Marine Pollution Bulletin 179 (2022) 113710

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Microplastics in Kenya's marine nearshore surface waters: Current status

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ARTICLE INFO

Keywords:
Microplastics
Polymers
Surface waters
East Africa, nearshore

ABSTRACT

Microplastics (MPs) were collected at six locations along Kenya's marine nearshore surface waters using a 300 μm mesh-size manta net. The samples were washed over a 125-μm mesh size sieve No.120 into a glass jar and preserved in 70% ethanol. MPs were sorted, counted visually under a dissecting microscope then identified using attenuated total reflection Fourier transform infrared (ATR-FTIR) spectroscopy. A total of 1473 particles with an overall mean concentration of 0.58 ± 1.29 MPs m^{-3}, were collected. Fragments were the most common types representing 55% of the total MPs, followed by films (40%) and fibers (2%). Polypropylene (PP) was dominant (52%), high-density polyethylene (HDPE) comprised 38% and low density polyethylene (LDPE) 10% of the total MPs. This study provided baseline information, in which Malindi was identified as a hot spot for MPs pollution. Furthermore, the outcomes will assist policy formulations and management strategies aimed at controlling marine plastics.

1. Introduction

Marine plastic pollution is described as one of the greatest environmental challenges of the present day. When plastic waste in the marine environment is exposed to UV radiation and mechanical forces, the plastic breaks down into smaller and smaller fragments ranging from between 1 and 5 mm, also known as secondary MPs (GESAMP, 2015; Avió et al., 2016; Maes et al., 2017; Lusher et al., 2017; Kazmiruk et al., 2018). Secondary contrast with primary MPs that include all particles commercially produced with a similar size range and include the raw material used as precursors of plastic products such as industrial pellets, fibers or the microbeads added as abrasives to cosmetic and cleaning products (Rodríguez-Seijo and Pereira, 2017; Da Costa et al., 2017). The small dimensions of MPs, occurring in a wide variety of colors and shapes make them available for ingestion by marine organisms (Collignon et al., 2012; Skalska et al., 2020). When ingested, they have the potential to cause mechanical effects, block the feeding appendages, hinder the passage of food through the intestinal tract or cause pseudo-satiation resulting in decreasing food intake (Wang et al., 2017).

Microplastic pollution awareness has increased in Africa in the last decade, however, very little is known about the occurrence, distribution and fate of MPs in different environmental compartments within the continent (Alimi et al., 2020). Furthermore, microplastic pollution in East African marine waters has been underreported compared to other regions of the world. Some information is starting to emerge, specifically relating to the Kenyan coast where the presence of MPs has been reported in Kenya's exclusive economic zone (EEZ) surface waters (Kosore et al., 2018) and some creeks (Kerubo et al., 2020). However, information on the abundances and locations of MPs accumulation in marine nearshore surface waters is still lacking. The questions, which need to be asked, are whether the organisms living in Kenya's marine nearshore waters are exposed to MPs, and if so, at what concentrations (Tremblay et al., 2019). The answers can be used to identify hotspots of risk to prioritize mitigation measures in the future when microplastic concentrations are expected to increase (Everaert et al., 2020).

The scope of the present study was to assess the current occurrence, distribution and characteristics of MPs in Kenya's marine nearshore surface waters. This information can lead to the formulation of best

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https://doi.org/10.1016/j.marpolbul.2022.113710
Received 6 September 2021; Received in revised form 11 March 2022; Accepted 25 April 2022
Available online 5 May 2022

