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# Microplastic pollution in the surface waters of creeks along the Kenyan coast, Western Indian Ocean (WIO)

Joyce O. Kerubo<sup>1\*</sup>, Agnes W. Muthumbi<sup>1</sup>, John M. Onyari<sup>2</sup>, Edward N. Kimani<sup>3</sup>, Deborah Robertson-Andersson<sup>4,5</sup>

<sup>1</sup> School of Biological Sciences, University of Nairobi, PO Box 30197-00100, Nairobi, Kenya

<sup>2</sup> Department of Chemistry, School of Physical Sciences, University of Nairobi, PO Box 30197-00100, Nairobi, Kenya

<sup>3</sup> Kenya Marine and Fisheries Research Institute (KMFRI), PO Box 81651-80100, Mombasa, Kenya

<sup>4</sup> School of Life Sciences, University of KwaZulu-Natal, Private Bag X54001, Durban, South Africa

<sup>5</sup> Chrysalis Nature Training, Kei Mouth

\* Corresponding Author: joycekerubo65@gmail.com

## Abstract

Microplastic pollution has been recognized as a global threat in marine environments and a danger to prey, predators and humans. Yet there have been limited studies in the Western Indian Ocean (WIO) and along the Kenyan coast making it difficult to estimate the extent of such pollution. This is the first study on microplastics (MPs) in the surface waters within creeks (Tudor, Port-Reitz and Mida creeks) in Kenya. Sampling was done in January/February and September 2018 to collect microplastics from surface water. Neuston nets of 500  $\mu\text{m}$  (large) and 250  $\mu\text{m}$  (medium) size were towed for ten minutes and 50 litres of seawater sieved through a 20  $\mu\text{m}$  net (small) in three replicates. The samples were digested in 10 % Potassium Hydroxide, sieved, and then filtered with cellulose nitrate membrane microfilters. Concentrations of total microplastics, different shapes and colours were established under a microscope. High concentrations of small size (20-250  $\mu\text{m}$ ) MPs were encountered and Tudor and Port Reitz had higher concentrations compared to Mida Creek. The study provides data on microplastic concentrations within the creeks and recommends focussing on small size microplastics for monitoring purposes, which due to their high concentrations can be hazardous to organisms.

**Keywords:** microplastics, marine, Kenya coast, Western Indian Ocean

## Introduction

Microplastics (MPs) are defined as tiny plastic particles measuring between 0.1  $\mu\text{m}$  and 5000  $\mu\text{m}$  (Andrady, 2011), although there is still no universally accepted definition of MPs (Frias and Nash, 2019). In this study, microplastics ranging from 20 to 5000  $\mu\text{m}$  were considered. Plastics are a major pollutant to marine environments that have been recognized as a global threat (Sharma and Chatterjee, 2017). Plastics have now joined other marine stressors like habitat destruction, overfishing, ocean acidification and climate change (Amaral-Zettler *et al.*, 2015). Most of the plastics manufactured are for single-use and it was estimated that

between  $4.8 \times 10^9$  –  $12.7 \times 10^9$  kg of plastics entered the ocean in 2010 (Jambeck *et al.*, 2014). Of these, an estimated  $2.7 \times 10^8$  kg was in surface waters (Eriksen *et al.*, 2014). It is estimated that by 2050 plastic production will hit 33 billion tons (Zalasiewicz *et al.*, 2016) which may result in a considerable amount of plastics reaching the oceans, hence the need to investigate the extent of MPs pollution along the Kenyan coast to inform policy formulation on plastic waste management and disposal.

Microplastics in the environment occur in either the primary (originally manufactured to be that size and

entering directly as nurdles; fibres, pellets or granules), secondary (if they originate from the breakdown of macroplastics forming fragments; small irregular shaped particles), or film form (Andrady, 2015; Frere *et al.*, 2014; Lusher *et al.*, 2013). Gradual degradation of plastics through biological and chemical processes adds MPs into the water thereby increasing their concentration (Halle *et al.*, 2016). Microplastics sorb many Persistent Organic Pollutants (POPs) due to their large surface to volume ratio and hydrophobic nature (Cauwenbergh *et al.*, 2015). The water column is a habitat to many key species in an aquatic environment and if ingested in considerable quantities, MPs may affect the biota therein (Halle *et al.*, 2016). Owing to their small size (0.1  $\mu\text{m}$ -5 mm) MPs are bioavailable to a great diversity of organisms since they mimic prey particles and sediment grains, causing some animals to mistake them for prey while filter feeders may incorporate them as prey (Botterell *et al.*, 2019). Microplastics transport POPs to biota from the environment and even at low levels could harm or kill organisms, ultimately causing a decrease in biodiversity (Invar do Sul and Costa, 2014). Bioaccumulation and biomagnification of MPs to higher trophic levels has also been observed where copepods and polychaete larvae ingesting 10  $\mu\text{m}$  of polystyrene transfer the particles to mysid shrimps (Setälä *et al.*, 2014). Earlier research found that MPs concentrations of > 12.5  $\mu\text{g/L}$  decrease survival and fecundity in *Tigriopus japonicus* Mori 1938 (Lee *et al.*, 2013), and concentrations of 0.25 mg/L cause analogous embryonic development in the sea urchin *Lytechinus variegatus* Lamark 1938 (Nobre *et al.*, 2015).

