Original Article

Seasonal difference in marine litter along the coast of Dar es Salaam, Tanzania

Florence J. Peter[1,2], Anale M. Rocha[3]

[1] Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Brussels, Belgium

[2] Institute of Marine Sciences, University of Dar es Salaam, PO Box 668 Buyu, Zanzibar, United Republic of Tanzania

[3] Nipe-Fagio, PO Box 11747, Dar es Salaam, Tanzania

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*** Corresponding author:**
frolencejovenary@gmail.com

Abstract
Marine litter accumulation poses a significant threat to marine ecosystems and biodiversity. Marine litter and the influence of river discharge on marine litter accumulation during wet and dry seasons along the coast of Dar es Salaam was investigated. Litter samples collected between 2019 and 2021 from transects on beaches and by nets spanned across two rivers were counted, dried and weighed, and litter counts and weight (kg) calculated by area (litter/m^2) and volume (litter/m^3). Over three years, a total of 127,658 marine litter items weighing 470 kg were sampled from beaches, and 1,365 items from rivers, in nine different litter categories. Most of the litter (70 %) was produced locally and the marine litter density decreased by 61 % over the three years of the study. Litter densities at beaches and rivers were significantly greater during the wet than the dry season, attributed to the transport of litter in rivers to the ocean, especially plastics, which had a higher density than other riverine litter. It is concluded that high local plastic production and poor waste disposal systems require an intervention, and that a policy to minimize and reduce marine litter should be developed and implemented.

Keywords: marine litter, pollution, Dar es Salaam, plastics

Introduction
Marine litter is a global problem due to poor waste disposal management (Smail *et al.*, 2019) and has been associated with growth in industrial production (Salgado-Hernanz *et al.*, 2021). Schmidt *et al.* (2017) estimate that approximately 12 million tons of marine litter enters the oceans each year. It is also estimated that 80 % of the marine debris originates from the land and is transported to the ocean via surface runoff (Meijer *et al.*, 2021) and the rest originates from fisheries activities, shipping, ocean currents and tourism (GESAMP, 2015). This has severely impacted the environment worldwide, resulting in a deterioration in water quality and aquatic and terrestrial ecosystems, which impacts biodiversity (Barnes *et al.*, 2009). A significant proportion of marine litter is dominated by plastic debris (ranging from 50 % – 80 %) in comparison to other litter types (Cressey, 2016; Okuku *et al.*, 2021). The negative effects of plastic pollution in the environment are further exacerbated by its comparatively high persistence in nature, prolonging its negative effects on ecosystems (Lebreton *et al.*, 2017; Worm *et al.*, 2017).

Global industrial production of plastic has increased from 322 million tons in 2014 to 368 million tons in 2019 (Plastics Europe, 2021). This further complicates efforts to manage the ever-increasing resultant waste, particularly regarding single-use plastics (Barboza *et al.*, 2018). However, during the COVID-19 pandemic between 2019 to 2021, plastic production decreased by approximately 0.27 %, to about 367 million tons, due to a global decline in production across all sectors (Plastics Europe, 2021). In 2019, Tanzania became one of the few countries in the world that has imposed a ban on the use of disposable plastics (URT, 2019). Poor policy and lack of a marine litter action plan, however, has delayed the implementation of the ban in mainland Tanzania, while the Tanzanian Island of Zanzibar introduced a ban in November 2006 (Maione, 2021). However, the management of single-use plastic waste remains a major challenge in the Global South, including Tanzania and neighbouring countries (Ammendolia *et al.*, 2021). A recent brand audit conducted on marine litter in Kenya revealed that about 16 % of the litter originated from Tanzania (Okuku *et al.*, 2021).

According to the United Nations Environmental Programme, marine litter may be defined as "*any persistent, manufactured or processed solid materials discarded, disposed of or abandoned in the marine and coastal environment. Marine litter consists of items that have been made or used by people and deliberately discarded into the sea or river or on beaches; brought indirectly to the sea with rivers, sewage, stormwater, or winds; accidentally lost, including material lost at the sea in bad weather; or deliberately left by people on the beaches and shores*" (UNEP, 2021). Marine litter occurs in different forms, including paper, cardboard, hygiene products, processed wood, glass, rubber, clothing, plastics, fishing gear, metal, foam, construction material, and pottery (Potts and Hastings, 2011; Barnardo and Ribbink, 2020). Plastic waste accounts for 75 % of marine litter, representing the highest proportion in comparison to other litter types (Galgani *et al.*, 2019). Plastic debris is grouped into three categories based on size, viz. macroplastic (> 25 mm), mesoplastic (5-25 mm), and microplastic (< 5 mm) (Barnes *et al.*, 2009; Barnardo and Ribbink, 2020). Additional categories referring to megaplastic and nanoplastic have recently been described to include plastic debris > 1 m (Smail *et al.*, 2019) and < 1μm (Ramkumar *et al.*, 2022) in diameter respectively. Currently, approximately 75 % of marine plastic pollution studies are focusing on microplastics

