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Microplastics in Marine Nearshore Surface Waters of Dar es Salaam and Zanzibar, East Africa

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Abstract

Limited information exists on the occurrence of microplastics (MPs) in East African coastal waters. A 300 µm manta net was used to collect surface water from 8 sites in the regions Dar es Salaam (DES) and Zanzibar (ZZ) during low and high tides. DES had a higher ($p<0.05$) abundance of MPs than ZZ. Fragments and fibers were the dominant MP types at all sites. The number of fibers was significantly higher ($p=0.002$) in DES than in ZZ. MPs were more prevalent during high tide in both DES and ZZ. The MPs within the 2–5 mm size range were identified most often. White and blue MPs were the most common in study sites comprising 45% and 18% of the total MPs respectively. Three polymers polypropylene (PP) high-density polyethylene (HDPE) and low-density polyethylene (LDPE) were identified. The occurrence of MPs in nearshore waters of DES and ZZ is probably due to their proximity to industrial areas, poor solid waste management, and high population pressure.

Keywords Tanzania · Marine environment · low and high tides · polypropylene · high-density polyethylene · low-density polyethylene

It has been estimated that the annual global release of plastic debris from land-based activities to the marine environment is ca. 4.8–12.7 mt (Jambeck et al. 2015) of which 50–80% of MPs float on surface waters (Barnes et al. 2009). Larger plastic items degrade into smaller particles (MPs < 5 mm in size (Arthur et al. 2009) after being exposed to UV radiation, oxygen and mechanical forces (Maes et al. 2017). MPs in marine environments can be either primary MPs that are specifically manufactured as abrasives and fillers and secondary MPs that result from the breakdown of larger items. MPs may originate from the land-based plastics pollutions and can be transported by different atmospheric and freshwater conveyances coupled with tidal forces distributing the MPs to different parts of the ocean (Park et al. 2020; Petersen and Hubbart 2021). Moreover, hydrodynamic forces and the intrinsic properties of the MPs such as density, shape, size, and chemical composition determine their distribution (Wang et al. 2018; Browne et al. 2011) outlined sources of MPs in marine waters as including fishing gears, plastic household goods, plastic films, bottle lids and polyester-associated clothes.

The abundance and distribution of MPs in nearshore marine surface waters in the Pacific and Atlantic have been widely documented (Boyle and Örmeci 2020). However, this is not the case for the Western Indian Ocean except for South Africa where MPs pollution has been studied for

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Table 1 Sampling sites along the Dar es Salaam and Zanzibar coastline

Sites	Site code	Coordinates	Location	Potential sources of plastic pollution
Ocean Road	OCR	06°48′,039°18′	Dar es Salaam	Sewage pipe, Msimbazi river, fish market
Ununio	UNU	06°36′,039°10′	Dar es Salaam	Fishing, Nyakasangwe and Tegeta rivers.
Mjimwema	MJM	06°60′,039°21′	Dar es Salaam	Harbor, oil pipes, fishing.
Kunduchi	KDC	06°39′,039°13′	Dar es Salaam	Recreational, residential and fishing.
Nungwi	NGW	05°50′,039°12′	Zanzibar	Recreational and fishing
Bububu	BBB	06°87′, 039°21′	Zanzibar	Fishing activities, market
Paje	PAJ	06°21′,039°35′	Zanzibar	Recreational and fishing.
Fumba	FMB	06°11′,039°15′	Zanzibar	Recreational, fishing and residential.

over three decades (e.g., Verster et al. 2017; Chaukura et al. 2021). In East Africa, pollution by MPs receives little attention (Shilla 2019), with few studies reporting MP pollution in aquatic environment e.g. Kerubo et al. (2020), Kosore et al. (2018;2022) from Kenya and Mayoma et al. (2020) and Shilla (2019) from Tanzania, even though the ocean is bordered by large and fast growing cities which are potential sources of plastic debris.