Most coastal cities in the world are the source of plastics through manufacturing, packaging, building and construction, textile, food processing industries, fishing and tourist activities (Frere *et al.*, 2017). Some industries in some parts of the world release their effluents into the sea, major contributors being coastal cities of China, Indonesia, Philippines and Africa (Ocean Conservancy Report, 2017). Industrial effluents together with discarded plastics (Okuku *et al.*, 2011) introduce MPs into the oceans. On the Kenyan coast for example, Mombasa City is a busy coastal port with dense human settlement, many industrial plants, fishing and tourist activities and produces vast quantities of waste, including plastic waste. Research studies documenting the presence of MPs in the surface waters along the Kenyan coast are virtually non-existent, resulting in a severe deficit of information on the extent of microplastic pollution in the

area. A study in the central part of Kenya's Exclusive Economic Zone (EEZ) found 33-275 particles  $\text{m}^{-3}$  (Kosore *et al.*, 2018); a concentration that is lower than that of some of the most polluted waters of the world such as Geoje Island, South Korea where 16000  $\pm$  14000 items  $\text{m}^{-3}$  were found (Song *et al.*, 2014), China sea with 4137.3  $\pm$  2461.5 items  $\text{m}^{-3}$  (Zhao *et al.*, 2014), and the west coast of Sweden with 150-2400 items  $\text{m}^{-3}$  (Noren, 2007). The microplastic concentrations in the EEZ were similar to those detected in the North Sea and East Pacific (275  $\pm$  255  $\text{m}^{-3}$ ) (Desforges *et al.*, 2014). Following the report by Kenya's National Environmental Management Agency (NEMA) in conjunction with the United Nations Environmental Programme (UNEP), and the Kenya Institute of Public Policy Research and Analysis (KIPPA), that showed that supermarkets alone contribute tens of millions of plastic bags into the environment annually, the Kenya Government effected a ban in February 2017 on the use of low weight plastic bags.

This study aimed at providing an assessment of the presence of MPs in the surface waters in Tudor and Port-Reitz creeks in Mombasa City, and Mida Creek within a less urban environment near Watamu. Mida Creek, being within a marine National Reserve (KWS, 1997), was the control. The data and information generated will allow an evaluation of the effect of the Kenya Government ban on low weight plastic bag production and use effected in February 2017, and provide a baseline for future monitoring as there are no previous estimates of MPs levels available (NEMA, 2017). It will also provide data and information for the formulation of plastic waste management policies to protect the ecosystem which is rich in both terrestrial and marine biodiversity (Rochman, 2016).

## Materials and methods

The study was carried out in two creeks in Mombasa County (Tudor and Port-Reitz) and one creek in Kilifi County (Mida) along the Kenyan coast (Fig. 1). The creeks are enclosed, with limited water flow, low currents, and are surrounded by informal settlements, villages and manufacturing industries (Okuku *et al.*, 2011) making them prone to plastic pollution. The Coastal Region of Kenya has two rainy seasons with maxima in May and October, and a mean annual rainfall of 1204 mm (Obiero and Onyando, 2013). The region experiences fairly high average temperatures ranging between 26 and 32  $^{\circ}\text{C}$ , with a small diurnal range of between 7 and 9  $^{\circ}\text{C}$  (Obiero and Onyando, 2013). The creeks are subjected to

semi-diurnal patterns of tides averaging between 0.6 and 1.0 m during neap tide and 2.5 and 4.5 m during spring tide (Nguli *et al.*, 2006). Highly populated villages surround the creeks, such as Mushomoroni and Mikindani around Tudor Creek, Dongo Kaya, Dunga Nusa and Ngala around Port-Reitz Creek, and Kirepwe and Dabaso around Mida Creek (Maritim

*et al.*, 1999). Tudor Creek passes under Nyali Bridge and is bordered by Makupa causeway which dissects it into Tudor Creek to the east and Port-Reitz to the west (Kitheka *et al.*, 1999). The Kibarani dumpsite at Makupa station lies within Port-Reitz. The channels are fringed by mangrove forests, mainly *Rhizophora mucronata* Lam and *Avicennia marina* Vierh.