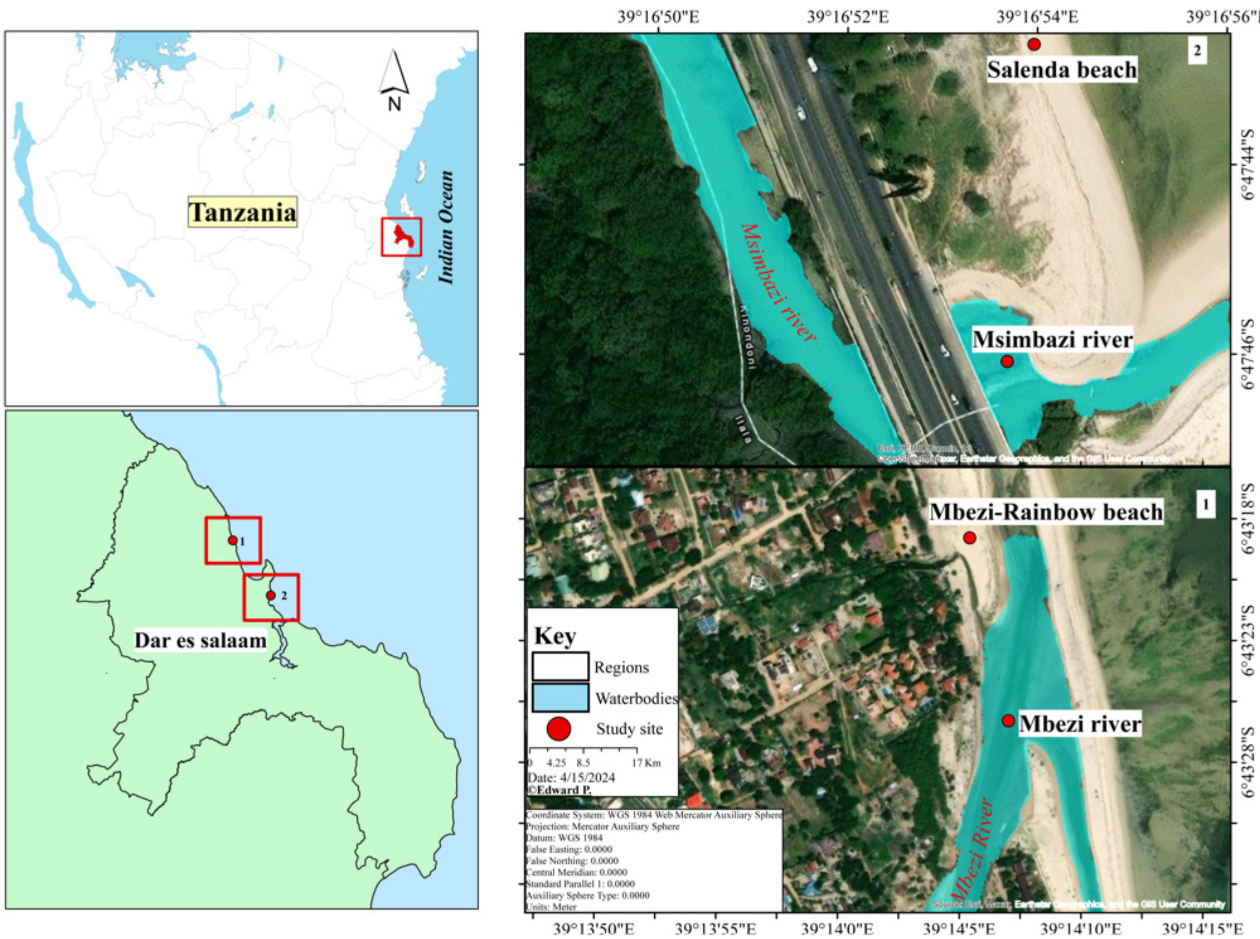


Figure 1. Study areas in Dar es Salaam, with sampling sites at Mbezi Rainbow Beach and Salenda Beach, and adjacent Mbezi and Msimbazi Rivers.

worldwide, which implies macro and mesoplastic pollution remain comparatively under-investigated. Most of these studies (approximately 80 %) are executed in the Global North (Blettler *et al.*, 2018).

The accumulation of marine litter contributes significantly to the deterioration of marine ecosystems and their biodiversity (Hastings and Potts, 2013). The impact of marine litter has been worsening progressively, resulting in a myriad of negative impacts on marine organisms. These impacts include entanglement (Potts and Hastings, 2011), ingestion, destruction of breeding grounds, reproduction problems (Laist, 1987), and developmental impairment (Fowler, 1987), therefore, making unconducive environments for organisms to live in. This is attributable to its non-biodegradable nature, which makes it highly persistent in the environment over long periods of time (Galgani *et al.*, 2019). Additionally, plastic litter often fragments into minute particles (micro- and nanoplastics), that can have major, sustained impacts throughout marine food webs through bioaccumulation and bioconcentration (Miller, *et al.,* 2020).

Several beach clean-ups along the Dar es Salaam coast have helped reduce the marine litter problem, but the rate of riverine discharge of litter and discards by coastal communities exceeds the rate of clean-up (Rangel-Buitrago *et al.*, 2018). Therefore, this study aimed at the quantification of marine litter at selected sites along the Western Indian Ocean coast in Dar es Salaam, Tanzania to bring the concerned ministries together for effectively policy implementation (URT, 2019).

Material and methods

Study area

The study was conducted in Dar es Salaam (Fig. 1), a city with diverse economic activities, including a major port, large markets and shopping centers, railway, construction, industries and factories, and small enterprises. It is among the fastest-growing cities in Africa, ranked third in 2010 (Mkalawa and Haixiao, 2014). Dar es Salaam is densely populated, with an estimated population of 7 million people and an annual growth rate of about 5.2 % (Dar Es Salaam Population, 2021). Samples were collected from four sampling sites, two on beaches and two in rivers, namely: Mbezi Rainbow Beach and Salenda Beach (Salenda bridge), and the adjacent Mbezi and Msimbazi Rivers. These are the major rivers traversing different localities in Dar es Salaam, flowing into the Indian Ocean.