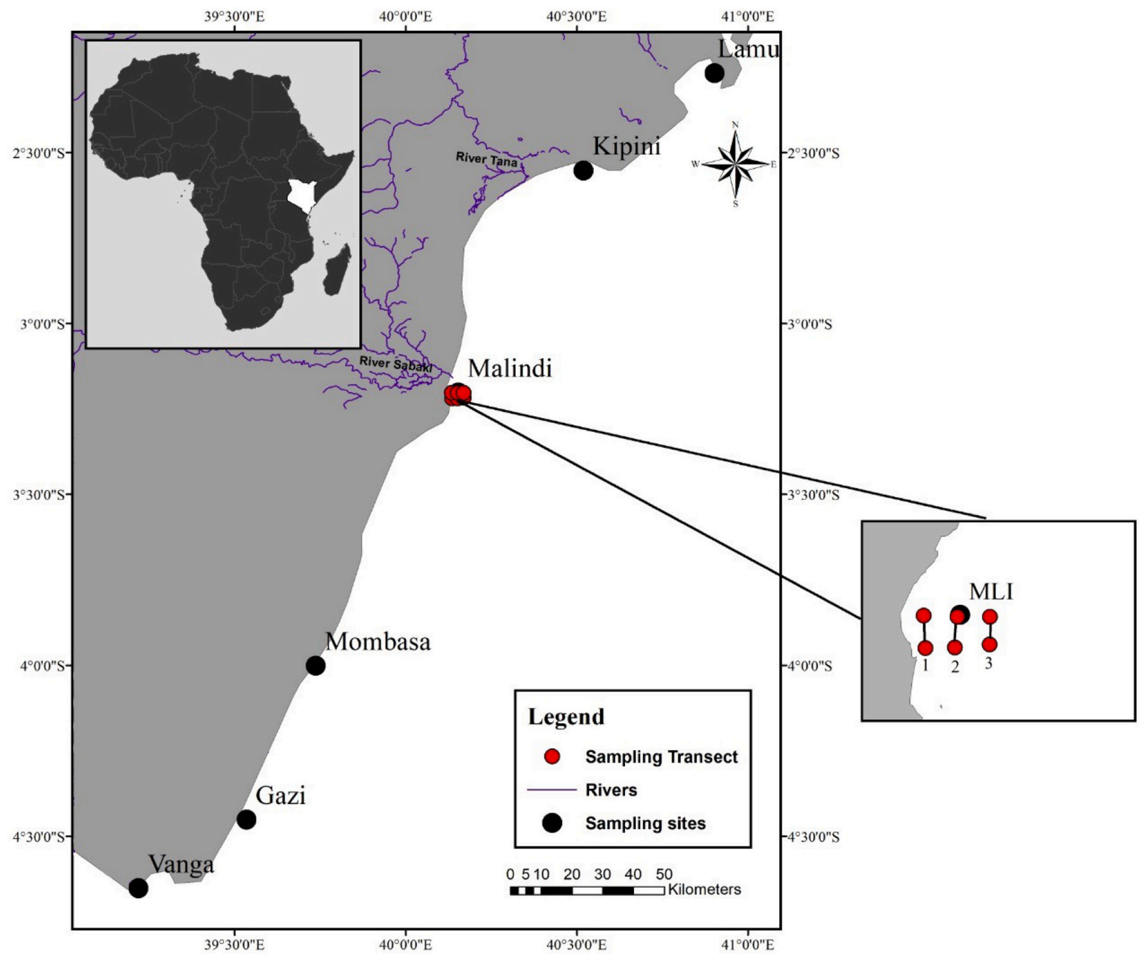

Fig. 1. A map showing the six sampling locations in Kenya: Lamu (LMU), Kipini (KPN), Malindi (MLI), Mombasa (MSA), Gazi (GZI) and Vanga (VGA). Sampling transects are illustrated using MLI as an example.

practices and plastic pollution management strategies.

2. Materials and methods

2.1. Study areas and sample collection

Six (6) sampling sites were selected in Kenya's marine nearshore waters based on their close proximity to major coastal urban centers such as Lamu (LMU), Kipini (KPN), Malindi (MLI), Mombasa (MSA), Gazi (GZI) and Vanga (VGA) (Fig. 1). LMU is an urban island, which is impacted by boating, fishing, tourism and Lamu port's construction activities. KPN is a small, less populated town (8 people km^{-2} in 2019) with fishing as the major economic activity and is interconnected with Tana River. MLI is an urban center where plastic waste input is fairly high due to its considerable population (116 people km^{-2} in 2019) and connection with River Sabaki. In addition, MLI comprises shipping, fishing and tourism activities. MSA is the capital of the coast region and is highly populated (5495 people km^{-2} in 2019). The sampling location in MSA was open to the sea, adjacent to a number of beach hotels, public beaches with a number of activities including heavy recreational activities for tourists and fish landing sites. GZI is a small, less populated (105 km^{-2} in 2019) town inhabited by a fishing community and less impacted by anthropogenic activities. VGA is also a less populated (105 km^{-2} in 2019) border town between Kenya and Tanzania, close to the Pemba channel, which is characterized by surface water currents with velocities ranging from 0.04 to 1.34 ms^{-1} and its water flow is primarily driven by the East African Coastal current, which flows northward throughout the year (Semba et al., 2019), this location can be used to represent transboundary microplastic pollution. VGA is inhabited by a fishing community and is considered to be less impacted by anthropogenic activities.