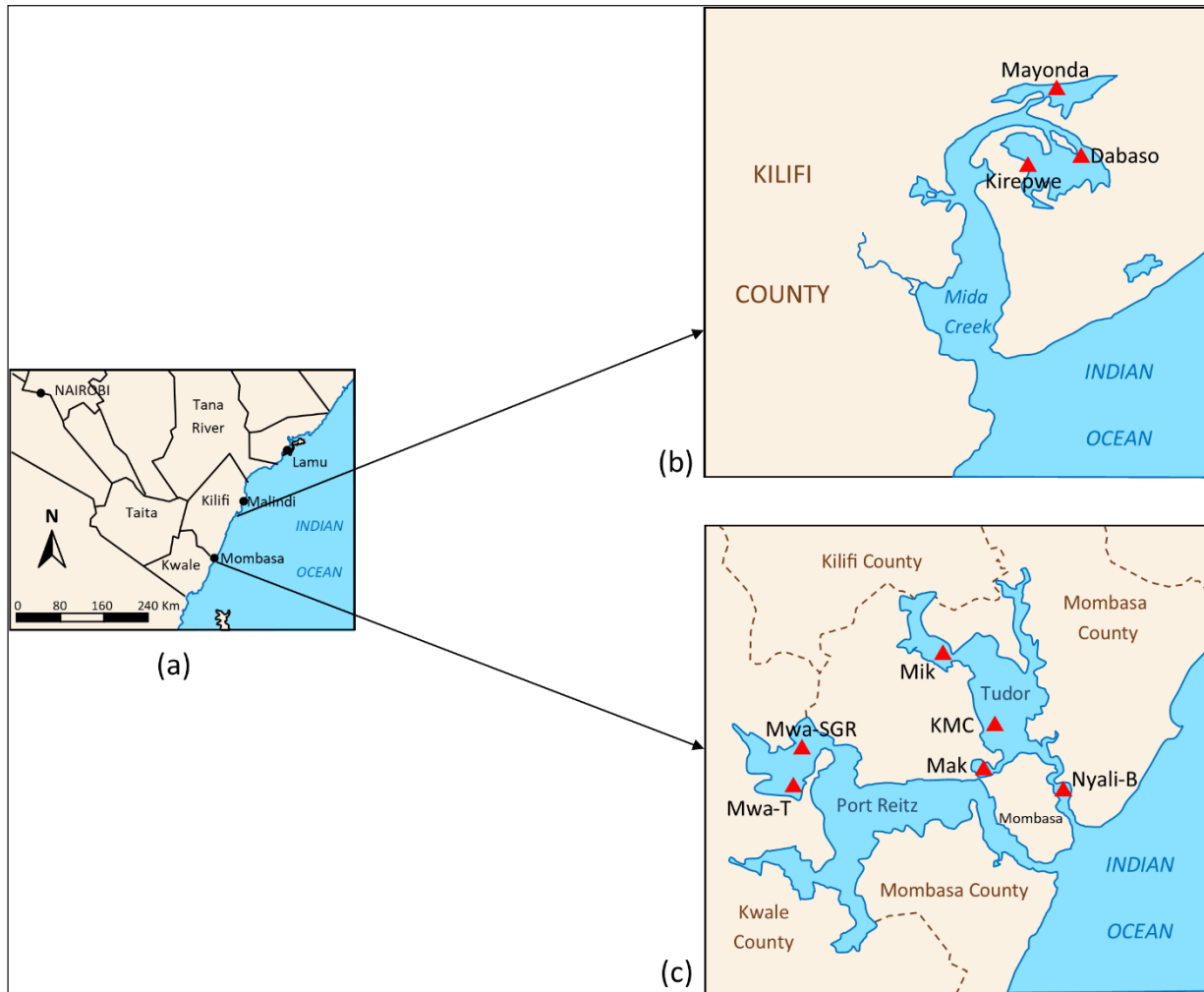


Figure 1. Map of Kenya showing the sampling sites and stations (Table 1). a) Kenya Coastal region; b) Mida Creek; c) Mombasa Island with Tudor and Port-Reitz creeks.

*et al.*, 2016). Rapid urbanization and high population growth have led to the development of informal settlements around the Coast General Hospital and Kenya Meat Commission near Tudor Creek (Okuku *et al.*, 2011).

Port-Reitz Creek receives freshwater from the Mwaché, Cha Shimba, and Mwambone rivers while Tudor Creek is fed by two main seasonal rivers, Kombeni and Tsalu, which arise from around Mariakani town, 32 km northwest of Mombasa (Kitheka

Mida creek, located on the Kenyan north coast, generally has gentle tidal currents (Kitheka, 1998). The constricted narrow entrance, sills and rough bottom generate modified currents that show significant spatial-temporal variations (Kitheka, 1998). The speed of currents at the entrance can be high, reaching 2.0 ms<sup>-1</sup> during spring tide. At low tide, currents are barotropic with minor deviations with changing tidal elevation. In the main creek channel, the flow is flood-dominated compared to the backwater region (Kitheka, 1998). Next to Sudi Island the tides are asymmetrical

Table 1. Sampling sites and GPS locations of sampling sites and stations.