Sampling

Beaches

The survey design was based on the accumulation and standing-stock survey method, in a 5 000 m² transect (250 m length, 20 m width) (Fig. 2) (Barnardo and Ribbink, 2020). Sampling was done during low tide. Two transects were set on each beach. The sampling was based on each category of marine litter count. The data were collected in two seasons, viz. the dry (July) and wet (April) season, over a period of three years (2019 to 2021). Before sampling the beaches were cleaned two to three days before the survey and the accumulation survey was carried out on 10 consecutive days. Two sections of the beach were sampled, the intertidal and supratidal zone. Litter from the intertidal zone was dried, sorted based on the category of the litter, counted, and weighed. Litter from the supratidal zone was also sorted according to litter type, counted, but not dried before weighing. A waste audit and brand audit (WABA) was implemented to identify the source (company, country) and nature of the litter (Barnardo and Ribbink 2020). This was done by looking at the label which indicates the manufacturer details and in which country the item was made.

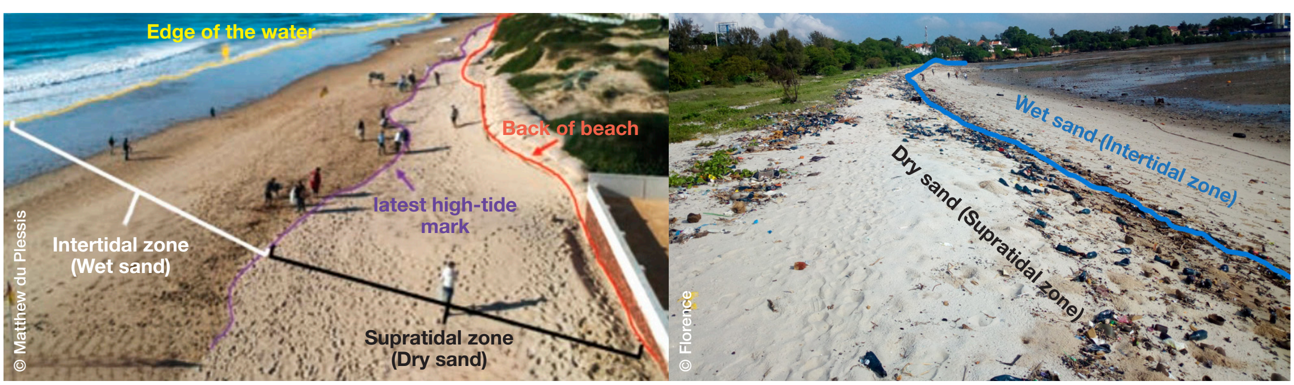


Figure 2. The supratidal and intertidal zone where transects of 250 m length and 20 m width were placed for marine litter sampling.

Rivers

A net of 2 mm mesh size fixed to a metal frame of 2 m length, 1 m height, and 1 m width, was used to collect litter in the rivers (Barnardo and Ribbink, 2020). The length, width, and height of the net allowed the calculation of litter/m^3. The net was fixed with ropes under a bridge perpendicular to the current flow (Fig. 3). To estimate the current velocity, the width of the bridge was measured. A stopwatch was then used to measure the time a plastic object moved under the bridge on three occasions, and the average velocity was calculated. Velocity was grouped in three categories: low velocity (0.1 m/s to 0.6), moderate velocity (0.6 m/s to 2 m/s), and high velocity (2 m/s). The net was lifted four times (duplicates); every 30 minutes each from the river, 15 minutes each for taking data and setting the net back into the river for a period of three hours. Data in each duplicate was sorted per litter type, summed and averaged to get total count as 1 sample of a day. This procedure was carried out on 10 consecutive days. Therefore, the samples (the litter type count) for each of the 10 days were summed to get the total count as one large sample of a given season. 1 sample (total count) was obtained from each river per season, which makes a total of 4 samples for two seasons every year and a total of 12 samples in three years. The lower part of the net was lifted first to keep the entangled marine litter in the net. The material collected by the net from the river was counted, dried, and weighed (Barnardo and Ribbink 2020).

Data analysis

The mean density of litter on the beaches in each season per year was calculated as counts of items per area (m^2), and for litter in the rivers items/m^3 (Smail *et al.*, 2019). Litter in the rivers and on beaches for both dry and wet seasons were summed, then divided by volume and the area to get the mean density of marine litter for each year respectively. Marine litter density by weight per area was calculated as kg/m^2 and litter from the river was calculated in kg/m^3 (Edyvane *et al.*, 2004). The percentage composition of marine litter was also calculated (Okuku *et al.*, 2020, 2021).

Descriptive statistics were computed using Microsoft Excel and R-Studio (Barnardo and Ribbink2020). The mean current velocity in the river was expressed as m/s (Li *et al.*, 2020). One-way ANOVA was used to test for significant differences in the marine litter contribution between seasons for both river and beach respectively (Okuku *et al.*, 2021). Two-way ANOVA was used to test for significant differences between seasons and years on beaches.

Cluster (Principle component analysis and Agglomerative hierarchical clustering) was used to investigate the relationship between marine litter composition and abundance in seasons and zones respectively (Asensio-Montesinos *et al.*, 2019). Analysis of Similarity (ANOSIM) was also used to test the similarity in marine litter abundance between seasons. (Pham *et al.*, 2014).

Results

Marine litter composition and its trend along the coast of Dar es Salaam

A total of 127,658 marine litter items, equivalent to a total weight of 470 kg, were sampled in the three years on the beaches. The items were composed of clothing and fishing gear, and hygiene, metal, foam, paper, wood, plastic, and rubber objects. The density of litter decreased from 5.7 ± 2.09 items/m^2 in 2019 to 2.2 ± 0.06 items/m^2 in 2021 (Fig. 5). However, two-way ANOVA showed no significant difference between the Mbezi Rainbow Beach and Salenda Beach and between the rivers (Fig. 4). Locations (Mbezi and Salenda) showed no significant differences ($F(1, 106) = 2.63$, $p = 0.11$.

