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CHARACTERISTICS, DISTRIBUTION PATTERNS AND EFFORTS TO HANDLE MACROPLASTIC WASTE ON THE BORDER OF THE MUSI RIVER, PALEMBANG CITY, INDONESIA

Abstract: The research aims to identify the characteristics of waste generation and its composition, map the distribution of macroplastic waste generation and efforts to reduce waste generation through the use of plastic. The method used is a survey with a quantitative descriptive approach. The research subject was the generation of macroplastic plastic waste located on river borders, and the research sample was determined using purposive sampling. Data collection techniques use documentation and survey instruments as checklists to record waste generation found on river borders. Data analysis was carried out descriptively using frequency tables and Near Neighborhood Analysis. The research results show that the amount of waste generation and composition continues to increase yearly. A lot of rubbish was not recorded and was found scattered around their house. The composition of macroplastics (MP) found consisted of drinking bottles, plastic bags, food wrappers, industrial packaging (such as detergent, soap, fragrance, snacks, shampoo), straws, plastic carpets, cement-packed sandals, styrofoam lunch boxes and other types of other types that are difficult to identify. The distribution of macroplastic waste generation shows an evenly distributed pattern in each sub-district in Palembang City. Efforts are being made to reduce the generation of macroplastic waste, making temporary dump sites scattered in public places, using plastic floating in small rivers to collect macroplastic waste, distinguishing between organic and non-organic waste, and carrying out river restoration. Musi River restoration is carried out every year and involves all government agencies, Pertamina, youth, and volunteers from various communities.

Key words: waste generation, macroplastics, pollution, river borders

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Introduction

Environmental problems are problems caused by humans. These anthropogenic activities largely contribute to plastic waste. Plastic is generally a popular item used by the public. Because the properties of plastic are powerful, durable, light and easy to carry (Risnani et al., 2016; Yona 2019; Chaudhary, 2014). Single-use plastic is thrown away and ends up in rivers. Rivers play an important role in transporting plastic waste from land to the ocean, plastic pollution also has a direct impact on river ecosystems (Emmerik & Schwarz, 2020). Plastic pollution is not limited by national borders and may not be easily reversed (Alexiadou, et al., 2019).

Plastic pollution is of serious concern to every country in the world. It is estimated that between 1.15 and 2.41 million tonnes of plastic waste currently enters the ocean each year from rivers, with more than 74% of emissions occurring between May and October (Lebreton, et al., 2017). The most plastic waste is domestic waste. Plastic pollution is one of the most dangerous anthropogenic consequences can be found everywhere, and persists for a long time in the marine environment (Barnes et al., 2009; Moore, 2008) because it is difficult to decompose. Decomposing plastic will pose other, more serious threats. Decomposed plastics are classified into four groups, namely nanoplastics, microplastics, mesoplastics and macroplastics, which are characterized by the respective dimensions of macroplastics (>25mm), mesoplastics (5-25 mm), microplastics (5-1 μm) and nanoplastics (<1μm) (Iwasaki et al., 2017).

Plastic enters river systems in various ways, both consciously and unconsciously. River plastic can be traced back to plastic discarded on river banks, an activity carried out both consciously and unconsciously. This includes plastic dumped directly on riverbanks, dumped directly from boats, leakage from waterlogged landfills, and leakage of land-based plastic waste by urban water runoff and wind, and dumped through urban network channels. (Kiessling et al., 2019; Rech et al., 2014; Bruge et al., 2018; Tasseron et al., 2020).

Plastic waste that enters the environment is the result of human activities. With the increase in population, of course, the amount of waste entering the environment increases. Palembang City is one of the big cities on the island of Sumatra. The population in Palembang City increases yearly, which increases the amount of waste produced yearly. Palembang City has an area of 400.62 km^2 and 18 sub-districts. Sungai besar yang ada di wilayah Kota Palembang adalah Sungai Musi.