Site	Station	Southing	Easting
Tudor	Mikindani (Mik)	4° 41' 51"	39° 21' 12"
	Nyali Bridge (Nyali-B)	4° 2' 48.1"	39° 40' 27.4"
	Kenya Meat Commission (KMC)	4° 1' 34.7"	39° 38' 47.5"
Port-Reitz	Makupa (Mak)	4° 2' 16.5"	39° 38' 50.1"
	Mwache Tsunza (Mwa-T)	4° 2' 47"	39° 40' 26.7"
	Mwache SGR (Mwa-SGR)	4° 1' 53.6"	39° 48' 47"
Mida	Kirepwe (Kir)	4° 3' 23.5"	39° 48' 47"
	Mayonda (May)	3° 19' 33.2"	39° 59' 47"
	Dabaso (Dab)	3° 20' 39.8"	39° 59' 12.8"

with ebb flow being dominant compared to flood flow (Kitheka 1998). Water conductivity is highest in August ( $53 \mu\text{S cm}^{-1}$ ) during the dry spell and low during the rainy season (Kitheka, 1998).

### Sampling strategy

At each of the three sites (Tudor, Port-Reitz, and Mida creeks) three stations were identified for sampling (Table 1). Sampling was done in January/February 2018 during a dry period and in September 2018 during the short rains to collect sea surface water for microplastic analysis. At each station, GPS coordinates were recorded (Table 1) using a handheld GPS (version Mitac mio168) and various physico-chemical parameters (water conductivity ( $\mu\text{S cm}^{-1}$ ), salinity (PSU) and temperature ( $^{\circ}\text{C}$ )) were measured using a multi parameter meter (YSI ProDSS).

### Surface water sampling

The microplastics were categorized into three different sizes (large size - 500-4999  $\mu\text{m}$ ; medium size - 249-500  $\mu\text{m}$ ; and small size - 20-249  $\mu\text{m}$ ). For the large and medium sizes, samples were collected from the surface water by towing neuston nets (500 and 250  $\mu\text{m}$  pore sizes) fitted with a flowmeter for 10 min per tow according to Hidalgo-Ruz *et al.* (2012). Surface water was sampled in triplicate for each station keeping nets as close to the surface as possible in order to capture any MPs in the water surface. The large size net mouth area was 0.2  $\text{m}^2$  while that of the medium size was 0.07  $\text{m}^2$ . The boat moved at a speed between 0.5-1.5 knots, sampling between 525.5– 1329.2  $\text{m}^3$  of water for the large net size and 177.1– 550.2  $\text{m}^3$  for the medium net size. For the small size MPs, 50 litres of seawater was drawn with a metal bucket and filtered

through a 20  $\mu\text{m}$  neuston net. All the sampling was replicated three times for each station. Material on the net was rinsed into glass sample bottles using sieved seawater and the bottles were corked with aluminium foil-lined lids. The samples were transferred to the laboratory and stored in a refrigerator at  $-6^{\circ}\text{C}$  awaiting processing. To minimize contamination in the field, hand gloves were worn throughout, glass or metal equipment used, and sample bottles covered with aluminium lined lids immediately after filling. Samples of towing gear material were examined under a microscope at 40x magnification for microplastics, and any similar microplastics in the water samples were not included in the total counts.

### Laboratory analysis

#### Quality control check

Sample processing and analysis were done in a clean room with negative air flow and limited foot traffic. Microplastic contamination through exposure to air was reduced by covering samples with aluminium foil and glass covers, the use of distilled water-rinsed glassware and metal equipment (Liebezeit and Liebezeit, 2014). The working surface was thoroughly cleaned with 70 % ethanol on non-shedding paper three times and allowed to dry before use (Cole *et al.*, 2014). A cotton laboratory coat was worn over natural or synthetic fibre clothes throughout. Hand gloves were used throughout the sample processing and analysis period. Sample fibres from clothing, and any potential contaminants from ropes and mesh screens were analysed alongside the surface water samples by setting up blanks (1 blank per three samples analysed). A dampened filter paper (30 mm diameter, Whatman No. 1) (Courtene-Jones *et al.*,

2017) was placed in a petri dish and left exposed during the processing and analysis period. The counts per blank were subtracted from the total count in each sample to correct ground contamination.

### Microplastic extraction process

**Sieving:** The samples of the large size were sieved through 5000  $\mu\text{m}$  (to remove MPs sizes larger than 5 mm) and collected on 500  $\mu\text{m}$  sieves to obtain microplastics between 500 and 4999  $\mu\text{m}$ . Materials on the 500  $\mu\text{m}$  sieve were retained for further analysis. The samples for the medium size were sieved through 500  $\mu\text{m}$  and collected onto a 250  $\mu\text{m}$  sieve to remove particles above 500  $\mu\text{m}$ . The material on the 250  $\mu\text{m}$  sieve was retained for further analysis. The 20  $\mu\text{m}$  samples were sieved using the 250  $\mu\text{m}$  and collected onto a 20  $\mu\text{m}$  sieve. The material from the 250  $\mu\text{m}$  sieve was discarded while that on 20  $\mu\text{m}$  sieve was retained for further analysis.