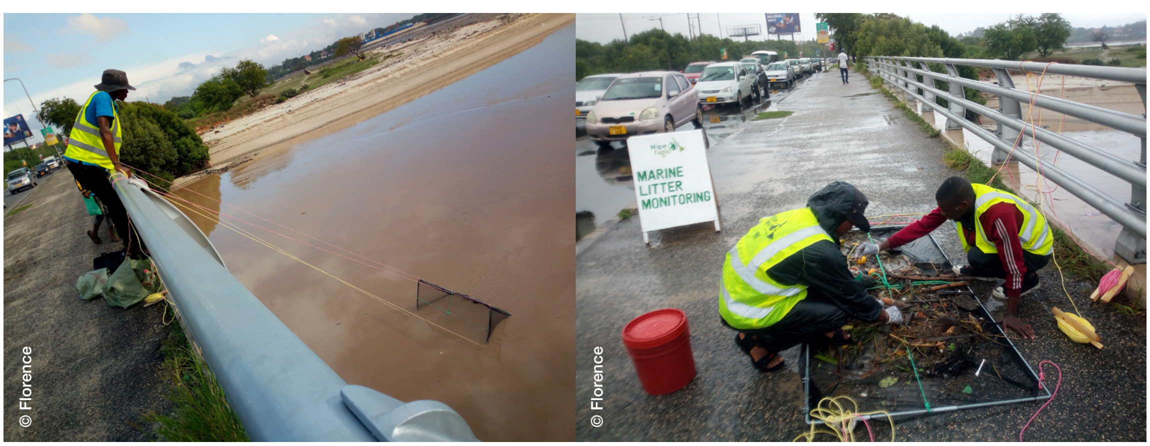


Figure 3. Placement of the net used to sample litter in the rivers.

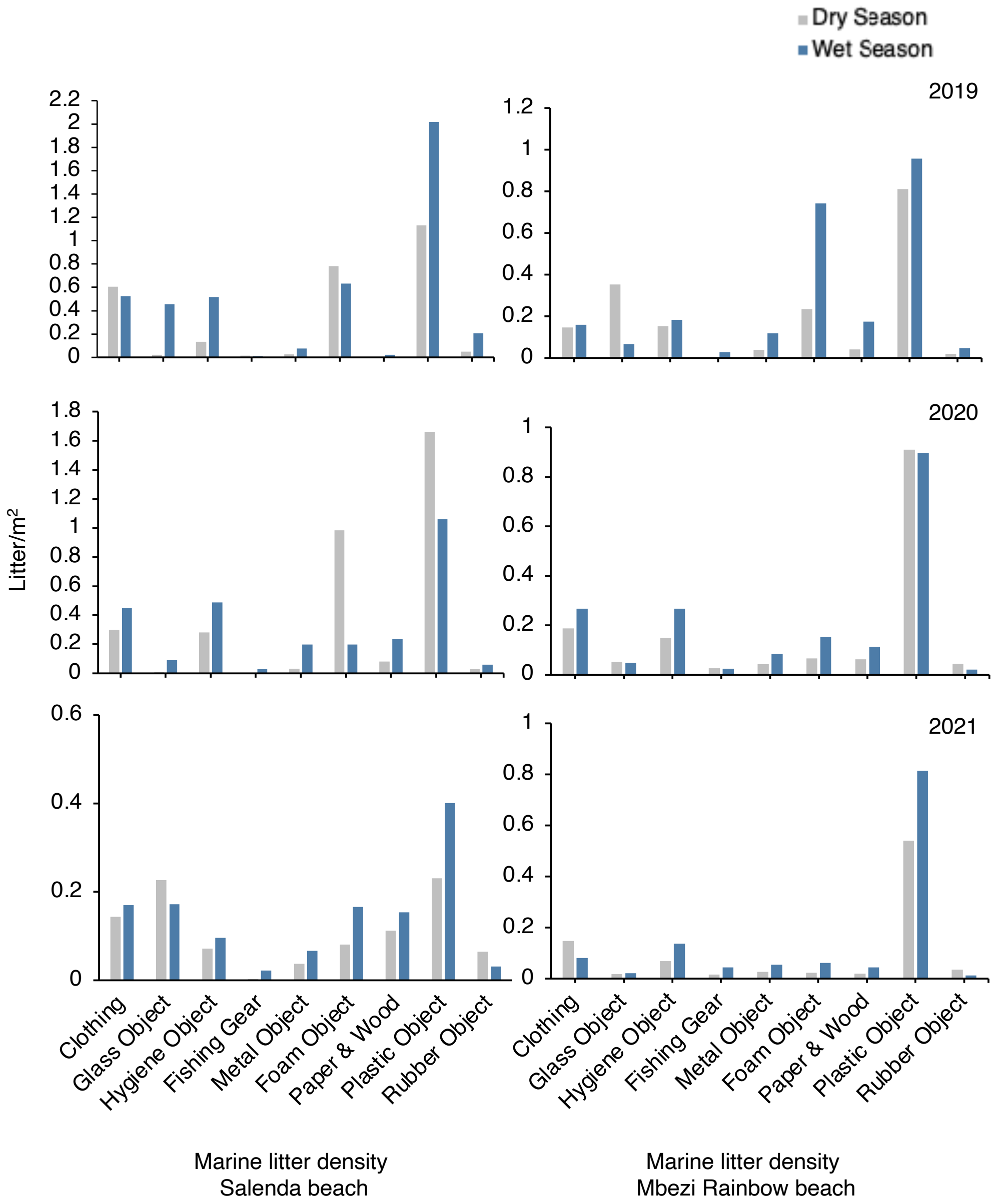


Figure 4. Marine litter composition at the two beach sites during dry and wet seasons.

Also, the interaction between year and seasons showed no significance difference F(1, 106) = 0.12, p = 0.72. However, one-way ANOVA showed significant differences between years F (2, 106) = 3.58, p = 0.03.

