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CHARACTERISTICS OF INORGANIC MARINE WASTE IN THE TANJUNG BUNGA AREA OF MAKASSAR CITY

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Abstract

Marine debris has emerged as a critical environmental issue that threatens the sustainability of coastal ecosystems, particularly in areas experiencing intensive human activities. This study aimed to analyze the characteristics of inorganic marine debris in the Tanjung Bunga coastal area, Makassar City, Indonesia. A quantitative descriptive approach was employed through field observations at three sampling stations representing residential, recreational, and shoreline environments. Marine debris was collected using the NOAA line transect method during the lowest tidal conditions and classified according to type, size, abundance, and mass. Oceanographic data, including currents, waves, and tides, were obtained from the Meteorological, Climatological, and Geophysical Agency (BMKG). The results showed that plastic was the dominant type of inorganic marine debris at all observation stations, followed by wood, metal, Styrofoam, rubber, and glass. Macro-sized debris accounted for the largest proportion of collected materials, while the shoreline station exhibited the highest debris mass, indicating that coastal hydrodynamics significantly influence debris transport and accumulation. Differences in debris composition among stations reflected variations in surrounding anthropogenic activities, including residential settlements, tourism, and coastal utilization. These findings highlight the importance of strengthening integrated coastal waste management through improved waste infrastructure, environmental education, regular beach clean-up programs, and policies to reduce plastic pollution, thereby supporting sustainable coastal ecosystem management.

Keywords: *coastal; debris; management; plastic; pollution*

INTRODUCTION

Marine debris has emerged as one of the most significant environmental challenges affecting marine ecosystems worldwide. Over the last few decades, the rapid increase in plastic production and consumption has resulted in an unprecedented accumulation of solid waste in oceans and coastal environments. It is estimated that approximately 8 million metric tons of plastic waste enter marine ecosystems every year, threatening biodiversity, ecosystem functioning, fisheries, tourism, and human health (Jambeck et al., 2015). Unlike organic materials, inorganic marine debris, including plastics, metals, glass, rubber, and synthetic products, decomposes extremely slowly and may persist in marine environments for several centuries. During this process, larger debris gradually fragments into microplastics that are capable of entering marine food webs and ultimately affecting human health through seafood consumption (UNEP, 2021; GESAMP, 2015). In addition, ocean currents, tidal movements, wind circulation, and coastal human activities continuously transport and redistribute marine debris, resulting in its accumulation along coastlines and estuarine environments (Lebreton et al., 2017).

Indonesia, an archipelagic country with more than 17,000 islands and one of the world's longest coastlines, is recognized as one of the major contributors to plastic leakage into the marine environment (Jambeck et al., 2015). This condition is strongly associated with rapid population growth, increasing urbanization, inadequate waste management systems, and intensive economic activities occurring in coastal regions (World Bank, 2021). Previous studies have demonstrated that Indonesian marine debris is predominantly composed of single-use plastic packaging, plastic bottles, food containers, beverage straws, fishing gear, and other synthetic materials originating from domestic, commercial, fisheries, and tourism activities (Cordova et al., 2019; Seftianingrum et al., 2023). Considering Indonesia's dependence on marine resources for fisheries, food security, transportation, and tourism, increasing marine pollution represents a serious threat to ecological sustainability and socio-economic development (Putri, 2021).

Coastal areas constitute the primary interface between terrestrial and marine ecosystems and therefore function as the main accumulation zones for marine debris. Various anthropogenic activities, including tourism, fisheries, coastal settlements, industrial development, and maritime transportation, substantially increase the quantity of waste entering coastal waters (Browne et al., 2015). Simultaneously, river discharge serves as one of the major pathways transporting terrestrial waste into marine ecosystems (Lebreton et al., 2017). Consequently, coastal pollution has become an increasingly complex environmental issue because it reduces ecological productivity, degrades coastal habitats, threatens marine biodiversity, and negatively affects economic sectors that depend on healthy coastal ecosystems, particularly fisheries and marine tourism (Ningrum, 2019; Subhan, 2020).

Marine debris is generally defined as any manufactured or processed solid material that is intentionally or unintentionally discarded into the marine environment from both land-based and ocean-based sources (UNEP, 2021). The majority of marine debris originates from human activities and reaches coastal waters through rivers, stormwater runoff, illegal dumping, fisheries, shipping, tourism, and inadequate waste management systems (Surjanto et al., 2023). The persistence of inorganic waste has transformed marine pollution into a multidimensional environmental problem requiring integrated management involving government institutions, local communities, tourism stakeholders, and the private sector. Without effective intervention, continuous waste accumulation will further reduce coastal environmental quality, increase environmental remediation costs, and threaten ecosystem resilience under changing climatic conditions (GESAMP, 2015).