The Musi River divides the Palembang City area into two administrative parts, namely Ulu and Ilir. The Musi River resources are used directly by the people of Palembang City for eating, drinking, washing and transportation. Because the Musi River greatly impacts the people of Palembang City, many people live on the riverbanks. The government collects some of the waste produced by the community through the Environment and Forestry Service (DLHK) and the Sukawinatan TPA. Others are still found around people's homes and have yet to be recorded. The community dumps this rubbish directly into their environment, which is a tributary of the river. This causes waste generation to spread throughout the Palembang City area. This research aims to identify the characteristics of waste generation and its composition, map the distribution of macroplastic waste generation, as well as efforts to reduce waste through the use of plastic.

Materials and Methods

Study Area

The criteria for determining the location for observing macroplastic deposits are areas associated with the Musi River, easy to reach/accessible, and located in densely populated areas. This research was conducted in areas/sub-districts in the city of Palembang consisting of 18 sub-districts. The sampling technique used purposive sampling with consideration of the sub-districts through which the Musi River passes or the sub-districts that directly border the Musi River. The locations for this research are Plaju District, SU 1 District, SU II District, Jakabaring District, Kertapati District, Kalidoni District, Ilir Timur I District, Ilir Timur II District, Ilir Timur III District, Bukit Kecil District, Ilir Barat I District and Gandus District (Figure 1).

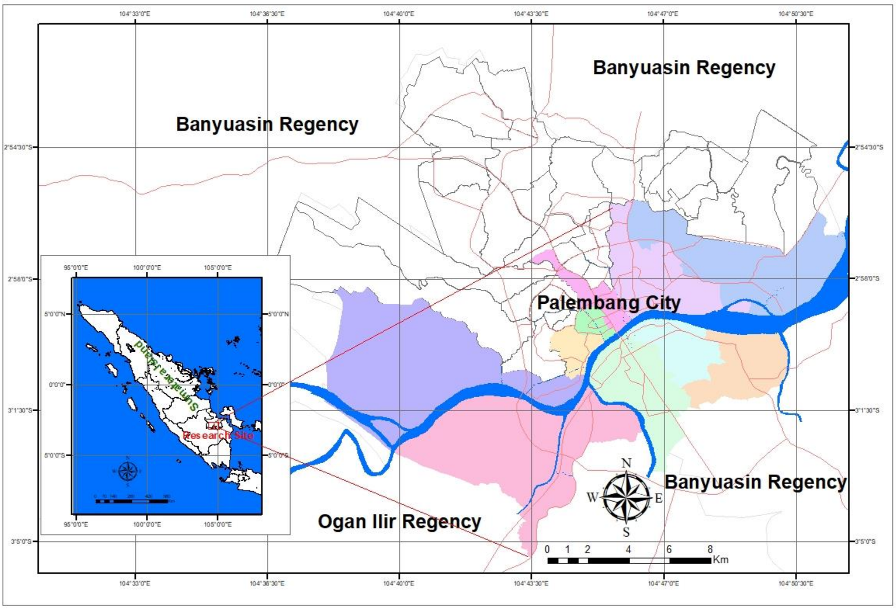

Fig. 1. The data collection location for macroplastic generation is located around the Musi River, Palembang City.

The research method used is a survey with a quantitative approach. The data source for this research uses primary data and secondary data. Primary data in this research is type of waste, composition of waste, place/location of waste disposal, and volume of waste. Secondary data in this research is Palembang City BPS in numbers, the Palembang city administration map and waste data at the Cleaning Service. The population of this research is macroplastic waste in Palembang City and the sample for this research is macroplastic waste in the area around the river. The sampling technique used was purposive sampling.

The variables that will be observed while in the field are the location of the waste generation (absolute and relative), the area of the waste generation (m^2), the type of plastic (7 types mentioned), the status of the waste generation location (legal/illegal), the management of waste generation (community/government/collaboration, Participation, Trash facilities.

