m^2, 6.1 g/m^2, and 0.4 g/m^2

respectively. It has been established that urbanization and modernization of specific areas pollute the environment, particularly the coastal marine area. Increased human activity is also associated with environmental pollution [15].

Table 1
Macro marine litter categories collected from Kuala Perlis and Langkawi Northwest coastal zone

Marine Litter	Unit	Station					
		S1	S2	S3	S4	S5	S6
Macroplastic	g/m^2	1.33E+01	1.44E+01	2.47E+01	2.19E+01	3.24E+00	5.23E-01
	%	85.3%	80.9%	74.1%	59.5%	77.0%	100.0%
Rubber	g/m^2	2.00E-01	1.00E-01	1.70E+00	3.10E+00	0	0
	%	1.28%	0.56%	5.11%	8.43%	0%	0%
Metal	g/m^2	0	0	0	1.00E-01	0	0
	%	0%	0%	0%	0.27%	0%	0%
Glass	g/m^2	9.00E-01	1.90E+00	5.10E+00	5.40E+00	4.00E-01	0
	%	5.76%	10.70%	15.33%	14.68%	4.24%	0%
Wood	g/m^2	8.00E-01	1.10E+00	0	2.00E-01	2.00E-01	0
	%	5.12%	6.20%	0%	0.54%	2.12%	0%
Cloth	g/m^2	4.00E-01	3.00E-01	1.80E+00	6.10E+00	4.00E-01	0
	%	2.56%	1.69%	5.41%	16.59%	4.24%	0%

3.2 Macroplastic by Market Sector

Figure 5 summarises the macroplastic composition in each sector as a percentage of plastic weight. Packaging was the most common type of plastic found in all locations, while automotive, electrical and electronic, and agriculture were only found at S4 (Kurung Tengar) with 0.64 %, 4 %, and 2 %, respectively. Because S4 is close to a residential area and a fishing village, the macroplastics discovered are likely from the automotive, agriculture, and electrical and electronic sectors.

At S1 (near Jetty), the highest plastic discovered was in packaging category (68%), 24% from household, leisure and sport category with included plastic bucket, strainer, toys, stationaries, and sport equipment, 7.5% of others derived from fishing equipment, mechanical engineering, and appliance and 0.5 % from building and construction category which consist of pipes. S2 (Mosque) and S3 (Medan Selera), both located near tourist attractions, have the highest packaging categories with 65%, followed by other categories with 20% and 18%. Household, leisure, and sport contributed approximately 13% to S2 and 17% to S3, which includes plastic from household and sporting equipment. S2 has the lowest percentage of the category building and construction (1.7 %), and neither S2 nor S3 has any of the categories of automotive, health, agriculture, and, electrical and electronic.

It was discovered in S5 (Pasir Tengkorak) that approximately 57% was found in the packaging category; the second highest category of plastic was household, leisure, and sport with 21%, which was likely contributed from beach visitors. Others and building and construction categories contributed approximately 17% and 5%, respectively. The existing litter from the building and construction sectors was from a small construction site in a location for constructing facilities such as benches and a shack. Fishing net fragmentation is another industry. It was known that the location is not a fishing spot, but the plastics may come from fishing activity in the ocean and transported to the beach by wave and wind [16]. Packaging sectors contributed significantly to the macroplastic discovered at S6 (Teluk Datai), accounting for 100% of the total macroplastic discovered.