**Digestion:** The sieved samples of different size categories were digested in 50 ml 10 % Potassium Hydroxide (KOH) at 60 °C for fourteen hours to remove organic matter (Lusher *et al.*, 2017, modified protocol). After 14 hours, the digested samples were then sieved through the respective sieve sizes (500, 250 and 20  $\mu\text{m}$ ), thoroughly rinsed with distilled water, and transferred to individual glass beakers using distilled water. The samples were then filtered through a vacuum pump fitted with a cellulose nitrate membrane (millipore HA of 0.8  $\mu\text{m}$ ). The membrane filters were placed in a membrane dish-holder, covered and dried at 40 °C for 12 hours (modified protocol) after which the samples were ready for microplastic enumeration and characterisation.

### Microplastic enumeration and characterisation

The membrane filters were examined under a dissecting microscope at 40 x magnification as described by Hidalgo-Ruz *et al.* (2012) and microplastics confirmed using the hot needle test as outlined by Devriese *et al.* (2015). Further confirmation was done by observing particles under a stereomicroscope while prodding them with tweezers. Plastic particles sprung on prodding while non-plastic particles broke. Sand and salt crystals broke with a glass sound when prodded and were pushed aside. Under a stereomicroscope, the MPs were characterised as fibre (thread-like, microfibrils, filaments or strands), fragments (irregular shaped particles, crystals, fluffs or granules) and films (sheet-like soft fragments) according to Hidalgo-Ruz *et al.* (2012), and their colour noted.

### Data analyses

Data was processed using the Statistics and Data (STATA) version 15. The data was checked for normality using the Shapiro-Wilk W test for normality. Since all the three sets of data were not normally distributed, the data was log transformed. Both the large size and small size microplastic data became normally distributed while the medium size did not achieve normality. Thus, for testing for significant differences, ANOVA was used for the data on large and small size, while a non-parametric test (Kruskal-Wallis) was used for the data on the medium size microplastics. The total mean concentration and the concentrations of the different shapes and colours were assessed between sites (Tudor, Port-Reitz and Mida creeks) and between stations in each of the sites. The tests were considered significant at  $p < 0.05$ .

## Results

### Physical factors

The physical factors of the surface water within the creeks did not vary significantly between seasons and sites ( $p > 0.05$ ). Surface water temperature was relatively low with Tudor having a mean of  $23.6 \pm 0.7$  °C, Port-Reitz  $21.9 \pm 0.8$  °C and Mida  $22.2 \pm 0.9$  °C. Salinity was almost similar in all the sites with Tudor recording a mean of  $34.7 \pm 0.1$  PSU, Port-Reitz  $34.5 \pm 0.1$  PSU and Mida  $34.4 \pm 0.1$  PSU. Similarly, conductivity was almost the same across sites with Tudor having  $55810.1 \mu\text{S cm}^{-1}$ , Port-Reitz  $55985.1 \mu\text{S cm}^{-1}$ , and Mida  $55682.1 \mu\text{S cm}^{-1}$ .

### Small Size (20-249 $\mu\text{m}$ ) microplastics category

The overall ( $\pm$ SE) mean MPs concentration of the small size was  $2897.7 \pm 232$  microplastic particles per cubic meter ( $\text{mp m}^{-3}$ ) of water. Mean MPs concentrations were  $3364 \pm 431 \text{ mp m}^{-3}$  in the first sampling campaign and  $2534 \pm 223 \text{ mp m}^{-3}$  in the second, but were not significantly different ( $p > 0.05$ ). The mean concentrations were high across sites averaging  $3161.3 \pm 363.7 \text{ mp m}^{-3}$  in Tudor,  $2883.3 \pm 485.4 \text{ mp m}^{-3}$  in Port-Reitz, and  $2523.3 \pm 211.8 \text{ mp m}^{-3}$  in Mida, but the difference between sites was not significant (ANOVA:  $F_{2,45} = 0.52$ ;  $p$ -value = 0.6).

There was no significant difference in the concentrations between stations (ANOVA:  $F_{8,39} = 1.8$ ;  $p$ -value = 0.1). Mikindani in Tudor averaged  $4520 \pm 425.7 \text{ mp m}^{-3}$ , Makupa in Port-Reitz averaged  $3736.7 \pm 893 \text{ mp m}^{-3}$ , Mwache-Tsunza in Port Reitz averaged  $2040 \pm 311.7 \text{ mp m}^{-3}$ , and Dabaso in Mida averaged  $2100 \pm 177.8 \text{ mp m}^{-3}$  (Table 2).