Table 1. Research variables

Indicators / Variables	Parameter	Information
Location of Occurrence	Absolute Relatively	Redzwan and Ramli, 2007 Ridwan, et.al., 2024
Generation Area	m²	Zhang et al., 2020
Plastic Type	Plastic bags Drink bottle Industrial Packaging Personal Equipment Tableware	Wenneker and Oosterbaan, 2010 Armitage, et.al. 2022 Winton, et.al (2020) Halden, 2010; Andrady, 2011; Ghosh, et.al., 2013) Abdullah, et.al 2022
Status of waste generation locations	Legal (Temporary Disposal Place) Illegal (Rivers, empty land, etc.)	Peraturan daerah Kota Palembang, No 03 year 2015
Waste Generation Management	Public Government Collaboration	Peraturan Walikota Kota Palembang, No. 72 year 2018
Participation	Live Participation Indirect participation	Damri, et.al 2020
Trash facilities	Rubbish bin River/anything Mobile City Cleaning Department	Lestari et al. 2018
Settlement Density	Building distance Building density	PUPR

Source: researcher's analysis

Data collection in this research uses observation and documentation. When collecting observation data, researchers will use observation sheets to collect data on waste generation by looking at the type of waste, composition of waste, place/location of throwing waste, volume of waste, and length of pile. Researchers will take photos of the area to support research, data on waste generation at the Sukawinatan TPA, and regulations related to waste.

Data analysis

The data analyzed is the amount of waste generation, and waste composition, waste distribution and waste reduction efforts. Data analysis is used to measure the amount of waste generation and waste composition, and frequency analysis is used. To measure the distribution of macroplastics using Near Neighborhood Analysis. Next, waste reduction efforts will be analyzed using descriptive analysis.

Results and Discussion

Waste Generation and Composition

Waste, especially macroplastic (MP) waste, can increase as a result of daily human activities. Data shows the generation of waste every year in every sub-district that has direct contact with the Musi City River. Human waste recorded every day for a year has increased every year, although sometimes there has been a decrease. Data obtained as in Table 1 of waste generation per sub-district and outlined in Figure 1 of waste generation per year are as follows:

Table 1. Waste generation per sub-district

Sub-district	Waste Generation 2018	Waste Generation 2019	Waste Generation 2020	Waste Generation 2021	Waste Generation 2022
Ilir Barat 2	6,119,022.6	6,496,566.64	6,531,267.84	643,812.2	6,643,706.2
Gandus	9,178,533.8	9,744,849.96	9,796,901.76	965,718.3	9,965,559.3
Seberang Ulu 1	9,178,533.8	9,744,849.96	9,796,901.76	965,718.3	9,965,559.3
Kertapati	6,119,022.6	6,496,566.64	6,531,267.84	643,812.2	6,643,706.2
Jakabaring	33,654,624	35,731,116.52	35,921,973.12	3,540,967.1	36,540,384.1
Seberang Ulu 2	6,119,022.6	6,496,566.64	6,531,267.84	643,812.2	6,643,706.2
Plaju	15,603,508	16,566,244.93	16,654,732.99	1,641,721.11	16,941,450.81
Bukitkecil	33,654,624	35,731,116.52	35,921,973.12	3,540,967.1	36,540,384.1
Ilir Timur 1	39,773,647	42,227,683.16	42,453,240.96	4,184,779.3	43,184,090.3
Ilir Timur 2	20,804,677	22,088,326.58	22,206,310.66	2,188,961.48	22,588,601.08
Kalidoni	3,059,511.3	3,248,283.32	3,265,633.92	321,906.1	3,321,853.1
Ilir Timur 3	9,178,533.8	9,744,849.96	9,796,901.76	965,718.3	9,965,559.3
Total	192,443,260.5	204,317,020.8	205,408,373.6	20,247,893.69	208,944,560

Data analysis shows that there is an annual increase in waste generation in each sub-district which has a direct impact on the Musi River (Table 1). Interestingly, although there are annual fluctuations, the general trend shows a consistent increase (Dao, et.al. 2024). This increase reflects not only population and consumption growth, but also a lack of awareness and adequate waste management infrastructure.