The rapid expansion of tourism, coastal urbanization, and increasing population density have intensified environmental pressures on many Indonesian coastal areas, including Makassar City. Tourism activities, recreational use of beaches, coastal settlements, and commercial activities generate considerable quantities of solid waste that often remain unmanaged due to limited environmental awareness and inadequate waste collection facilities (Chotimah et al., 2021). Consequently, coastal pollution not only threatens ecological integrity but also diminishes the aesthetic value of tourist destinations, reduces fisheries productivity, and negatively influences the livelihoods of coastal communities that depend directly on marine resources.

One of the coastal areas currently experiencing increasing anthropogenic pressure is Tanjung Bunga, located in Tamalate District, Makassar City, South Sulawesi. The area functions as an important center for tourism, fisheries, coastal settlements, and recreational activities, attracting thousands of local visitors each year. However, increasing human activities have been accompanied by visible accumulations of inorganic marine debris along beaches and adjacent coastal waters. Plastic bottles, food packaging, disposable containers, plastic bags, fishing-related materials, metal cans, and glass fragments are frequently observed, indicating substantial waste inputs from both land-based and marine-based sources. These conditions suggest that the environmental quality of the Tanjung Bunga coastal ecosystem is increasingly threatened by anthropogenic pollution.

Despite its ecological and socio-economic importance, comprehensive scientific information regarding the characteristics and composition of inorganic marine debris in the Tanjung Bunga coastal area remains limited. Existing environmental management efforts have primarily focused on waste collection campaigns rather than systematic scientific assessments capable of identifying dominant waste categories and their spatial characteristics. Moreover, limited public awareness, inadequate waste management infrastructure, and insufficient environmental monitoring continue to exacerbate marine litter accumulation in this coastal region (Murtaza, 2022). The absence of reliable baseline data restricts evidence-based policymaking and limits the development of effective coastal waste management strategies.

Therefore, this study aims to analyze the characteristics of inorganic marine debris in the Tanjung Bunga coastal area, Makassar City, by identifying the dominant waste categories and describing their occurrence within the study area. The findings are expected to provide scientific evidence for strengthening coastal environmental management, supporting sustainable marine pollution mitigation policies, and promoting greater public awareness regarding coastal environmental conservation.

METHODS

This study employed a quantitative descriptive approach to characterize inorganic marine debris in the coastal area of Tanjung Bunga, Makassar City, South Sulawesi, Indonesia. Field observations were conducted during May 2025, with sampling performed three times throughout the month under the lowest tidal conditions to ensure optimal exposure of the intertidal zone. Tanjung Bunga was selected because it represents one of the most intensively utilized coastal areas in Makassar, characterized by residential settlements, tourism activities, fisheries, and recreational facilities that potentially contribute to the accumulation of marine debris. To capture spatial variations in debris distribution, the study area was divided into three observation stations representing different anthropogenic activities, namely Station 1 (residential area), Station 2 (gazebo and recreational area), and Station 3 (open shoreline area). This zoning approach enabled comparisons of marine debris characteristics among coastal environments with different levels of human activities (Cheshire et al., 2009; NOAA, 2013).

Marine debris sampling followed the standardized shoreline monitoring protocol developed by the National Oceanic and Atmospheric Administration (NOAA) for intertidal marine debris surveys (NOAA, 2013; Burgess et al., 2021). At each observation station, a 100 m line transect was established parallel to the shoreline and divided into three transects, with each transect further subdivided into three sampling plots measuring 10 × 10 m. Consequently, each station consisted of nine observation plots, and sampling was repeated three times throughout the study period. Prior to fieldwork, preliminary site surveys, literature reviews, equipment preparation, and determination of sampling points were conducted to ensure representative sampling locations. During the lowest tide, all inorganic marine debris encountered within each plot was manually collected using protective gloves, sorted according to material type, including plastic, glass, metal, rubber, and other inorganic materials, and subsequently weighed using a digital scale with a capacity of 10–50 kg. The number of debris items, total weight, sampling location, and material category were recorded following internationally recognized marine debris monitoring guidelines (Cheshire et al., 2009; NOAA, 2013; UNEP, 2021).