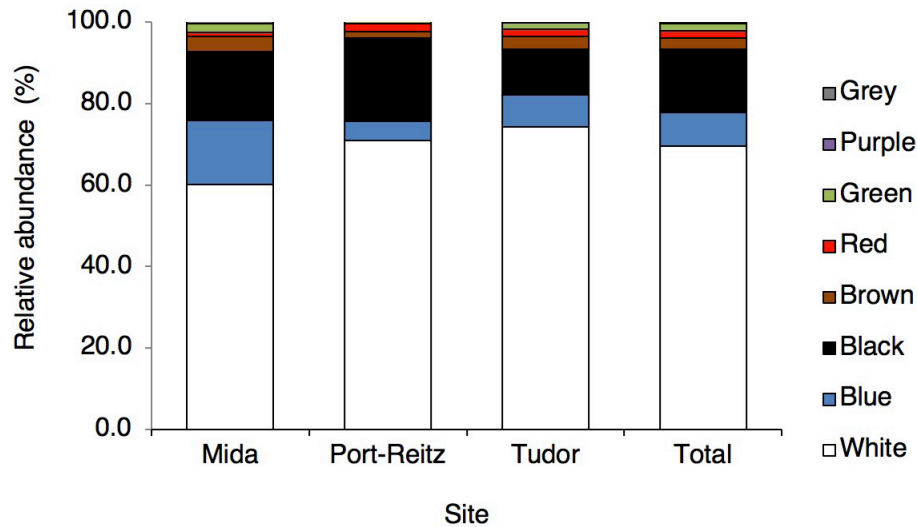


Figure 2. Mean percentage proportions of microplastic particles of different colours in the small size category in different sites.

Three categories of MPs based on shape were encountered in the surface water identified as fibres, fragments and films. Generally, in the small size MPs category, fibres were the most abundant ( $2703 \pm 226 \text{ mp m}^{-3}$ ) accounting for 93 %, followed by fragments ( $164.6 \pm 20.4 \text{ mp m}^{-3}$ ) accounting for 6 %, then films ( $33.5 \pm 9.2 \text{ mp m}^{-3}$ ) accounting for only 1 %, and the differences were statistically significant (ANOVA:  $F_{2,45} = 5.61$ ;  $p\text{-value} = 0.01$ ).

There was no significant difference ( $p > 0.05$ ) in the concentration of MPs categories between sites. In Tudor fibres averaged  $2931.7 \pm 358.5 \text{ mp m}^{-3}$ , Port-Reitz averaged  $2716 \pm 474.4 \text{ pm m}^{-3}$  and Mida averaged  $2340.8 \pm 186.1 \text{ mp m}^{-3}$ . Fragments in Tudor averaged  $197.8 \pm 31.9 \text{ pm m}^{-3}$ , Mida averaged  $176.7 \pm 39.8 \text{ pm m}^{-3}$  and Port-Reitz averaged  $123.3 \pm 146.3 \text{ pm m}^{-3}$ . The mean concentration of films was significantly higher ( $\text{Chisq}_{2,41} = 8.5$ ,  $p\text{-value} = 0.01$ ) in Port-Reitz ( $53.3 \pm$

Table 2. Mean concentration ( $\text{m}^{-3}$ ) of the different microplastics of the small size in different stations.

Site	Station	Total MPs	Fiber	Fragment	Film
Mida	Dabaso	$2100 \pm 177.8$	$1966.7 \pm 225.2$	$126.7 \pm 67.7$	$6.7 \pm 6.7$
	Kirepwe	$2776.7 \pm 391.3$	$2515 \pm 342.4$	$253.3 \pm 58.3$	$8.3 \pm 8.3$
	Mayonda	$2440 \pm 180.4$	$2366.7 \pm 155.1$	$73.3 \pm 29.1$	$0 \pm 0$
	Makupa	$3736.7 \pm 893$	$3575 \pm 867.7$	$146.6 \pm 81.6$	$25 \pm 8.9$
Port Reitz	Mwache-SGR	$2873.3 \pm 1105$	$2758 \pm 1081$	$131.6 \pm 47.2$	$3.3 \pm 3.3$
	Mwache-Tsunza	$2040 \pm 311.7$	$1816 \pm 255$	$91.7 \pm 53.9$	$131.3 \pm 57$
	KMC	$2328.3 \pm 658$	$2180 \pm 651.9$	$113.3 \pm 68.4$	$35 \pm 13.6$
Tudor	Mikindani	$4520 \pm 425.7$	$4245 \pm 439.1$	$245 \pm 33.8$	$30 \pm 11$
	Nyali-Bridge	$2636.7 \pm 415.1$	$2370 \pm 414.6$	$235 \pm 49.0$	$31.7 \pm 8.7$
Total		$2897.7 \pm 232$	$2703.3 \pm 226$	$164.6 \pm 20.4$	$33.5 \pm 9.2$
F		1.81	1.81	0.94	1.93
Df		8	8	8	8
$p\text{-value}$		0.1038	0.103	0.5	0.09