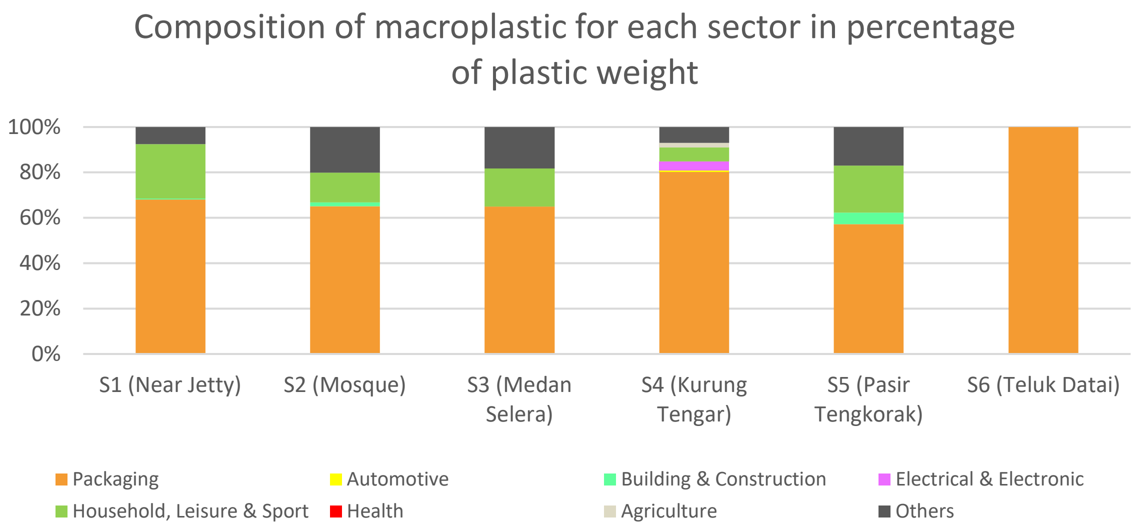

Fig. 5. Composition of macroplastic for each sector in percentage of plastic weight

3.3 Microplastic in Sediment

The abundance of microplastics collected in the study area is expressed as weight per unit volume (g/m^3). According to Figure 6, the total heaviest weight of microplastics found during sampling is at S3 with 2.972 g/m^3 where the seafood restaurant and hotel are located, which is similar to the finding of macroplastic litter. This area was characterised by a variety of anthropogenic pressures, such as high touristic activities in the area, which included numerous seafood restaurants, hotels, and motels. The high periodic population density in the area, coupled with the combination of eateries, hotels, and traffic density, resulted in a higher abundance of microplastic collected on beach sediment [17]. The beach at a 5-star resort with the lightest weight of microplastic discovered was S6 (0.081 g/m^3). The lowest amount of microplastic collected was apparently due to low human activity and a small scale of development in conjunction with the preservation of the natural environment surrounding the area [18]. The second highest abundance of microplastic collected was at S4 with 2.526 g/m^3, which is close to the fishing village, followed by S2 (2.454 g/m^3), S1 (2.249 g/m^3), both of which are tourist attractions, and finally S5 with 0.812 g/m^3, which is also a popular spot for leisure activities.