This study focuses on the abundance and distribution of MPs in surface waters of the Dar es Salaam (DES) and Zanzibar (ZZ) coastlines, and how this is impacted by tides. DES is amongst the fastest-growing cities in sub–Saharan Africa with a population growth rate of approximately 8% per year (Aikaeli et al. 2021). This growth places pressure on already overburdened resources and services including the management of solid wastes. As a result, many solid wastes may end up in landfills and/or illegally dumped in waterways or near the coastal ecosystems. Information regarding the occurrence of MPs in nearshore waters of DES and ZZ is currently lacking. This study aimed to assess the abundance, distribution and composition of MPs along the coastline of DES and ZZ.

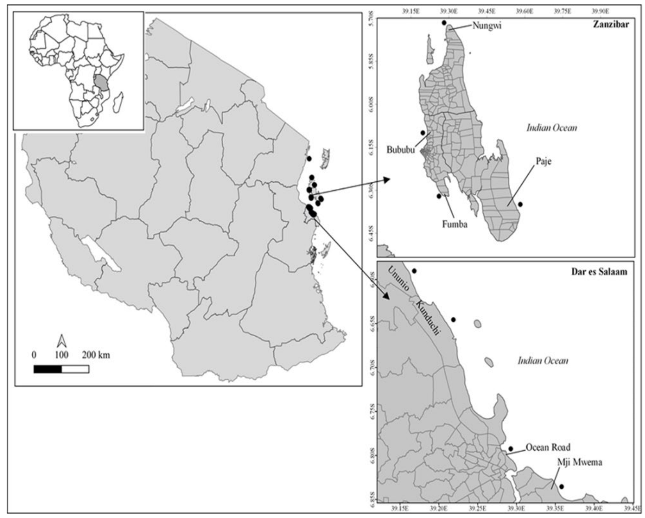

Fig. 1 Map showing the locations of the study sites (black dots) along the Dar es Salaam and Zanzibar coastline. (Source-National Bureau of Statistics Database). Inset: map of Africa hoghlighting Tanznia. See Table 1 for site descriptions

Materials and Methods

The sampling was conducted for two weeks, 14th – 28th December 2019, along the coasts of DES and ZZ, Tanzania. Samples were collected at all 8 sites in three transects from the shoreline and right angles to the shoreline offshore (Table 1; Fig,1). This was repeated at both low and high tides during the Northeast Monsoon with calm winds having minimal impact on wind speed during sampling. A manta net 2 m long, 300 µm mesh size, a rectangular opening of 29.5 cm × 14.5 cm, and a cylindrical collecting cod end of 300 µm mesh size was used. The trawls were hauled horizontally from a motorboat, thus collecting water from 0 to 14.5 cm water depth, at a speed of 2–3 knots for 20–30 min against the wind direction to ensure the manta net was fully. A flowmeter was tied at the trawl opening and the counts were recorded at the start and stop of each trawl event. GPS coordinates were recorded at the start and end of transects. Each sample was transferred to a 250 mL glass jar and stored in 70% ethanol for preservation and identification of MPs as described by Qiu et al. (2016).

A total of 48 water samples from the 8 sites were sieved with filtered seawater through a 125 µm mesh-size sieve, transferred from the glass jars to clean glass petri dishes and visually sorted using an optical microscope fitted with a Stemi 305 trino body (Carl Zeiss Suzhou Co. Ltd, Germany) and a dissecting microscope equipped with Axiocam ERc 5s camera. MPs were transferred to separate clean petri dishes using tweezers. The MPs were enumerated and categorized by type (fragments, fibers, films, pellets and foams) according to Bessa et al. (2019), size (> 5 mm, 2–5 mm, 1–2 mm, 0.5-1.0 mm and 0.3–0.5 mm) and by color (red, green, blue, black, white, multicolored, transparent and others) according to Viršek et al. (2016). The abundance of MPs per site was determined by dividing the total number of MPs collected at each site by the volume of water sampled and presented in MPs/m^3.