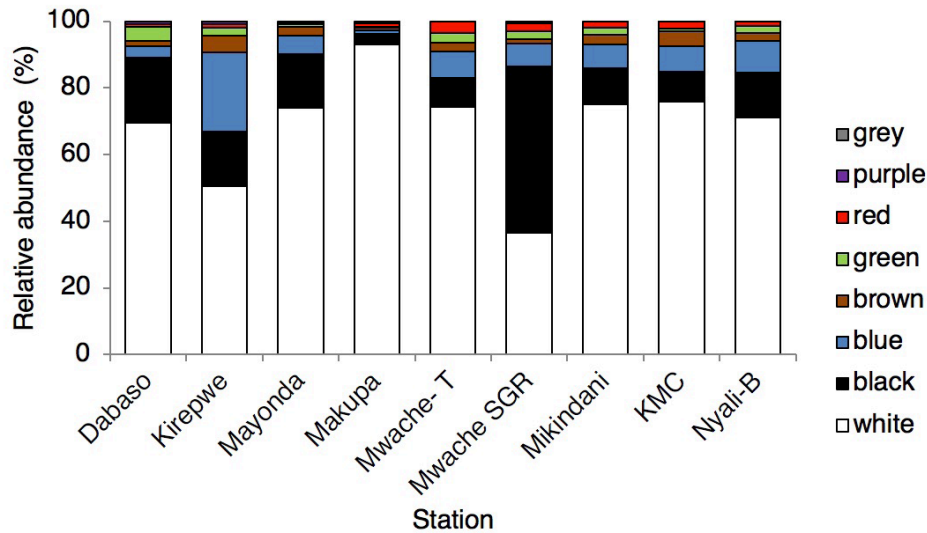


Figure 3. Mean percentage proportions of microplastic particles of different colours in the small size category in different stations.

22.8 mp m<sup>-3</sup>) compared to Tudor (32.2 ± 6.1 mp m<sup>-3</sup>), and Mida (5.8 ± 4.4 mp m<sup>-3</sup>) (Table 2).

The mean concentration of MPs categories did not vary significantly (p > 0.05) between stations (Table 2). Mikindani averaged 4245 ± 437.1 pm m<sup>-3</sup> fibres, Makupa averaged 3575 ± 867.7 pm m<sup>-3</sup>, while Dabaso averaged 1966.7 ± 225.2 mp m<sup>-3</sup>, and Mwache-Tsunza averaged 1816 ± 255.6 pm m<sup>-3</sup>. On the other hand, fragments were most abundant in Kirepwe averaging 253.3 ± 58.3 mp m<sup>-3</sup>, Mikindani averaged 245 ± 33.8 mp m<sup>-3</sup> and Nyali-Bridge averaged 235 ± 49.0 mp m<sup>-3</sup>, while films were most abundant in Mwache-Tsunza averaging 131.7 ± 57.5 mp m<sup>-3</sup> (Table 2).

Eight colours of MPs were encountered among the small size MPs. Overall, the concentrations were significantly different (p < 0.05) and white colour was predominant (2015.2 ± 203.6 mp m<sup>-3</sup>) accounting for 69.6 %, followed by black (453.5 ± 159.7 mp m<sup>-3</sup>) 15.6 %, blue (239.6 ± 35.6 mp m<sup>-3</sup>) 8.2 %, brown (76.9 ± 15.2 mp m<sup>-3</sup>) 2.7 %, green (53.3 ± 10.2 mp m<sup>-3</sup>) 1.8 %, red (48.5 ± 9.6 mp m<sup>-3</sup>) 1.7 %, purple (6.3 ± 3.4 mp m<sup>-3</sup>) 0.2 %, and finally grey (4.4 ± 2.1 mp m<sup>-3</sup>) 0.2 %. By site, the mean concentration of MPs colours did not differ significantly (p < 0.05) but white in Tudor averaged 2348.3 ± 312 mp m<sup>-3</sup>, accounting for 74 %, Port-Reitz averaged 2012 ± 424 mp m<sup>-3</sup> (71 %), and Mida averaged 1519 ± 169.7 mp m<sup>-3</sup> (60 %) (Fig. 2). The mean concentration of MPs of black colour averaged 348 ± 81.1 mp m<sup>-3</sup> (20.2 %) in Port-Reitz, while blue averaged (250.6 ± 36.4 mp m<sup>-3</sup>) (17 %) in Mida (Fig. 2).

By station, the mean concentrations for white and blue were significantly different (p < 0.05). Makupa (3475 ± 934 mp m<sup>-3</sup>) had the highest mean concentration for white accounting for 93 %, while Mwache-SGR (1050 ± 468.3 mp m<sup>-3</sup>) had the lowest accounting for 36.5 %. Blue MPs were most abundant in Kirepwe (660 ± 160.7 mp m<sup>-3</sup>) accounting for 23.8 %. Mwache-SGR recorded a mean concentration of 1431.7 ± 1256.4 mp m<sup>-3</sup> for black MPs accounting for 49.9 %, while Makupa recorded a low concentration accounting for 3.2 % (Fig. 3).