The collected data were analyzed quantitatively to determine the abundance, composition, and weight of inorganic marine debris at each observation station. The total number and total weight of each debris category were calculated using the equations proposed by Djugana et al. (2019), where the total abundance of each debris type represents the sum of all observations across the three transects, while the average abundance and weight were obtained by dividing the cumulative values by the total number of transects. Subsequently, the composition of inorganic marine debris was described using frequencies, percentages, average abundance, and average weight for each debris category to identify the dominant waste types and compare their spatial distribution among sampling stations. Descriptive statistical analysis was employed to provide a comprehensive characterization of inorganic marine debris in the Tanjung Bunga coastal area and to generate baseline scientific information supporting coastal waste management and marine pollution mitigation strategies (Burgess et al., 2021; NOAA, 2013).

RESULTS AND DISCUSSION

Field observations conducted at three observation stations revealed considerable spatial variation in the characteristics of inorganic marine debris, reflecting differences in human activities and coastal environmental conditions. The study area comprised residential settlements (Station 1), recreational facilities (Station 2), and the shoreline (Station 3), representing the principal sources and accumulation zones of marine litter within the Tanjung Bunga coastal ecosystem. Oceanographic conditions recorded during the study indicated relatively stable currents flowing from north to northwest with velocities ranging from 19.2 to 43.6 cm s^{-1}, while wave heights fluctuated between 0.28 and 0.40 m, accompanied by a semi-diurnal tidal pattern based on data obtained from BMKG Makassar. These hydrodynamic conditions strongly influence the transport, redistribution, and accumulation of floating marine debris along the coastline. Similar findings have been reported by Jambeck et al. (2015), Lebreton et al. (2017), and Ryan (2015), who emphasized that current velocity, wave action, and tidal fluctuations represent the primary physical mechanisms governing marine debris movement and deposition within coastal environments.

The distribution of marine debris varied considerably among the three stations, indicating that both anthropogenic activities and oceanographic processes simultaneously determine debris accumulation patterns. Residential areas primarily contributed domestic waste generated from household activities, while the recreational area reflected waste associated with tourism activities. Meanwhile, the shoreline functioned as the final accumulation zone receiving debris transported both from terrestrial sources and offshore waters. This observation supports the conceptual framework proposed by UNEP (2021) and GESAMP (2019) that coastal debris accumulation is controlled by interactions between land-based waste generation and hydrodynamic transport processes.

The composition analysis demonstrated that plastic constituted the dominant type of inorganic marine debris across all observation stations. Plastic represented approximately 29% of total debris at Station 1, 31% at Station 2, and increased to 37% at Station 3. Overall, 674 plastic items were recorded, making plastic the most abundant marine debris category throughout the study area. Other debris categories included wood (576 items), metals (354 items), Styrofoam (202 items), rubber (170 items), and glass (94 items). The increasing proportion of plastics toward the shoreline indicates that lightweight plastic materials possess greater floating capacity and are therefore more easily transported by coastal currents before ultimately accumulating along the beach.

The predominance of plastic debris is consistent with global observations indicating that plastics comprise between 60% and 90% of marine litter worldwide because of their extensive production, widespread consumption, buoyancy, and exceptional persistence in marine environments (Barnes et al., 2009; Jambeck et al., 2015; UNEP, 2021). Plastic materials degrade very slowly, often requiring several hundred years before complete decomposition, during which they gradually fragment into microplastics capable of entering marine food webs and threatening aquatic organisms (Cózar et al., 2014; GESAMP, 2019). The dominance of plastic observed in Tanjung Bunga therefore reflects not only local waste management deficiencies but also broader global patterns of plastic pollution affecting coastal ecosystems.

Differences in debris composition among observation stations further illustrate the influence of surrounding land use. Station 1 exhibited relatively higher proportions of metals and household-related waste, suggesting substantial contributions from domestic activities. Station 2 contained greater amounts of plastics, rubber, and beverage containers associated with tourism and recreational activities. Conversely, Station 3 recorded the highest abundance of plastic and wood debris, indicating that the shoreline functions as the primary deposition area for materials transported both from upstream terrestrial sources and offshore waters. Similar spatial patterns have been documented by Hardesty et al. (2017) and UNEP (2021), who reported that beaches commonly serve as terminal accumulation zones where floating debris becomes stranded following repeated tidal and wave movements.