Surface water samples for MPs were collected along three transects at different distances beginning near the shoreline continuing in the middle shore and going offshore during low and high tides. The aim was to study the influences of anthropogenic and tidal variations respectively. A manta net from Hydro-Bios, Germany, with a rectangular opening of 14.5 cm × 29.5 cm, a 300 μm mesh net and a cylindrical collecting cod end of 300 μm mesh-size with two wings for balancing was used for MPs collection. The trawls were towed horizontally at a speed of 3 knots for 30 min. GPS coordinates were recorded at the start and end positions respectively. The volume of water collected was calculated from the manta trawl opening area (m^2) multiplied by the transect length (m) obtained from GPS coordinates at start and stop positions route. Each manta trawl sample collected in the cod end was washed with filtered seawater over 125-μm mesh-size sieve No. 120 to remove the unwanted materials. The remaining materials were concentrated on one side of the sieve, transferred into a 250 mL glass jar, and preserved in filtered 70% ethanol. Seawater and ethanol were vacuum filtered using Rocker 400 vacuum pump; Taiwan and Glasso Boro 3.3 Filtration system over 0.7 μm Whatman GF/C glass filter papers. The use of 70% ethanol was crucial to preserve the sample as well as to help to discolor the organisms/organic materials so that MPs were easier to find (Viršek et al., 2016).

2.2. Physical and chemical analysis of MPs

In the laboratory, each sample was placed in clean glass petri dish, which was previously cleaned with detergent, followed by thorough rinsing with filtered distilled water, and then air dried in a laminar flow hood. The samples were observed under a dissecting microscope (Stemi 305 trino Body, Carl Zeiss Suzhou Co. Ltd, Germany equipped with Axiocam ERc 5s camera). Microplastic particles were picked, sorted and counted (Viršek et al., 2016) using forceps and put in a separate clean petri dish. MPs concentrations were obtained as number of particles per unit volume (m^{-3}) according to Viršek et al. (2016) and Gewert et al. (2017). The particles were photographed then classified into absolute sizes (2–5 mm, 1–2 mm, 0.5–1 mm, and 0.3–0.5 mm). They were further categorized as large microplastics (LMPs), upper range small MPs (UR-SMPs; 0.5–1 mm), and lower range small MPs (LR-SMPs; <0.5 mm), type (fragments, films, fibers, filaments and foams) and color (white, transparent, black, blue, red, green, multicolor and others) according to established methods (Viršek et al., 2016; Gago et al., 2018). Polymer identification of LMPs (1–≤5 mm) (Gago et al., 2018) was performed according to Massos and Turner (2017) and Kanhai et al. (2017) using an Alpha p-FTIR spectrometer in attenuated total reflection mode (ATR-FTIR) from Bruker, Germany. Before polymer identification using FTIR, the sorted MPs were washed with distilled water to purify them, in case they were covered with biofilms and/or other organic and inorganic adherents, which might influence the IR spectra. The particles were then placed in aluminium-trays and dried in an oven at 30 °C to evaporate the water, which strongly absorbs IR radiation then stored for further analysis (Viršek et al., 2016). A particle was clamped firmly onto the ATR diamond internal reflection element to ensure good contact between both. Measurement comprised 24 scans in the range of 4000 to 650 cm^{-1} (the latter being the lower limit of sensitivity for a diamond internal reflection element) at a resolution of 4 cm^{-1}. Identification of the resulting spectra was achieved by comparing them with a reference database compiled in-house by the National Museum of Denmark comprising more than 300 known, new and degraded commercially available plastics all of which were analyzed using the Alpha p-FTIR spectrometer in ATR mode. A minimum threshold value of 80% was deemed a satisfactory correlation score and matches lower than this value were rejected.