Of the 849 MPs collected in total across all sites, 25%, that is 209 MPs, were selected at random for polymer identification. MPs were analyzed using Attenuated Total Reflection-Fourier Transform Infrared (ATR-FTIR) spectroscopy on an Alpha-p spectrometer from Bruker, Germany according to La Daana et al. (2017). MPs were clamped onto the ATR diamond crystal before measurement, which comprised 24 scans in the range of 4000 to 650 cm^{-1} at a resolution of 4 cm^{-1}. Bruker's Opus 7.5 spectroscopy software was used for processing and the National Museum of Denmark's reference database comprising more than 500 spectra of both new and degraded plastics was used to identify MPs. A minimum threshold value of 80% was considered a satisfactory correlation score with the reference database and matches lower than this value were rejected.

Quality control was conducted following the methods of Cincinelli et al. (2017). Data analysis was performed using ORIGIN PRO version 9.0. MPs abundance, shape, size, color and the effects of the tide were analyzed using one-way ANOVA. Prior to all analyses, the assumptions of normal distribution (Shapiro–Wilk test) and homogeneity of variances (Levene's or Bartlett's tests) were checked, and all the data were log10(x + 1)- transformed. Tukey's post-hoc tests were performed to reveal significant differences between individual means.

Results and Discussion

A total of 849 MPs were identified, of which 90.6% originated from DES and 9.4% from ZZ. MPs were identified in all water samples collected. The abundance of MPs in DES and ZZ varied between sites and was statistically different ($p = 0.01$ one-way ANOVA). The overall mean concentration of MPs for DES and ZZ was 0.24 ± 0.17 items/m^3. DES had significantly higher mean concentrations of MPs (0.47 ± 0.22 items/m^3) than ZZ (0.07 ± 0.06 items/m^3) ($p = 0.001$). This could be explained by the higher population pressure in DES urban which is estimated at 7 million (NBS 2014) coupled with greater human activities that produced plastic debris. Furthermore, the presence of large, medium and small industries associated with the use of plastic raw materials and produce short life span single used plastic goods distributed to the community, hospitals, luxuries hotels, petty traders and massive unattended solid wastes and poor sewage systems could be the reasons for high MP concentrations in DES coastal areas. The influence

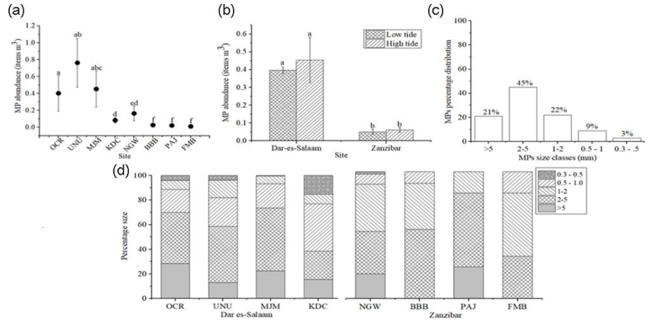

Fig. 2 Abundance and size data across study sites. (a) Average abundances of MPs (items/m^3) in water samples across shown as differences between sites and (b) differences between high and low tide at Dar es Salaam and Zanzibar, respectively. Different letters indicate significant differences between data (one-way ANOVA; Tukey's HSD test, $p < 0.05$). (item/m^3), mean ± SE, n = 3). (c) MP size distribution (in %) showing overall data for all sites combined and then (d) size breakdowns of individual sites of Dar es Salaam and Zanzibar. For site abbreviations refer to Table 1

of human activities such as fisheries (fishing nets, fishing lines) and mariculture (seaweed farming) on MPs distribution along coastal zone concur with Wang et al. (2020) who reported similar situation in China.