Marine litter distribution during dry and wet seasons

Agglomerative Hierarchical Clustering (AH) identified two major clusters (Fig. 6). The first cluster includes dry season samples DSM19, DSS19 and DSS20, and one wet season sample WSS19. The second cluster has two sub-clusters of dry and wet season samples. The dry season samples included DSS21 and DSSM21, while the wet season divides further into two clusters, including WSS21 and WSM21 and another cluster of

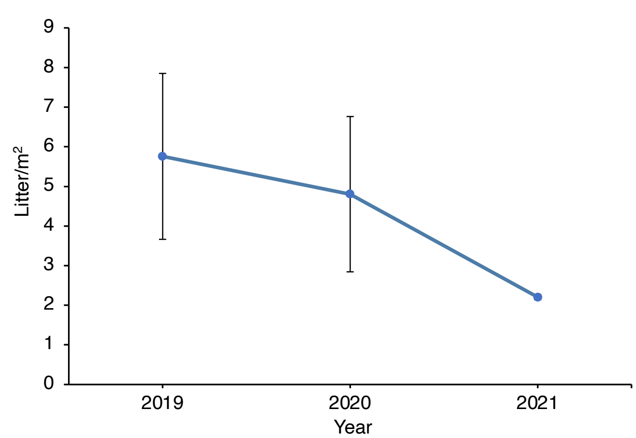
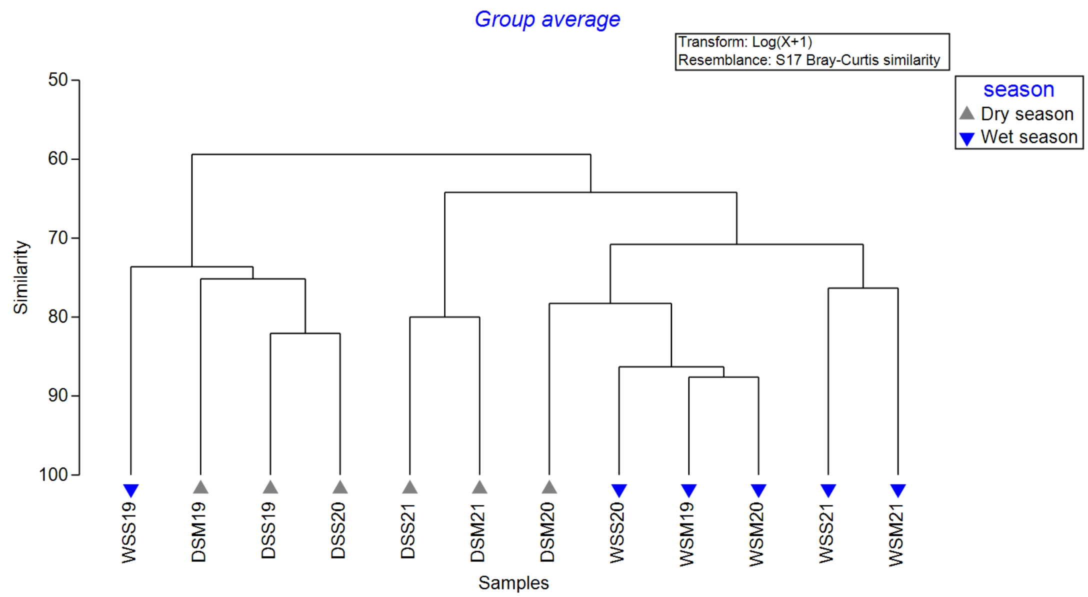


Figure 5. Decrease of marine litter density from 2019 to 2021.



Key: DSM and DSS – dry season Mbezi Beach and Salenda Beach, WSM and WSS – wet season Mbezi and Salenda, while 19, 20 and 21 are years 2019, 2020 and 2021 respectively.

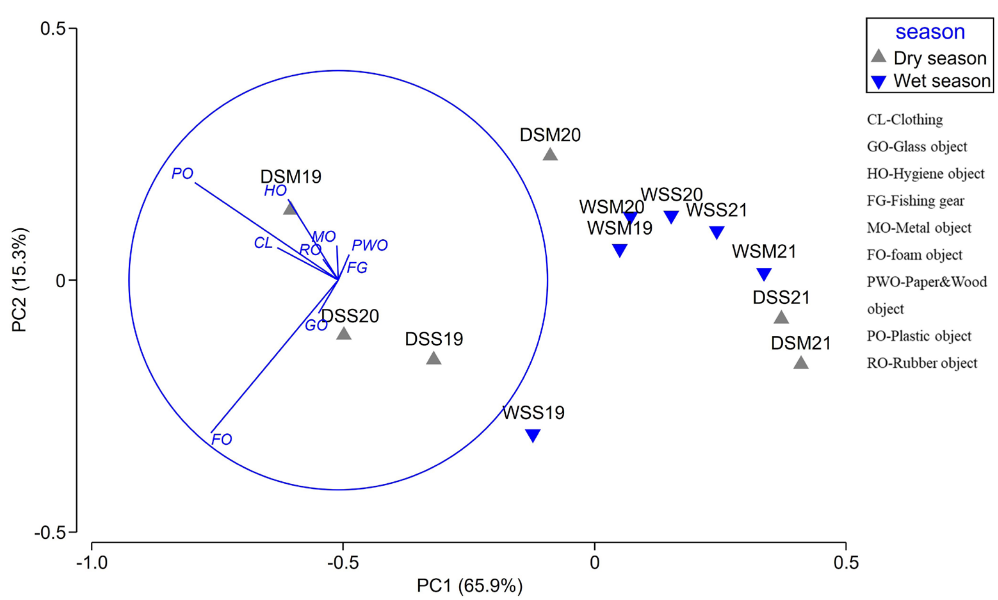
Figure 6. Bray-Curtis similarity of litter density during the wet and dry season in three years per location.