The results of data findings in the field show that the generation of macroplastic (MP) waste is also spread in other places around the community where they live. Human activities cause the generation of macroplastic waste which is found around people's residences. This shows that many people still throw plastic waste carelessly around the housing complex where they live. This proves that the macroplastic waste (MP) that is around the river where they live is macroplastic waste (MP) that is not recorded or, in other words is thrown directly by local residents in the river near where they live. Plastic waste that is thrown away continuously every day will give rise to the generation of plastic waste (MP), which will later cause a larger generation. Figure 2 shows the generation of macroplastic waste that occurs as a result of people throwing it away carelessly around their homes.

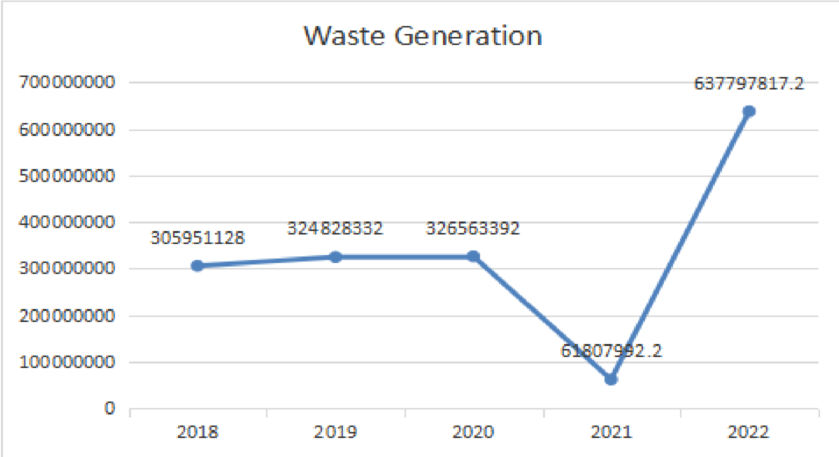

Fig. 2. Trends in Waste Generation

Fig. 3. Generation of Macroplastic Waste Around Community Settlements

The accumulation of plastic waste or a collection of unrecorded macroplastic (MP) waste inhabits areas around community settlements, spread across almost every sub-district in Palembang City (Figure 3). The generation of macroplastic waste is distributed in different sizes. The data shows the distribution of macroplastic waste in various sizes, which is classified into three categories based on area: 10 – 50 m^2, 50 – 100 m^2, and >100 m^2. This distribution reflects the heterogeneity of sources and waste disposal methods in the community. The generation of macroplastic waste is spread around people's residences along river flows in Palembang City (Figure 4).

The waste generated in final disposal sites has various types, both organic and non-organic. The incoming and recorded waste has several compositions consisting of food waste, wood/twigs, paper/cardboard, plastic, metal, cloth, rubber, glass and others. The most dominant waste recorded was food waste, and plastic waste was in second place. Plastic waste in landfills has several types of polymers, consisting of PETE, HDPE, PVC, LDPE, PP, PS, and others. To see more clearly the composition and abundance of waste, see Table 2.