The mean concentrations of MPs varied from 0.01 to 0.76 items/m^3in both DES and ZZ. In DES the highest MP concentration was measured at Ununio with an average of 0.76 ± 0.28 items /m^3, followed by Mjimwema (0.45 ± 0.21), Ocean Road (0.40 ± 0.21), while Kunduchi (0.08 ± 0.03) had a relatively lower MP concentration (Fig. 2a). No significant difference in MP concentration was detected between Ocean Road and Ununio and Mjimwema ($p = 0.99$, One-way ANOVA). However, both sites were significantly different from Kunduchi ($p = 0.001$). In ZZ, the Nungwi site had the highest numbers of MPs (0.164 ± 0.088) and showed significant differences with Bububu and Paje (Fig. 2a, $p = 0.002$). No significant difference was shown between low and high tide in DES. Similarly, no variations were revealed in ZZ between low and high tide. Moreover, higher MP abundances were recorded in DES than ZZ at both low and high tide (Fig. 2b). However, according to Zhang (2017) the distribution of MPs in the intertidal marine surface water is very uneven and strands of MPs have been reported on high tide lines during its ebb phase (Thiel et al. 2013). High accumulation of MPs has also been reported during low tide due to deposition caused by low energy (Mathalon and Hill 2014).

The highest concentration of MPs was found at Ununio which could be explained by the presence of the Nyakasangwe and Tegeta Rivers flowing from unplanned settlements at Tegeta and Ununio directing wastes into the ocean. The high concentration of MPs, identified at Mjimwema and Ocean Road may be due to their geographical location and the presence of the Msimbazi River running from the

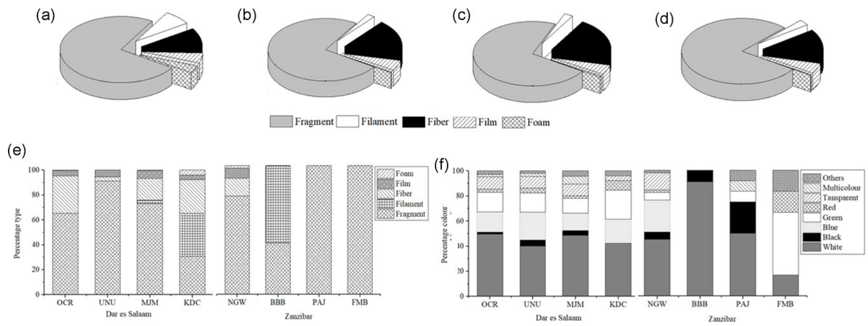

Fig. 3 MPs types and colour abundances across study sites. (a) MP type combined across sites in Zanzibar (a) and Dar es Salaam (b) sites, and at high tide (c) and low tide (d), respectively. The breakdown of types for individual sites at Dar es Salaam and Zanzibar (f). Breakdown of color abundance at each sampling site at Dar es Salaam sites and Zanzibar (f). See Table 1 for site name abbreviations

city center and carrying waste into Ocean Road which is not far from Mjimwema. The presence of a large sewage pipe entering Ocean Road from the city center and the presence of Aga Khan and Ocean Road hospitals discharging their wastewater to the sea could also account for higher concentrations of MPs at the two sites Zhu et al. (2020). Moreover, Ocean Road is bordered by DES port which also receives water from the Mzinga and Kizinga rivers (Mayoma et al. 2020 and the effect of surface turbulences. Low tides are often synonymous with high turbulence and water pressure, which disturb and transport buoyant MPs faster than at high tides (Expósito-Díaz et al. 2013). In ZZ the highest concentration of MPs at Nungwi could be due to the dense population of tourist hotels and activities along the beach that could contribute to waste into the ocean. MPs at these sites were mainly fragments, films and relatively small amounts of foam, implying that they originate from the breakdown of large plastic debris, perhaps food packaging and beverage packaging materials. Some MPs found in these areas were threadlike and possibly originate from the abandoned fishing net (including seines, gillnets, trawls and dredges) and plastic rope used in seaweed farming *'taitai'* and in boat anchoring.