The analysis of debris size revealed that macro-sized debris dominated all observation stations, accounting for 67% of total debris at Station 1, 61% at Station 2, and 64% at Station 3. Meso-sized debris contributed between 27% and 35%, whereas mega-sized debris represented only 4–6% of the total collected materials. The predominance of macro debris indicates that most waste entering the coastal environment remains relatively intact before undergoing extensive fragmentation. These findings suggest that waste inputs are relatively recent and originate primarily from ongoing human activities rather than long-term environmental degradation.

The substantial proportion of meso-sized debris further indicates that fragmentation processes have already begun under the influence of ultraviolet radiation, mechanical abrasion, wave action, and weathering. According to Andrady (2011) and UNEP (2021), large plastic objects gradually fragment into progressively smaller particles that eventually become microplastics. Consequently, effective marine debris management should prioritize preventing macro-sized waste from entering coastal waters before fragmentation occurs, as recovering smaller debris becomes substantially more difficult and environmentally costly.

Mass analysis also demonstrated distinct spatial characteristics among observation stations. Plastic exhibited the highest total mass at Station 3 (10.95 kg), followed by Station 1 (7.71 kg) and Station 2 (7.20 kg). Wood represented the second largest contributor at all stations, ranging between 6.74 and 7.11 kg, whereas glass dominated the recreational area with a recorded mass of 8.10 kg, suggesting considerable contributions from beverage containers discarded by visitors. Metals, rubber, and Styrofoam contributed relatively smaller proportions, although their persistence still poses significant ecological concerns.

The exceptionally high plastic mass recorded at the shoreline confirms that coastal areas function as major sinks for floating marine debris transported through both terrestrial runoff and marine circulation. Similar observations were reported by Lebreton et al. (2017), who demonstrated that ocean circulation continuously redistributes floating plastics toward coastal convergence zones before eventual deposition on beaches. The relatively high abundance of glass within the recreational area additionally indicates that tourism activities substantially influence local waste generation, highlighting the necessity for improved waste management infrastructure in public recreational facilities.

Overall, the findings demonstrate that the characteristics of inorganic marine debris within the Tanjung Bunga coastal area are strongly influenced by interactions between anthropogenic activities and oceanographic processes. Residential settlements primarily contribute household waste, recreational areas generate tourism-related debris, and shoreline environments act as terminal accumulation zones where transported materials become concentrated. The persistent dominance of plastics across all observation stations indicates that plastic pollution remains the principal environmental challenge facing this coastal ecosystem. Consequently, effective management should emphasize integrated waste reduction strategies through improved solid waste management systems, enhanced recycling infrastructure, stricter regulations concerning single-use plastics, routine coastal clean-up programs, and continuous environmental education targeting both local communities and visitors. Such integrated management approaches are widely recognized as essential for reducing marine debris inputs and ensuring the long-term sustainability of coastal ecosystems (UNEP, 2021; GESAMP, 2019; Hardesty et al., 2017).

CONCLUSION

Marine debris has become one of the most significant environmental challenges threatening the sustainability of coastal ecosystems, particularly in areas experiencing intensive human activities. This study aimed to analyze the characteristics of inorganic marine debris in the Tanjung Bunga coastal area, Makassar City, Indonesia. A quantitative descriptive approach was employed through field observations conducted at three observation stations representing residential, recreational, and shoreline areas. Marine debris was collected using the NOAA line transect method during the lowest tidal conditions, followed by classification based on material type, size, quantity, density, and mass. Supporting oceanographic data, including currents, waves, and tides, were obtained from the Meteorological, Climatological, and Geophysical Agency (BMKG). The findings revealed that plastic was the dominant type of inorganic marine debris at all observation stations, accounting for the highest proportion of the total debris collected, followed by wood, metal, Styrofoam, rubber, and glass. Macro-sized debris predominated across all stations, indicating that most debris remained in relatively intact forms before undergoing fragmentation. The shoreline station exhibited the greatest accumulation of debris mass, suggesting that coastal hydrodynamics, particularly currents, wave action, and tidal cycles, substantially influence debris transport and deposition. Variations in debris composition among stations reflected differences in surrounding anthropogenic activities, with residential areas contributing domestic waste, recreational areas generating tourism-related litter, and the shoreline functioning as the primary accumulation zone for land- and sea-based debris. These findings emphasize the urgent need for integrated coastal waste management through improved solid waste management systems, enhanced environmental awareness, routine coastal clean-up programs, and stronger policies aimed at reducing plastic waste entering marine environments. Such measures are essential to support sustainable coastal ecosystem management and mitigate the long-term impacts of marine debris pollution.

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