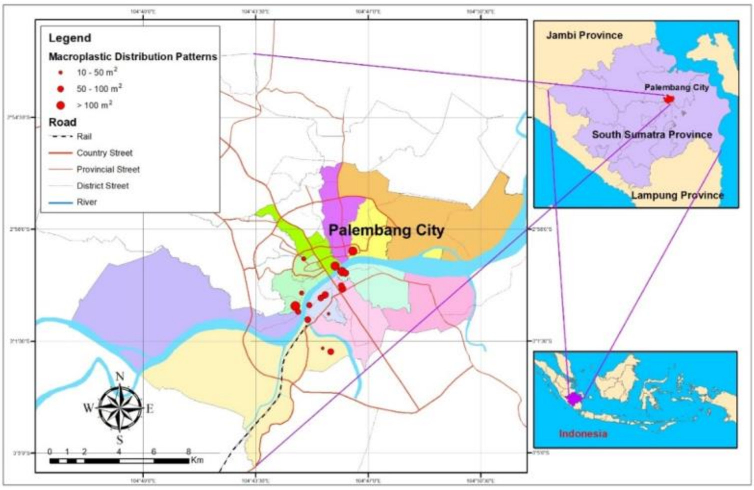

Fig. 4. Macroplastic Quantity Distribution Map

Table 2. Composition and Quantity of Waste

Year	Leftovers (%)	Wood-Twigs (%)	Paperboard (%)	Plastic (%)	Metal (%)	Cloth (%)	Rubber - Leather (%)	Glass (%)	Other (%)
2022	53,00	5,50	14,00	17,00	1,50	3,00	4,00	1,00	1,00
2021	56,90	5,40	15,10	17,50	0,50	2,70	0,30	0,80	0,80
2020	55,00	5,00	10,00	14,00	5,00	4,00	3,00	2,00	2,00
2019	51,20	6,70	17,20	18,00	0,60	2,80	0,50	1,20	1,90

Apart from the above waste composition, there is a generation of macroplastic waste which is not in final disposal sites but is found elsewhere. It is the result of human activities that throw away carelessly and create unrecorded macroplastic (MP) waste generation. Macroplastic waste found at the observation location can be grouped into 3 types of plastic waste, namely large waste, medium waste and small waste (Tharani et al., 2021). Macroplastics also vary widely in size, morphology, and other physical properties, and there is currently a lack of harmonization regarding these characterizations (Hurley et al. 2023).

The Oslo and Paris Convention (OSPAR) categorizes macroplastic waste into 12 categories, which cover various types of plastic products that are often found in the environment. The research found that most of these categories were represented at the observation sites, with drinking bottles and plastic bags being the most common types of macroplastic waste (Wenneker & Oosterbaan, 2010). Apart from that, there are also several types of waste that have not been included in this category. Abdullah et al. (2022) stated that the common types are single-use plastic tablecloths, rolls of used plastic tape, pieces of plastic rope and electrical cables, drink bottles, and single-use plastic products such as cups, plates, straws, spoons, glasses, shoes. Disposables, plastics of pharmaceutical origin, personal care products, plastic bags, large plastic sheets, large plastic sacks, food and fruit wrappers of various sizes, and disposable pieces of foam and cork sheets.

If we look at the 12 categories of macroplastic waste, most of them are found at observation sites (Figure 4). The types of macroplastic waste that are most often found around people's homes are drinking bottles, plastic bags, plastic food wrappers, industrial packaging, personal care products and eating utensils (Figure 4). In other places, plastic carpets, sandals, cement wrappers, baby diapers and sanitary napkins, styrofoam lunch boxes and other types were also found, which were difficult to identify because they had been sitting in the sediment for a long time. The plastic waste found around their homes is the result of their daily use. Figure 5 shows that the macroplastic waste found has various sizes, types and textures ranging from small to large, as well as types of plastic with a soft or hard plastic texture.