2.3. Quality control

Sampling, microscopic isolation and sorting of MPs were carefully performed in order to ensure that no items were missed. Measures were taken to prevent samples from being contaminated by artifacts and airborne particles. Glass and stainless steel tools were used at all stages of the process. In the cases where plastic had to be utilized, it was rinsed several times with filtered ethanol before use. The glassware, tools and workspaces were thoroughly cleaned with filtered water and paper towels prior to use. Sieves were also washed and dried in a laminar flow hood before and after use. Latex gloves were worn for sorting and counting to prevent hands from contaminating the samples. All apparatus made of plastic (petri dishes, sieves, etc.) were further microscopically inspected before use to ensure that there was no contamination from any of these materials to the samples. During sampling and subsequent processes, cotton clothing and lab coats were worn at all times, avoiding wearing polyester-type clothing (such as fleece jackets and polyester lab coats). To check for any potential contamination occurring in the treatment and analysis of sample in the field and laboratory, including air and handling during sampling, visual sorting and identification, and during vacuum filtration, three procedural blanks consisting of filtered distilled water were run in parallel with the sampling process in the field and the samples in the laboratory (Cincinelli et al., 2017; Kosore et al., 2018).

Table 1
MPs' concentrations in per site in Kenya's marine nearshore surface waters.

Site	MPs m^{-3} (mean ± SD)
GZI	0.02 ± 0.00
KPN	0.02 ± 0.02
LMU	0.04 ± 0.02
MSA	0.07 ± 0.05
VGA	0.09 ± 0.07
MLI	3.22 ± 2.04
Overall range	0.02 ± 0.00–3.22 ± 2.04
Overall mean (mean ± SD)	0.58 ± 1.29

Table 2
MPs abundances reported in surface waters around the world compared to this study.

Region	Country	Marine compartment	Microplastic abundance	Reference
Europe	Portugal	Surface water	0.45 ± 0.52 items m^{-3}	Rodrigues et al., 2020
	Netherlands	Surface water	0–1.5 microplastic m^{-3}	Maes et al., 2017
	France	Surface water	0.24 ± 0.35 MP m^{-3}	Frère et al., 2017
Asia	China	Surface water	0.167 ± 0.138 n/m^{-3}	Zhao et al., 2015
	Qatar	Surface water	0.71 particles m^{-3} (range 0–3 particles m^{-3})	Castillo et al., 2016
Africa	South Africa	Surface water	1.15 ± 1.45 particles m^{-3}	Kanhai et al., 2017
	South Africa (Richard's Bay Harbour)	Surface water	413.3 ± 77.53 particles·m^{-3}	Nel et al., 2017
	South Africa (Durban Harbour)	Surface water	1200 ± 133.2 particles·m^{-3}	Nel and Froneman, 2015
	South Africa	Surface water	3640 particles (0.011 particles m^{-3})	Ryan, 1988
	Kenya	Surface water	0.58 ± 1.29 items m^{-3},	This study

2.4. Statistical analysis

Statistical analysis was performed using R software (R Core Team, 2020). The data was first tested for normality using Shapiro-Wilk test. One-way ANOVA was applied to determine significant differences in microplastic abundances among the areas, sites, and towing transects. Where significant differences occurred, Tukey multiple comparisons of means method was applied to determine where the differences occurred. *t*-Tests were applied to determine the tidal differences in microplastic abundances among the areas using Welch two-sample method. The significance level used to compare groups was set at $\alpha = 0.05$.

3. Results and discussion

3.1. Concentration of MPs in surface waters

No items were found in the procedural blanks; and therefore, no data correction was performed. A total of 1473 particles were confirmed to be MPs, which occurred in varying concentrations among the sites ranging from 0.02 ± 0.00–3.22 ± 2.04 MPs m^{-3} in which the lowest and highest concentrations were recorded in GZI and MLI, respectively (Table 1). The overall mean concentration was 0.58 ± 1.29 MPs m^{-3} with an overall significant difference ($p = 4.1e^{-05}$) being observed among the sites.