The distribution of MPs based on their sizes varied across sites in DES and ZZ ($p = 0.002$ one-way ANOVA). The numbers of MPs with sizes 2–5 mm were significantly higher than those of > 5 mm, 1–2 mm, 0.5-1 mm and 0.3–0.5 mm ($p = 0.02$ one-way ANOVA). However, no significant difference ($p = 0.07$) was revealed between > 5 mm and 1–2 mm size categories. MPs in the range of 2–5 mm were the most frequently found with the proportion of 45% followed by 1–2 mm (22.4%) and > 5 mm (20.6%), of the total observed MPs (Fig. 2c). The sizes collected in this study are consistent with those reported by Zhang et al. (2022). Similar size distribution of MPs was observed in samples collected during both low and high tides. MPs of 2–5 mm were the most abundant as shown elsewhere with smaller particles able to be transported longer distances by waves than larger particles (Tiwari et al. 2019). In Dar es Salaam MPs of size 2–5 mm were most common in Mjimwema (37.24%) followed by Unuio (31.5%), Ocean Road (29.5%) and Kunduchi (1.72%) (Fig. 2d). In ZZ, the MPs sized 2–5 mm were most common at Nungwi (53.13%) followed by Paje (21.87%), and Bububu (18.75%) while Fumba had the lowest proportion (6.26%) (Fig. 2d). Law (2017) reported a similar observation that approximately 95% of plastic particles gathered in surface waters were between 1 and 5 mm. The differences in MPs size between stations could be attributed to the sources and continuous fragmentation of microplastics from larger to smaller in the ocean.

Six types of MPs (i.e. fragments, filaments, fibers, films, foams and pellets) were identified (Fig. 3). Fragments were most commonly found at both ZZ and DES, comprising 76% and 76% of the total MPs, respectively (Fig. 3a & b). Fragments comprised 78% and 75% in ZZ 72% and 78% in DES (Fig. 3c & d) in high and low tide, respectively. The second most common type of MPs was fibers which were found across all sites, with 18% being recorded in DES and 11% in ZZ. Other types of MPs (films, filaments, foam and pellets) accounted for less than 10% of the total types observed. In DES, fragments were most common at Ununio accounting for 38% followed by Mjimwema (33%), Ocean Road (28%) and Kunduchi (1.4%) had the lowest proportion. While fibers were the most common in Ocean Road (55%) followed by Mjimwema (34%) (Fig. 3e). The distribution of MPs types among sites in ZZ showed that the highest proportion of fragments was found in Nungwi (88%) with the lowest number being found in Bububu, Fumbu and Paje while filaments were most common in Bububu (Fig. 3e).

The variation of MP types in the study sites can be associated with their proximity to industrial areas, poor solid waste management and high population pressure. For example, the Bububu site comprises a large market with poorly managed solid wastes which are disposed of in the ocean. Furthermore, fishing and seaweed farming in ZZ contributes to ocean plastic pollution. Additionally, recreational activity along the coasts attracting ~ 630,000 tourists per year, for instance at Nungwi and Fumba, contributes to plastic pollution. The fragments were significantly more frequently found than fibers ($p = 0.02$), filament, film, foam and pellet ($p = 0.01$). It was further found that more fragments were identified during low tide than at high tide ($p = 0.04$), MPs recovered in the study sites and identified using ATR-FTIR spectroscopy, probably originated from degradation and

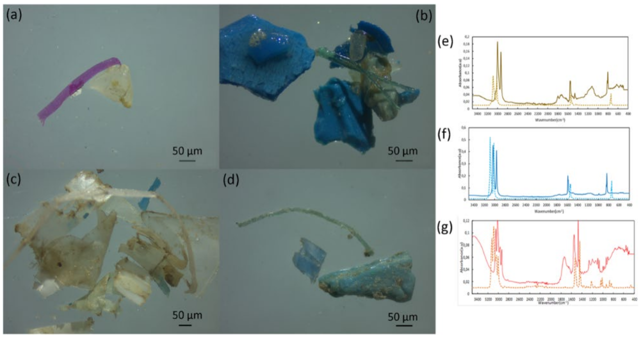

Fig. 4 Microscopic photographs of some of the (a) filament (b) fragments and (c) films and (d) fiber, found in surface waters of Dar es Salaam and Zanzibar. ATR-FTIR spectra of three representative samples of MPs collected from water. Reference spectra are shown using broken lines and slightly offset (e) blue fragment from Ocean Road 95.37% match with LDPE, (f) blue fragment from Nungwi 97.96% match with HDPE, (g) multi-color film from Mjimwema 92.45% match with PP