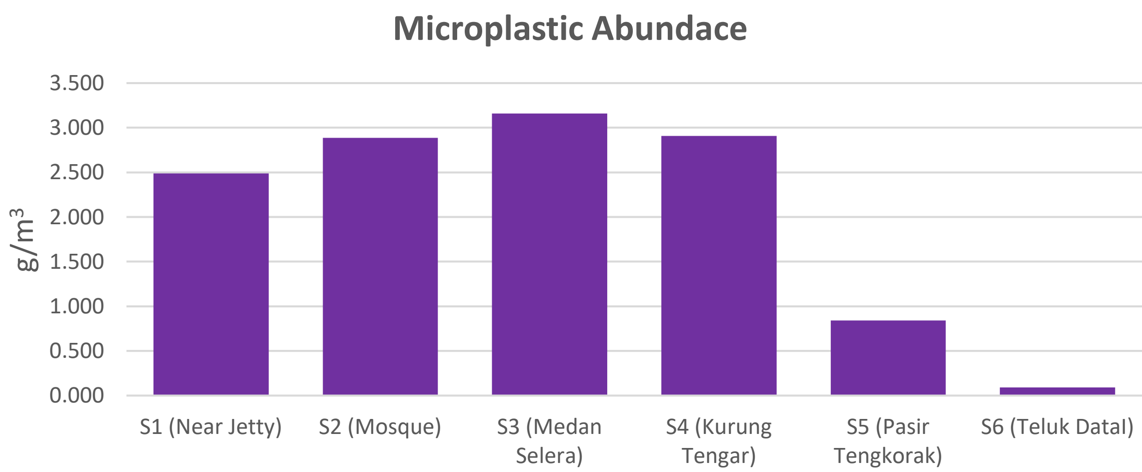

Fig. 6. Microplastic abundance (g/m^3) in sediment of the sampling area

3.4 Relationship between Macroplastic and Microplastic

This research finds an average of 1.849 g/m^3 of microplastic in beach sediment and 13.982 g/m^2 of macroplastic on the beach. In this study, statistical analysis revealed a strong correlation between the amount of macroplastic litter on the beach and the abundance of microplastic in the sediment. The linear regression analysis showed that the amount of macroplastic influences the amount of microplastic, implying that microplastic contamination levels in beach sediments can be estimated based on the level of macroplastic pollution [19]. Figure 7 captures the significant relationship between both macroplastic and microplastic. Regression analysis computed is given in the equation $y = 0.1927x - 0.0226$, where y represents the value of microplastic (g/m^3) while x is the macroplastic (g/m^2). The calculated value of R^2 is 0.7444, indicating that a high amount of macroplastic on the beach will result in a high amount of microplastic in the sediment layer. In other words, the amount of microplastics in the beach sediment and macroplastic litter on the beach is quite well represented (at nearly 75%) and captured in the model developed.

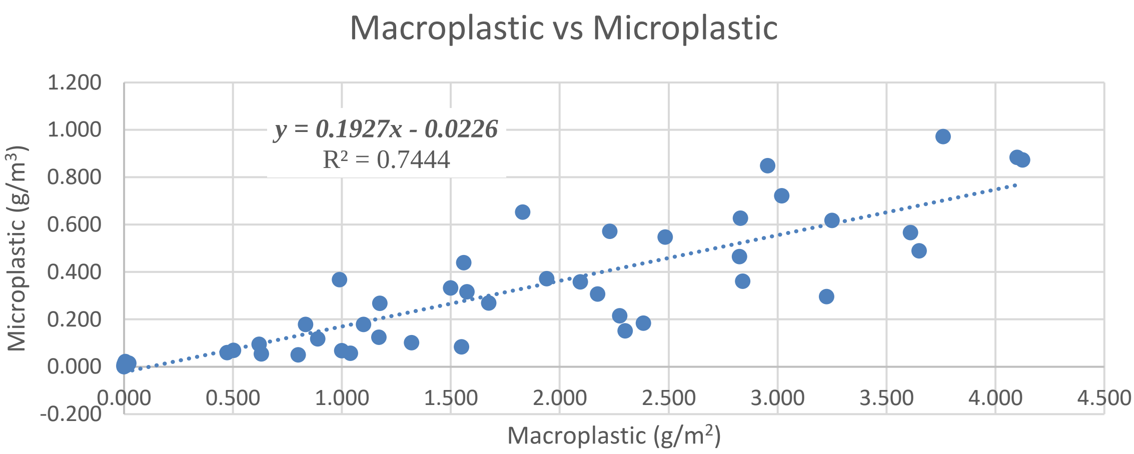

Fig. 7. Relationship between macroplastic and microplastic

Because microplastics are more difficult to collect than macroplastics due to their smaller size, the strong correlation makes locating potential hot spot areas based on the locations of macroplastic hot spots very useful. The abundance of microplastics was found to be highly correlated with the abundance of macroplastics in weight. This study's findings support the hypothesis that there is a relationship between macroplastic abundance on the beach and the amount of microplastic in beach sediments. This finding is also consistent with the findings of a 2012 study conducted on six beaches along Korea's southern coast, which discovered a strong correlation between the abundance of microplastic and macroplastic [20].

4. Conclusions

Anthropogenic activities are one of the factors that contribute to the higher abundance of macroplastics found in Kuala Perlis, which has a high tourism pressure and development along the coast. Coastal development, on the other hand, was almost non-existent on Langkawi's Northwest coast (Teluk Datai and Pantai Pasir Tengkorak), with the natural environment considered pristine and untouched.

Most of the marine litter found in six sampling locations was plastic, with metal being the least prevalent. Packaging sectors contribute the most in large plastic found, and the fact that the study area is a heavily visited recreational coastal area with a high tourist exposure may explain why debris from the packaging sector contributes significantly to the total amount of macroplastic in the study area. This led to another discovery, indicating that the proximity of the beach to human activities such as tourism, fishing, and housing is a factor influencing the abundance of plastic on the beach.

The correlation between macroplastic and microplastic reveals a strong relationship. The effect of macroplastics on microplastic abundance via assumed fragmentation and degradation based on plastic sizes and shapes. A strong relationship suggests that the presence of microplastic in beach sediment is linked to the abundance of macroplastic on the beach, as well as human activities and population density near the coast. This result serves as a baseline for future assessments. Management actions and responsible agencies should concentrate on prevention input of plastic litter into coastal areas, such as proper waste management, plastic recycling, and strict penalties.

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