This study reports one of the first quantifications of microplastic pollution in marine nearshore surface waters of Kenya. Our microplastic quantifications were in the same range as MPs' concentrations of 0.71

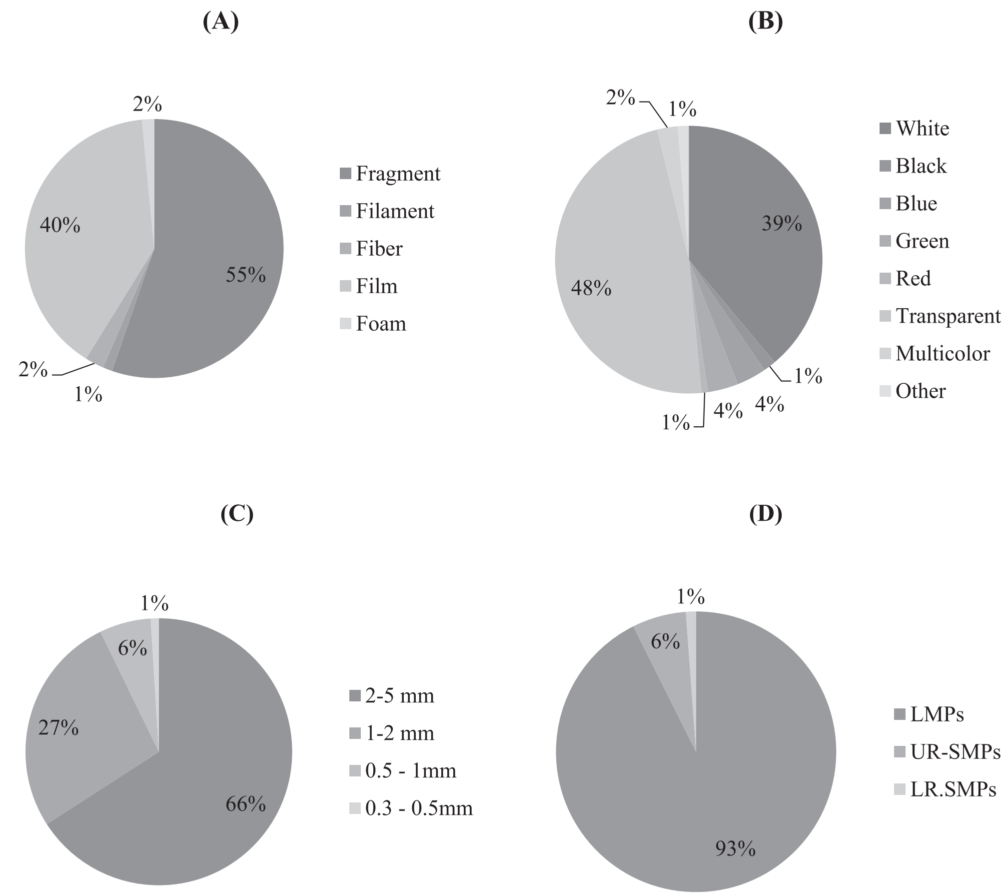

Fig. 2. Percent composition of microplastic particles identified in Kenya's marine nearshore surface waters: A, represents the composition of types; B, colors, C, absolute sizes and D, categorized sizes.

particles m^{-3} recorded in Qatar (Castillo et al., 2016), 0–1.5 m^{-3} in the Netherlands (Maes et al., 2017) and 1.15 ± 1.45 particles m^{-3} in South Africa (Kanhai et al., 2017). However, the abundances were higher than 0.45 ± 0.52 items m^{-3} reported by Rodrigues et al. (2020) at a Portuguese estuary and marine park, 0.24 ± 0.35 MP m^{-3} in France (Frère et al., 2017), 0.167 ± 0.138 number m^{-3} in China (Zhao et al., 2015), 0.011 particles m^{-3} reported by Ryan (1988) in Southern Cape Province, Southern Africa. More importantly, the concentrations were found to be two to three orders of magnitude lower than 413.3 ± 77.53 particles m^{-3} and 1200 ± 133.2 particles m^{-3} recorded within Richard's Bay Harbour and Durban Harbour, South Africa respectively (Nel et al., 2017) and 257.9–276.7 particles m^{-3} reported along the south-eastern coastline of South Africa (Nel and Froneman, 2015), 0.2 * 10^3–3.3 * 10^3 particles m^{-3} in Baltic Sea (Aytan et al., 2016), as given in Table 2.