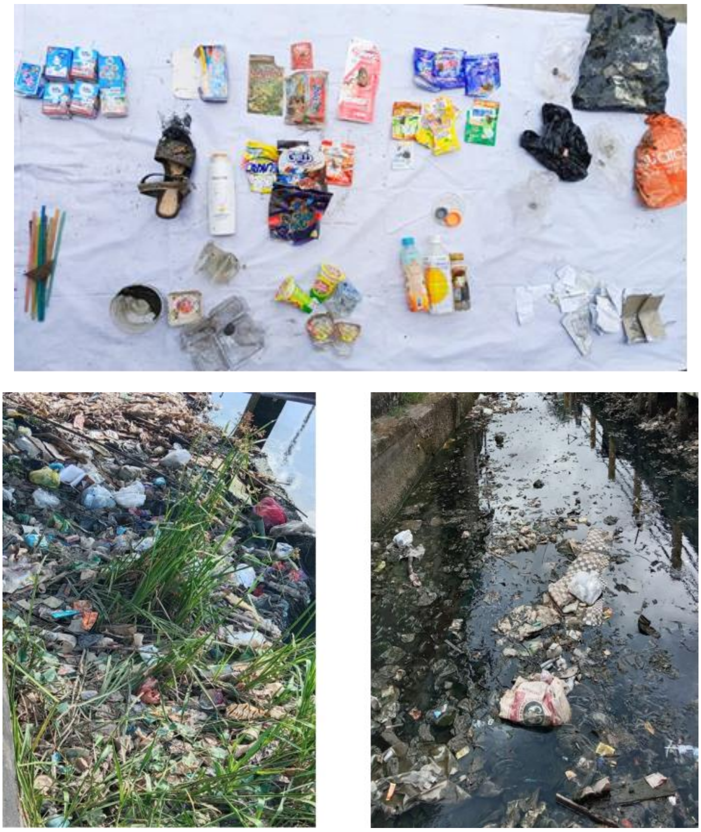

Fig. 5. Macroplastic waste found in the field

Table 3. Plastic categories found in the field

Katagori Plastik	Jenis Polimer
Drinking bottles	PET, LDPE, HDPE, PS, PP
Plastic bags	LDPE, HDPE
Food Packaging	PET, PVC, PP, PS
Industrial Packaging	HDPE, LDPE,PP
bottle cap	PET, LDPE, HDPE, PS, PP
Tableware	PET, PVC, PP, PS,LDPE
Sandal	PU
Personal Care Products	HDPE, PP, PET
diapers	PP

Note: PETE or PET (Polythylene Terephthalate); HDPE (High-Density Polyethylene); PVC (Polyvinyl Chloride); LDPE (Low-Density Plyethylene); PP (Polypropylene); PS (Polystyrene); Other Plastic Materials (BPA, Polycarbonate, and LEXAN)

The failure to record most of the macroplastic waste found around settlements shows weaknesses in the current waste management system. The community's habit of littering adds to the complexity of this problem, indicating an urgent need for more effective environmental education and strengthening regulations and their implementation (Sumarmi et al., 2022)

Dividing macroplastic waste by size and type provides essential insight into its source and potential impact on the environment. This study identified three main categories based on size: small, medium, and large, each of which has different implications for waste collection and processing strategies (Bhattacharya et al. 2024). In fact, the distribution and physical characteristics of macroplastic waste show significant variations, highlighting the need for a more structured approach in the characterization of plastic waste to strengthen management efforts (Hill, 2016).

The implications of these findings include the need for more effective waste management strategies, which not only focus on improving waste handling infrastructure but also on public education efforts to reduce the use of single-use plastics. Vuppaladadiyam et al. (2024) proposed a more integrated approach to managing macroplastic waste, including implementing a more efficient waste collection system and promoting the use of recyclable or more environmentally friendly products.

Distribution of Macroplastic Waste Generation

The distribution of macroplastic waste generation spread across various urban areas is an urgent environmental issue, especially in big cities in Indonesia such as Palembang. This city, with the Musi River running through it, experiences significant challenges related to macroplastic waste management. This research aims to identify distribution patterns of macroplastic waste in Palembang City using nearest-neighbor analysis. This method was introduced by Clark and Evans (1954) and continues to be used because of its high accuracy in assessing the spatial distribution of objects (Clark & Evans, 1954).

The distribution pattern of macroplastic waste is measured using a scale of values from 0 to more than 2.15, where a value of 0 – 0.9 indicates a clustered pattern, 1 – 2.14 indicates a random pattern and a value above 2.15 indicates an even distribution (Clark & Evans, 1954). From the analysis, the value obtained was 2.16, indicating an even distribution of macroplastic waste in every sub-district in Palembang. This shows that the generation of macroplastic waste is not concentrated in certain locations but is spread widely throughout the region.

The area studied includes nine sub-districts directly adjacent to the Musi River, including Seberang Ulu 1 and 2, Jakabaring, Kertapati, Bukit Kecil, Ilir Barat 2, Ilir Timur 1 and 2, and Gandus. In this research, 19 macroplastic distribution points were found which were evenly distributed in each region, with the Seberang Ulu 1 sub-district having the largest number of distribution points.

Environmental and housing conditions in sub-districts with the highest incidence of macroplastics show that urban design and population density contribute significantly to waste distribution. The distance between adjacent houses, difficulty of access, and the location of the house directly facing a river has the potential to increase the risk of accumulation of macroplastic waste in the water.