WSM19, WSM20 and WSS20 and DSM20 (Fig. 6). These cluster divisions are based on Bray-Curtis similarities in marine litter densities.

PCA shows that there was a higher density of foam and plastic objects in DSM19, DSS20, DSS19, and WSS19 than FG, HO, MO, RO, CL, PWO and GL. However, PO, FO, HO, CL, RO show low density abundance in DSS21, DSSM21, WSM21, WSS21 and WSS20. PO and FO show the relationship between them (Fig. 7). With ANOSIM test, years tested significantly different and these differences were between 2019 and 2021, as well as 2020 and 2021 except 2019 and 2020 (R = 0.3889, p = 0.013).

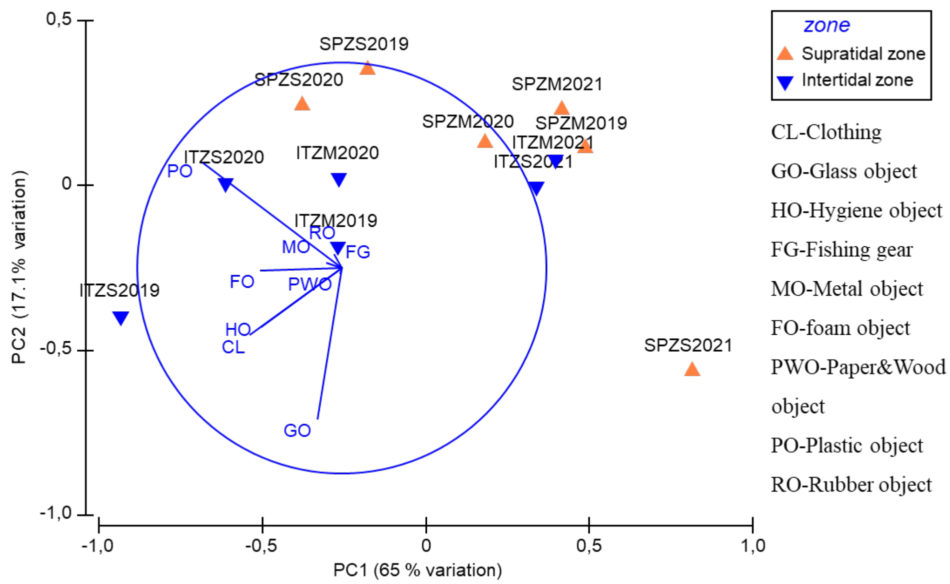
Marine litter composition and distribution in the supratidal and intertidal zone

The cluster analysis (PCA) shows higher density of PO, RO, FO, MO, and HO in ITZS2019, ITZM2019, SPZS2019, ITZS2020, ITZM2020, and SPZS2020, but low density in SPZM2019, SPZM2020, SPZM2021,



Key: DSM and DSS – dry season Mbezi Beach and Salenda Beach, WSM and WSS – wet season Mbezi Beach and Salenda Beach, while 19, 20 and 21 are years 2019, 2020 and 2021 respectively.

Figure 7. Principle Component Analysis of litter during the wet season and dry season from 2019 to 2021.



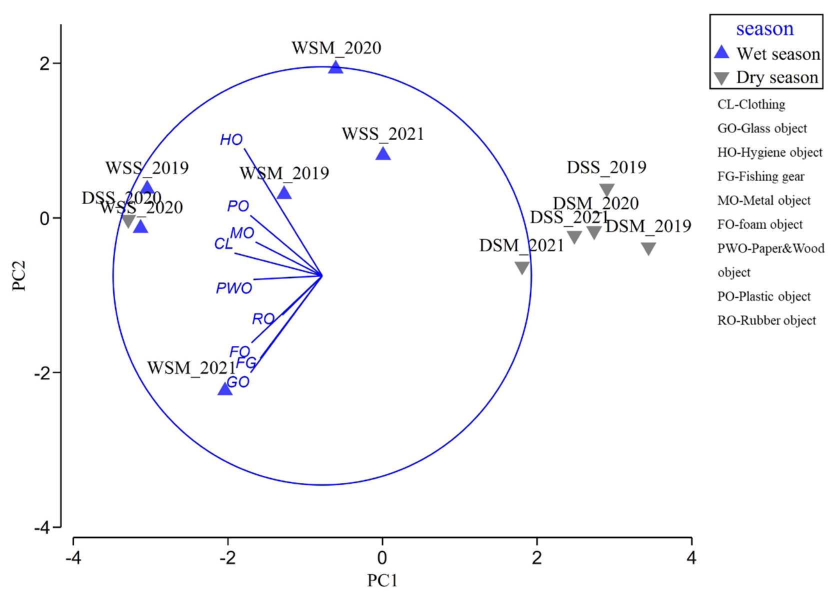
Key: ITZS – Intertidal zone at Salenda Beach, ITZM – Intertidal zone Mbezi Beach, SPZS – Supratidal zone at Salenda Beach and SPZM - Supratidal zone at Mbezi Beach.

Figure 8. Principle Component Analysis of litter density in the zone from Mbezi Rainbow Beach and Salenda Beach.

ITZM2021, ITZS2021 and SPZS2021. However, CL, PWO, FG and GO showed low density in SPZM2019, SPZM2020, SPZM2021, ITZM2021, ITZS2021 and SPZS2021 but have moderate abundance in ITZS2019, ITZM2019, SPZS2019, ITZS2020, ITZM2020, and SPZS2020. The density of marine litter gave a total of 82.1 % variation as PC1 encountered 17.1% of variation while PC2 encountered 65.0 % variation (Fig. 8).