Rivers are believed to be the critical pathway by which MPs enter the oceans (Xu et al., 2020), but see the contradictory opinions about estuaries of lowland rivers (Van et al., 2022). This can be validated by the highest abundance recorded in MLI probably because the area connects with River Sabaki, whose headwaters connect to the Nairobi River. This river collects effluents and runoffs from the Dandora dumpsite, effluent from industrial activities and informal settlements dominating land use around Nairobi and livestock farming, including small-scale irrigation activities downstream before it discharges into the Indian Ocean at Malindi Bay. Furthermore, since the survey was conducted just after the short rains, which have been reported to occur in October and November each year (Government of Kenya, 2017), it is expected that the source of the high microplastic concentrations recorded in MLI also comprised flood and runoff water driven all the way from Nairobi and land anthropogenic activities. On the contrary, KPN, which is interconnected to River Tana, recorded lower MPs probably because its headwaters and catchment are not as impacted as those of River Sabaki. Influence by recreational activities such as beach hotels and associated tourism activities as observed in MSA.

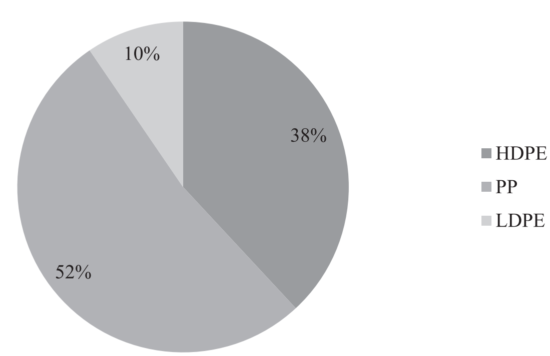

Fig. 3. Percent composition of the three polymers (PP, HDPE and LDPE). identified in Kenya's marine nearshore surface waters.

3.2. *Physical and chemical characteristics of MPs*

Fragments were the dominant microplastic types representing 55% of the MPs found, followed by films (40%), fiber (2%) and filaments (1%) (Fig. 2A). The dominant color was transparent accounting for 48% of all colors in the six sites, followed by white (39%), blue and green (4%), multicolor (2%), and black, red and others (1%) (Fig. 2B). Sizes, 2–5 mm were the most common accounting for 66% of all MPs, followed by 1–2 mm (27%), 0.5–1 mm (6%) and 0.3–0.5 mm (1%) (Fig. 2C). Furthermore, the categorized size LMPs accounted for 93% of the