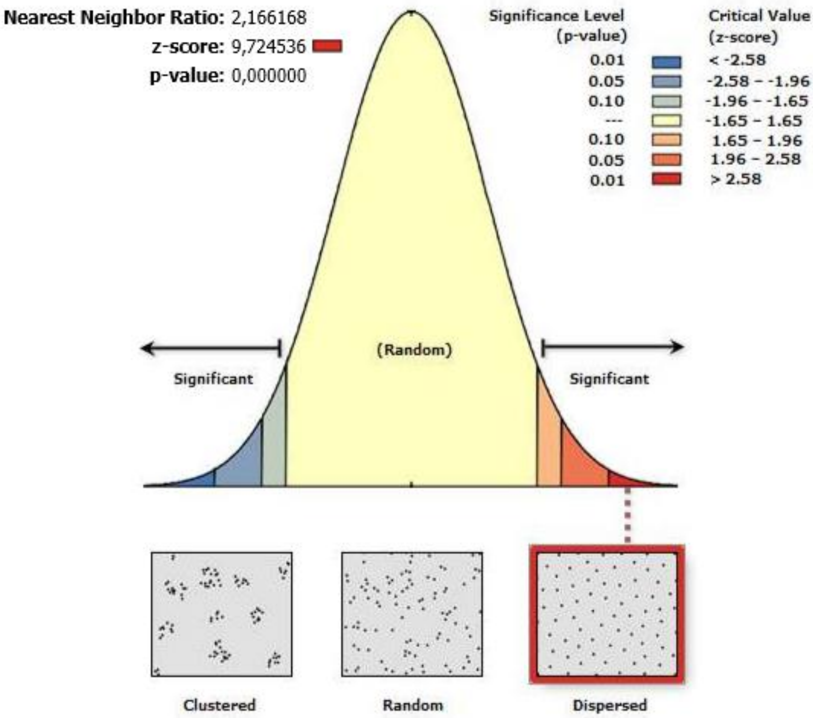

Fig. 3. Nearest neighbour analysis

This research provides insight into the distribution of macroplastic waste in large cities with large rivers, such as Palembang, and shows the importance of effective waste management and environmentally conscious urban design. Furthermore, these findings support previous literature regarding the influence of human activities and urbanization on plastic waste pollution in the aquatic environment (Indrawati, 2011 and Djaguna, 2019).

In facing global challenges related to plastic pollution, this research emphasizes the importance of a multidisciplinary approach that includes waste management, urban planning and public education. In the future, a comprehensive strategy involving local stakeholders, government and the international community is needed to overcome the problem of macroplastic waste in the urban environment.

Correlation of Population Growth with Waste Generation

The population certainly experiences changes because it is influenced by births, deaths, immigration and emigration. Based on data recorded over 5 years, the population in Palembang City has also experienced changes (figure 2) starting from 2018 as many as 1,028,412 people; in 2019 it rose to 1,040,796 people, then in 2020 it decreased to 992,670 people due to At that time the Covid-19 pandemic occurred, in the following year

2021 experienced an increase again to 999706 people and in 2022 the population increased to 1,016,669 people.

Before carrying out the product moment correlation analysis, a prerequisite test is carried out first to find out whether the data obtained is linear and normal. Data linearity and normality tests were carried out for 5 years from 2018 to 2022 (Table 4).

Table 4. Product Moment Correlation Prerequisite Test

No	Year	Linearity	Normality
1	2018	0.017	0.685
2	2019	0.012	0.693
3	2020	0.012	0.967
4	2021	0.029	0.952
5	2022	0.016	0.939

Analysis of Palembang City population data for the period 2018 to 2022 shows variations in population, where there are increases and decreases related to birth, death and migration factors, including the significant impact of the Covid-19 pandemic in 2020. Prerequisite tests carried out before the analysis Product moment correlation, including linearity and normality tests, showed that the data had a significant linear and normal distribution, with p-values of more than 0.05 for both tests over the five-year study period (Table 5).