weathering of larger plastic materials (Saipolbahri et al. 2020).

The distribution of MPs based on their color varied across sites in DES and ZZ (p = 0.04). The colors found included white, black, blue, green, red, transparent, multicolor and others (Fig. 3f). White coloured MPs were the most common with an average of 8.9 ± 4.4 item/m^3 per site accounting for almost half of all MPs found, followed by blue 5.0 ± 2.22 item/m^3 (18.0%), green 4.35 ± 2.0 (14.0%), transparent 4.25 ± 1.76 (9.8%), black 2.0 ± 0.7 (4 0.0%), multicolor 2.6 ± 1.56 (3.4%), others 1.68 ± 0.7 (3%), red 1.8 ± 0.5 (3.0%). In ZZ, white MPs accounted for 50.0% (2.0 ± 1.4 item/m^3) of the total observed MPs, while in Dar es Salaam, white MPs accounted for 45.0% (15.6 ± 7.8 item/m^3). The number of white MPs identified was significantly higher during high tide than low tide (p = 0.02). Different colored MPs recorded in this study may imply various sources of MPs at the different study sites, though the explanation of the difference in color distribution was not apparent. Some of the microscopic photographs of the microplastic types are shown in Fig. 4. Purple and green filaments were found (Fig. 4a), fragments showed various shapes and colors i.e. blue, green and grey (Fig. 4b), the film was found as white and multicolor (Fig. 4c) and fiber was found as green and blue (Fig. 4d). This finding agrees with Zhu et al. (2020) reports on the relationship between MP colors, weathering and degradation of various plastics.

Of 209 MPs from across sites and types analysed by ATR-FTIR, the polymer types identified included low-density polyethylene (LDPE), high-density polyethylene (HDPE) and polypropylene (PP) (Fig. 4e, f and g). Comparing ATR-FTIR spectra with the National Museum of Denmark's reference database indicated that blue fragments from Ocean Road had a 95.4% match with LDPE (Fig. 6e), while blue fragments from Nungwi had a 98.0% match with HDPE (Fig. 4f) and multi-colored film from Mjimwema showed 92.4% match with PP (Fig. 4 g). These are commonly found polymers because of their broad application in packaging materials and 90% of world plastics comprise these three materials (Boyle and Örmeci 2020). PP is commonly found in surface waters worldwide because its low density of ca. 0.95 g/cm^3Martin et al. (2017). The ubiquity of these polymers means that it is not possible to attribute microplastics to any specific sources. MPs comprising PP (more abundant), LDPE and HDPE (less abundant) are likely to originate from fragmented abandoned fishing nets (Zhang et al. 2021), plastic ropes used in seaweed farming (Msuya 2005), anchor tying ropes, beverage containers and packaging materials (Boyle and Örmeci 2020).

In conclusion, the abundance and distribution of MPs in DES waters were higher than those found in ZZ. Fragments and fibers were the most common types of MPs found in both coastal regions. The percentages of fibers were higher in DES than ZZ probably due to population pressure coupled with high anthropogenic activities such as washing clothes. The three polymers identified were PP, HDPE and LDPE. High abundance of MPs observed in the two study coastal regions is probably linked to proximity to industrial areas, tourism, population pressure, and poor solid waste. We recommend awareness programs on the effects of MPs pollution in the marine environments and the promotion of sustainable plastics management strategies around the Western Indian Ocean to reduce the escalating plastic pollution.

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