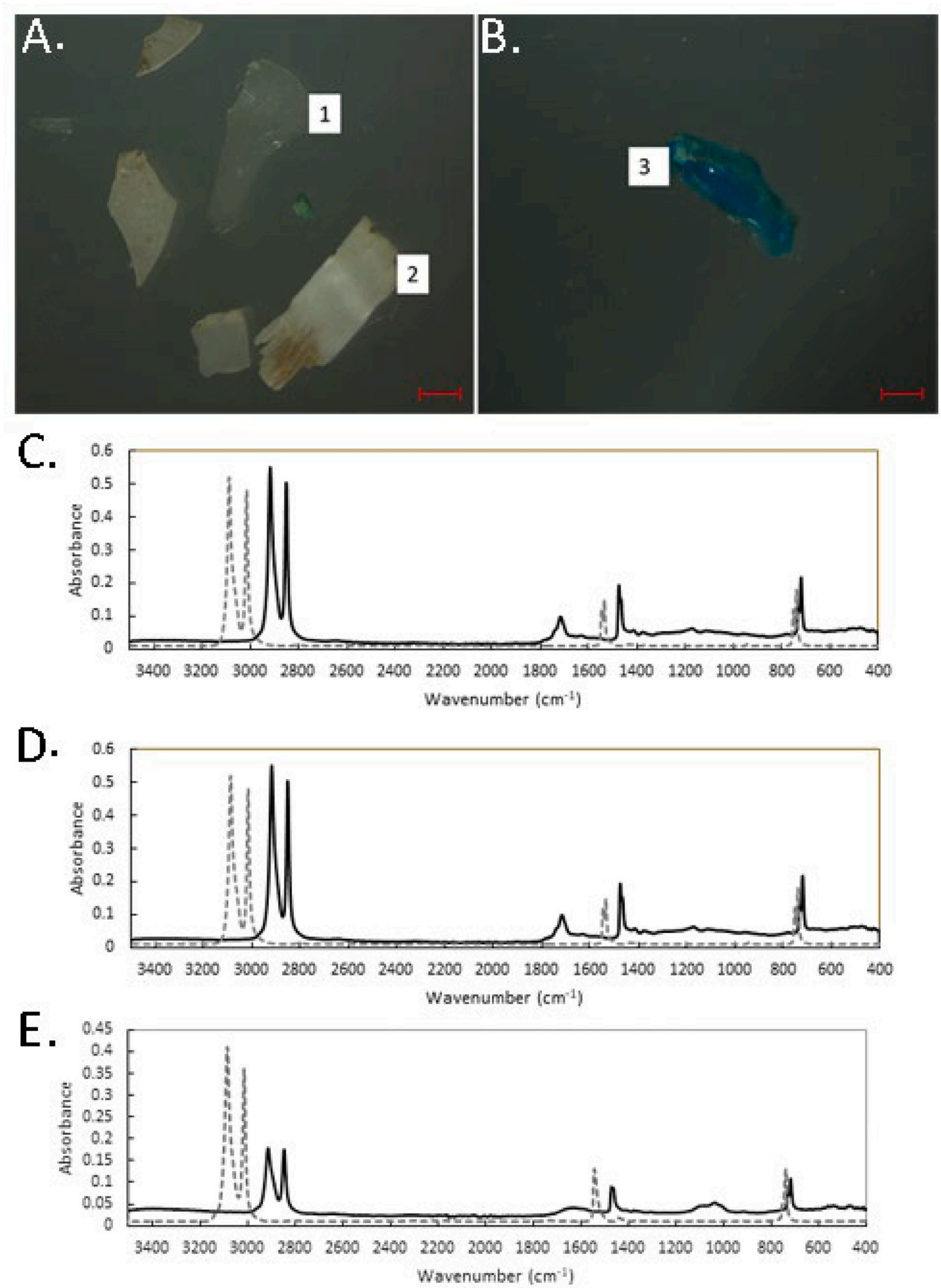

Fig. 4. Microscope photographs of MPs' particles (A and B) and associated FTIR spectra (C-E): (1) Transparent film (A) is a 95.62% match with LDPE (C); (2) White sack sheet film (A) is a 87.22% match with PP (D). (3) Blue fragment (B) is a 97.78% match with HDPE (E). In images A and B the scale bar = 500 μm. ATR-FTIR spectra were compared to reference spectra using the National Museum of Denmark's reference database. Continuous line spectra represent the sample and the broken lines represent reference spectra for the three polymers and slightly offset to left to show comparison. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

particles, 6% were UR-SMPs, and 1% LR-SMPs as shown in Fig. 2D. Aliquots (n = 520) of the particles were taken and analyzed for polymer types, in which we identified three low density low density polymers (PP, HDPE and LDPE). PP was the most common polymer accounting for 52%, followed by HDPE (38%) and LDPE (10%) as shown in Fig. 3. The polymer spectra and microphotographs of MPs particles are given in Figs. 4.

The dominance by fragments (Fig. 2) is consistent with the reports by Maes et al. (2017); Helm (2017); Schnurr et al. (2018). The existence of fragments is hypothesized to be attributed to the breakdown of larger plastics (Frère et al., 2017) originating from land, being carried by hydrophysical vectors such as rivers, storm drains and alongshore currents into the ocean where they are subjected to further fragmentation (Pieper et al., 2015). Furthermore, plastic fragments can also comprise a combination of plastic types (Romeo et al., 2015). The high prevalence of plastic films and foils could be associated with consumer uses such as single-use plastic bags (Rizzi et al., 2019). Most fragments and films were found in MLI, possibly originating from Nairobi and its environs through River Sabaki and its catchment. Only 2% of the MPs were identified as fibers and may be associated with nets from fishing activities along the coastal areas. Kanhai et al. (2017) and Mu et al. (2019) suggest that fibers often originate from fishing gear and textiles (washing clothes) from urban centers. In addition to the local sources, fibrous MPs could also occur from sea-based sources transported by ocean currents or from shipping and commercial activities after a long-distance migration from other continents (UNEP, 2019).