Contribution of the rivers to marine litter

A total of 1,365 items of litter were sampled in the rivers from 2019 to 2021, and nine categories of litter as mentioned above. PCA, riverine litter showed high density during the rainy season compared to the dry season, but the density of riverine litter during the rainy season varied among locations. Plastic objects, metal objects, clothing, hygiene objects, paper and



Key: WSS – Wet season sample at Msimbazi River , WSM – Wet season sample at Mbezi River, DSS – Dry season sample at Msimbazi, and DSM -Dry season sample at Mbezi River in respective years.

Figure 9. PCA of litter per season from Mbezi and Msimbazi Rivers.

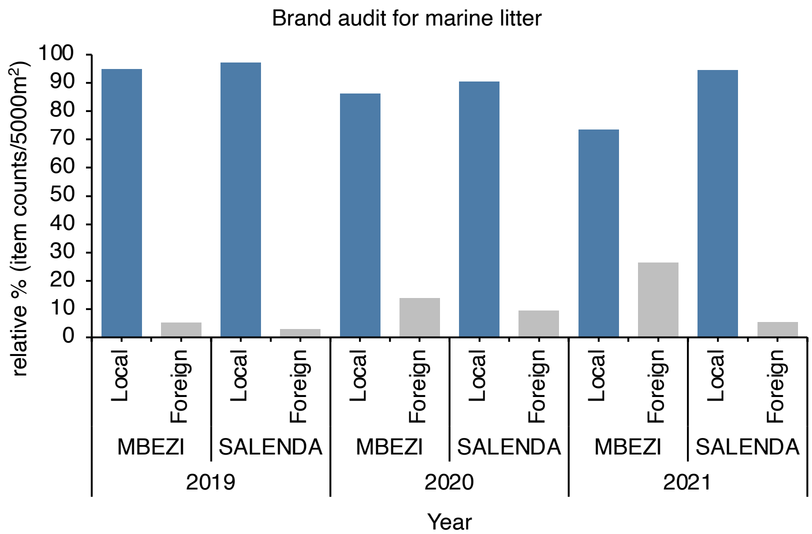


Figure 10. Proportion of marine litter branded by local and foreign manufacturers.

wood objects had a high density in seasonal samples WSS_2019, WSM_2019, WSS_2020, RSM_2020 and DSS_2019 while glass objects, fishing gear, and foams had a higher density in WSM_2021. However, riverine litter had a lower density in dry season samples except in sample DSS_2020 (Fig. 9). ANOSIUM shows no significant difference between the rivers Mbezi and Msimbazi (R = 0.34, p = 0.25). Also, ANOSIM analysis shows significant difference between the rainy and dry season (R = 0.387, p = 0.02).

Brand Audit

Local and foreign contributions to marine litter

Twenty-six brands were identified in the litter, involving local and foreign manufactured objects. Only 27,321 objects were assigned for brand audit among 127,658 objects sampled in total. Local brands contributed 70 % and foreign brands 30 %, which is equivalent to 19,124 and 8,196 objects, respectively. This shows that there is higher production and/or usage in the country than what is introduced from outside (Fig. 10). However, 30 % contributed by foreign branded objects included 21 % from China and 9 % from Kenya.

Contribution to marine litter accumulation at the local level and main manufacturers

At the local level, about 40 % of plastic items were manufactured by the Melt Group Ltd., followed by about 20 % by Azam and 10 % by Plastic Production Co. Ltd. Other manufacturers contributed <10 % (Fig. 11).

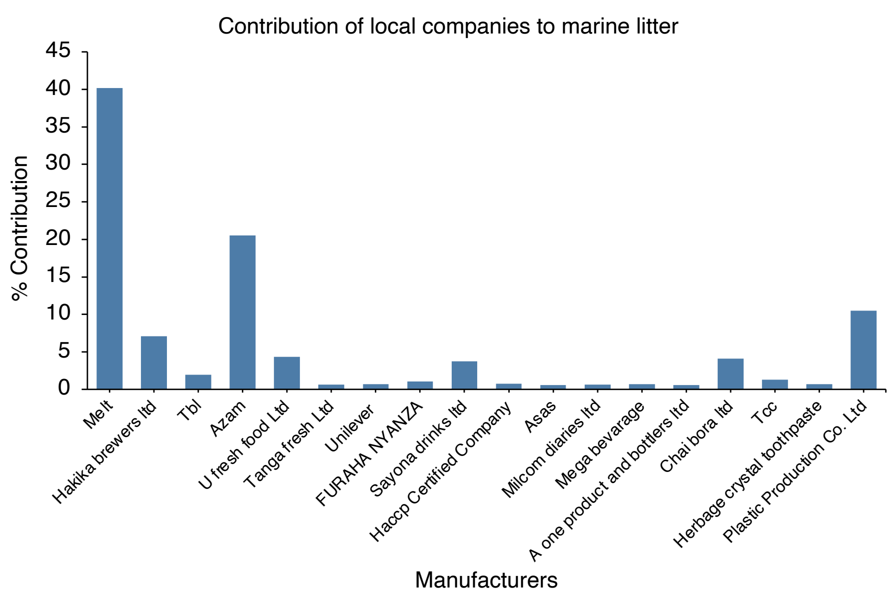
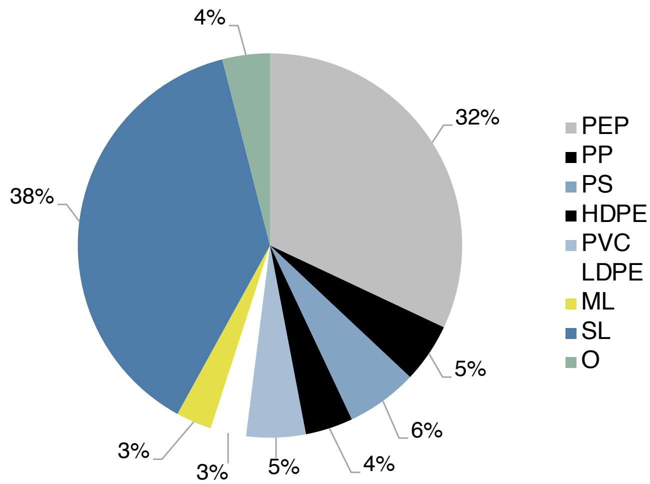


Figure 11. Manufacturers whose items contributed to marine litter along the Dar es Salaam coast.