Table 5. Product Moment Correlation Analysis

No	Year	Product Moment Correlation
1	2018	0.177
2	2019	0.172
3	2020	0.078
4	2021	0.069
5	2022	0.076

Further analysis using product moment correlation did not find a statistically significant relationship between population growth and waste generation, with correlation values over five years consistently greater than 0.05. This shows that, during the study period, population growth in Palembang City was not directly correlated with an increase in waste generation.

After testing the linearity and normality requirements to measure the correlation between population growth and waste generation. The results of the moment product analysis were obtained in 2018 with a value of 0.177, in 2019 with a value of 0.172, in 2020 with a value of 0.078, in 2021 with a value of 0.069 and in 2022 with a value of 0.076. This shows that the correlation value for 5 years is > 0.05; this means that there is no correlation between population growth and waste that has been recorded.

These findings challenge the common assumption that an increase in population is automatically associated with an increase in waste generation. Other factors, such as waste management policies, the level of environmental awareness of the population, and recycling infrastructure, may play an essential role in managing waste generation, regardless of population dynamics.

According to Sumarmi et al. (2022) and Shavon et al. (2024), the effectiveness of waste management is influenced by a combination of social, economic and technological factors, which can vary significantly between regions. Development of recycling infrastructure and waste reduction initiatives, as reported by Sumarmi et al. (2022), Chotimah et al. (2021), Qonaah (2019) and Sukirman (2023) contribute to more efficient waste management, even amidst population growth.

It is important to note that this research has limitations, including the data scope being limited to the city of Palembang and a five-year time period. Future research could expand this analysis to other regions and longer time periods to understand more complex dynamics between population growth and waste generation.

Waste Reduction Efforts

Reducing plastic waste generation in urban areas is one of the most pressing environmental challenges of the 21st century. The city of Palembang, for example, is facing a significant increase in plastic waste production, which not only affects public health but also environmental sustainability. This study explores various initiatives that have been implemented in Palembang City to address this problem, highlighting collaboration between local government, communities and waste care groups.

One of the first steps taken by the Palembang City Government is to provide easily accessible waste disposal sites in every public place. The strategic location of this rubbish dump is intended to encourage people to be more responsible in disposing of rubbish in the right place. Furthermore, the provision of Temporary Storage Places (TSP) has proven effective in managing the waste produced before it is further processed.

The use of floating plastic in small rivers is a local innovation aimed at catching flowing rubbish before it pollutes the larger Musi River. This initiative not only helps in reducing water pollution but also increases public awareness about the impact of waste on river ecosystems.

In terms of waste management, the approach adopted includes separating organic and non-organic waste. Organic waste is processed into compost, while non-organic waste, especially plastic, is processed for recycling. This process not only reduces the volume of waste that ends up in landfills but also produces products that have economic value.

Restoration of Musi River tributaries is also an important part of the waste management strategy in Palembang. This activity involves cleaning the river from plastic waste and rehabilitating the river environment to support biodiversity and social activities in the surrounding community.

The role of the community and waste care groups cannot be ignored. Initiatives such as waste banks, where people can exchange plastic waste for money or other goods, have encouraged active community participation in waste management. These groups also often hold educational activities about the importance of waste management and its impact on the environment.

Conclusions

This research reveals a significant increase in the generation and composition of plastic waste every year, highlighting a serious and pressing environmental problem. The increase in the amount of plastic waste, especially macroplastics, around settlements shows the unsustainability of current waste management practices. The dominant composition of macroplastic waste includes drinking bottles, plastic bags, food wrappers and industrial packaging, all contributing to environmental pollution. This study also found that the distribution of plastic waste tends to be evenly distributed in every sub-district in Palembang City, indicating that this problem is a widespread phenomenon and is not limited to certain areas.

Efforts that have been made by the Palembang City Government and the community to reduce the generation of macroplastic waste include providing TPS scattered in public places, using floating plastic in small rivers to catch macroplastic waste, managing organic and non-organic waste, and carrying out river restoration.

Based on the results of this research, we recommend several steps to overcome the plastic waste problem, including implementing an Effective Waste Management System, Increasing Public Awareness, and implementing a Policy for Restricting the Use of Single-Use Plastics.

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