MPs were present at all sampling locations and had diverse colors, in which (Au, 2017). Transparent MPs were most common probably due input by River Sabaki, which receives and inputs large amounts of packaging plastic wastes into the system from Dandora dumpsite via Nairobi River. This may be explained by the fact that packaging materials account for more than 40% of global production of plastics and the majority of these are transparent (Geyer et al., 2017). White MPs were the second most commonly found which is in line with those of Mu et al. (2019) in surface waters of the Northwest Pacific, the Bering Sea, and the Chukchi Sea. The ubiquity of LMPs was consistent with the findings of Reisser et al. (2013) in surface waters around Australia. However, this was contrary to the findings by Mu et al. (2019), which reported that UR-SMPs were the most common in the Northwest Pacific, the Bering Sea, and the Chukchi Sea. More importantly, since smaller MPs may be more easily ingested by organisms than larger ones.

PP was the dominant polymer in Kenya's nearshore marine waters, also reported to be have been the most common in Kenya's EEZ surface water (Kosore et al., 2018). PP is typically used to manufacture items such as food containers, plastic tableware, disposable cups, plates and jugs (Li, 2018). These items are mainly used by the population in the urban centers and hotels adjacent to the study sites and their wastes find their final destination in the ocean where they can further breakdown into microplastic particles (Frère et al., 2017). HDPE was the second dominant polymer and its presence could be attributed to its common application in the manufacturing of detergent bottles, milk jugs, tubes, pipes, insulation molding, while the presence of LDPE could be attributed to its application in the manufacturing of carrier bags and food packaging. Important to mention is that we only found low density plastics (PP, HDPE, and LDPE) that are buoyant in seawater (Anderson et al., 2016) which was the focus of study.

4. Conclusion

This study reports one of the first quantifications of microplastic pollution in marine nearshore surface water of Kenya, in which we found that on average, 0.58 ± 1.29 MPs m^{-3} were present. The MPs were mainly composed of large fragmented MPs, which can fragment further to smaller MPs categories and three plastics PP, HDPE and LDPE. Microplastic concentrations at Malindi were clearly elevated compared to other locations and can be viewed as a microplastic pollution hotspot. The results of this study are considered as baseline information in addition to setting the stage for policy formulations that will ensure best practices and management mitigations. These aim to control marine plastic debris and minimize human-driven impacts on marine life.

CRediT authorship contribution statement

Charles Mitto Kosore: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Validation, Formal analysis, Writing – original draft, Writing – review & editing. **Loice Ojwang:** Conceptualization, Supervision, Funding acquisition, Validation, Writing – review & editing. **Justin Maghanga:** Conceptualization, Supervision, Funding acquisition, Validation, Writing – review & editing. **Joseph Kamau:** Conceptualization, Supervision, Funding acquisition, Validation, Writing – review & editing. **Daniel Shilla:** Conceptualization, Funding acquisition, Project administration. **Gert Everaert:** Conceptualization, Validation, Data curation, Writing – review & editing. **Farhan R. Khan:** Conceptualization, Funding acquisition, Validation, Writing – review & editing. **Yvonne Shashoua:** Conceptualization, Funding acquisition, Data curation, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors wish to thank WIOMSA through MASMA research grant and National Research Fund (NRF)-Kenya for funding the study. We also thank the Kenya Marine and Fisheries Research Institute (KMFRI) for providing field and laboratory facilities. We thank Pwani University where the first author is currently undertaking a PhD in Chemistry. We thank Kennedy Oduor, Oliver Oyengo, Emmaculate Masinde and Ezekiel Nyanjong for fieldwork and laboratory assistance.

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