Key: PET-Polyethylene, PP-Polypropylene, PS-Polystyrene, HDPE-High-density polyethylene, PVC-Polyvinyl, and LDPE-Low-density Polyethylene, ML-Multilayer, SL-Single layer, O - others.

Figure 12. Types of plastic contributing to marine litter.

Type of plastics that contributed to marine litter

Different forms of plastics were identified during sampling (Fig. 12). These included Polyethylene (PET), Polypropylene (PP), Polystyrene (PS), High-Density Polyethylene (HDPE), Polyvinyl (PVC), and Low-Density Polyethylene (LDPE), Multilayer (ML), Single layer (SL), and other (O). Plastic objects showed higher diversity in all zones and seasons than other litter. SL and PET contributed more (38 % and 32 %, respectively) compared to other forms of plastics, while the contribution of ML and LDPE (each 3 %) was lower.

Discussion

Marine litter accumulation and composition on the beaches

A higher density of marine litter was found in most wet season samples compared to dry season samples. This was probably due to runoff that collects litter from towns, households, cities, and roads and unorganised dumping grounds into the river and then into the marine environment (Santos *et al.*, 2020). On the one hand, the decreasing trend of marine litter, especially in plastics, was due to the single-use plastic ban policy and law that was made in 2019, and other initiatives (URT, 2019). Each town council is required to develop a strategy to keep the environment clean, such as recycling plastics (URT, 2019). Some waste collecting trucks were bought in to collect waste from households. Different initiatives to minimise marine litter and waste in general involve zero waste, zero plastic, and a single-use plastic free East African Community (EAC) (Huaxia, 2021; GAIGA, 2022), world ocean day, world environment day, marine litter action plans and weekly clean-ups along the coast of Tanzania as well as Dar es Salaam. The active engagement and involvement of stakeholders, including children from primary and secondary schools, universities, ministries, coastal communities, organisations, political leaders, and musicians has contributed to the decrease in marine litter accumulation along the Dar es Salaam and other parts of the coast (Pettipas *et al.,* 2016).

Litter accumulation and composition in the intertidal and supratidal zone

The higher density of plastics in the intertidal and supratidal zones than other marine litter is because, during low tide, when the intertidal zone is exposed to the sun and dries out, some light waste from the intertidal zone can be blown by strong winds to the supratidal zone (Barnardo *et al.*, 2021). This might be the reason why foam objects had a higher density in the supratidal zone than in the intertidal zone. However, the decrease in litter in the intertidal and supratidal zones, especially between years 2019 and 2021 as well as 2020 and 2021, might be due to the introduction of the single-use plastic ban and other efforts, including weekly clean-ups, that have been made to reduce waste in the marine and terrestrial environment in Tanzania (URT, 2019).

Brand Audit

The higher proportion of locally produced objects in the litter might be due to industrial investments made in the country (Salgado-Hernanz *et al.*, 2021). However, it is apparent that the industries producing plastics do not consider environmentally friendly alternatives that are biodegradable, resulting in materials accumulating in the oceans (Hastings and Potts, 2013). The Melt Group, Azam Group, and Hakika Breweries Ltd. manufacture more than one product, accounting for the higher contribution of litter from these compared to other companies. Bakhresa food products Co. Ltd is also one of the top three manufacturers (23.8 %) that contributes to waste accumulation along the coast of Kenya (Okuku *et al.* 2021). There is a higher percentage (32 %) of Polyethylene (PET) in the environment, because most beverages are sold in PET bottles. PET bottles are very light, allowing them to be transported easily in water, accounting for the higher accumulation compared to other litter (Shilla, 2019).

Contribution of the rivers to marine litter accumulation on beaches

The transport of waste in rivers in the wet season to the ocean, especially plastic that has a higher density than other riverine litter, is due to poor waste disposal and high plastic production in the country. The current study revealed that marine litter increases during the wet season, because runoff collects wastes from land and discharges it into the ocean (Silva-Cavalcanti *et al.,* 2009; Silva *et al.,* 2016; Santos *et al.,* 2020). A study in the South East Pacific suggests that rivers are a major agent of marine litter accumulation in the ocean (Rech *et al.,* 2014).

Conclusions

The wet season produced a higher density of marine litter than in the dry season, and plastic is highly abundant in both seasons compared to other marine litter. Plastics showed a higher density in the intertidal zone than in the supratidal zone. This was also the case for riverine litter, where plastic objects showed higher density than other riverine litter. It can be concluded that local manufacturers are the main producers of most litter discarded into the ocean compared to foreign products. This is greatly influenced by industries' production, poor waste management, and lack of a marine litter action plan. The change in people's behaviour, reduction in industrial production, particularly of plastics, as well as a proper policy enforcement, will help to reduce the pollution of litter in marine environments. This will not only improve marine life, but will protect the health of humans in general. Several entities, including government, industries, traders, neighbouring countries, organisations and local people should continue to implement the single-use plastic ban. Therefore, stakeholders should come up with innovative packaging that is recyclable or reusable and introduce penalties and punishment that will change people's behaviour. In terms of further research, litter quantification in the offshore marine environment is required.

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