#### Medium size (250- 449µm) microplastics category

The overall mean concentration of the medium microplastics was generally low at 3.1 ± 0.4 mp m<sup>-3</sup> of water, compared to the small size category. The mean MPs concentrations were significantly different (Chisq<sub>1</sub> = 29.3, p-value < 0.01) between the two sampling campaigns, at 1.1 ± 0.2 mp m<sup>-3</sup> in the first sampling campaign and 4.5 ± 0.4 mp m<sup>-3</sup> during the second. Mida recorded the highest mean concentration (4.2 ± 0.58 mp m<sup>-3</sup>), followed by Port-Reitz (2.7 ± .71 mp m<sup>-3</sup>) and finally Tudor (2.6 ± .45 mp m<sup>-3</sup>). There was a significant difference (Chisq<sub>2,45</sub> = 6.4, p-value = 0.041) in mean MPs concentration between sites. Post hoc analysis showed that the mean concentration for Mida differed significantly from that of Tudor and Port-Reitz while the latter two sites were not different. By station, the mean concentration of microplastics was highest in Dabaso (6.2 ± 0.53 mp m<sup>-3</sup>), while the lowest mean concentration was recorded in Mwache-Tsunza (1.0 ± 0.2 mp m<sup>-3</sup>) (Table 3). The Kruskal Wallis test showed a

Table 3. Mean concentration ( $\text{m}^{-3}$ ) of the different microplastics of medium size in the different stations.

Site	Station	Total MPs	Fiber	Fragment	Film
	Dabaso	6.2 ± 0.5a	5.8 ± 0.5	0.2 ± 0.1	0.14 ± 0.1
Mida Creek	Kirepwe	2.7 ± 0.6bcd	2.5 ± 0.6	0.1 ± 0.1	0.09 ± 0
	Mayonda	5.5 ± 0.3a	5.2 ± 0.3	0.1 ± 0.0	0.22 ± 0.1
	Makupa	1.8 ± 0.6bcd	1.6 ± 0.5	0.2 ± 0.1	0.05 ± 0.0
Port Reitz	Mwache-Tsunza	1.0 ± 0.2cd	0.9 ± 0.2	0.1 ± 0.0	0 ± 0
	Mwache-SGR	5.4 ± 1.6a	4.5 ± 1.4	0.8 ± 0.2	0.07 ± 0.0
	KMC	2.3 ± 0.7bcd	2.1 ± 0.7	0.1 ± 0.1	0.1 ± 0.0
Tudor Creek	Mikindani	3.6 ± 1abc	2.9 ± 0.8	0.7 ± 0.3	0.09 ± 0.1
	Nyali-bridge	1.7 ± 0.4bcd	1.5 ± 0.3	0.2 ± 0.1	0.04 ± 0.0
	Total	3.1 ± 0.4	2.7 ± 0.3	0.3 ± 0.1	0.08 ± 0.0
	F	20.866	20.686	17.953	18.912
	Df	8	8	8	8
	<i>p</i> -value	0.008	0.008	0.02	0.02

Mean within columns followed by the same letters are not statistically different (Tukey test,  $p \leq 0.05$ )

statistically significant difference in mean microplastic concentration between stations (ANOVA:  $\text{Chisq}_{8,41} = 20.87$ ;  $p = 0.008$ ) (Table 3).

The mean concentration of medium size microplastic fibres was higher ( $2.7 \pm 0.3 \text{ mp m}^{-3}$ ) compared to fragments ( $0.3 \pm 0.1 \text{ mp m}^{-3}$ ) and films ( $0.1 \pm 0.01 \text{ mp m}^{-3}$ ). The mean concentration of fibres was significantly different ( $\text{Chisq}_{2,45} = 7.7$ ,  $p$ -value = 0.02;  $\text{Chisq}_{2,39} = 11.8$ ,  $p$ -value = 0.002, respectively), and higher in Mida Creek ( $4 \pm 0.6 \text{ mp m}^{-3}$ ) compared to Port-Reitz ( $2.3 \pm 0.6 \text{ mp m}^{-3}$ ) and Tudor ( $2.2 \pm 0.4 \text{ mp m}^{-3}$ ) creeks where the latter sites were not significantly different. The mean concentration of fragments was higher in Port-Reitz ( $0.4 \pm 0.4 \text{ mp m}^{-3}$ ) and Tudor creeks ( $0.3 \pm 0.1 \text{ mp m}^{-3}$ ) compared to Mida Creek ( $0.1 \pm 0 \text{ mp m}^{-3}$ ) and the difference was significant ( $\text{Chisq}_{2,45} = 7.7$ ,  $p$ -value = 0.02;  $\text{Chisq}_{2,39} = 11.8$ ,  $p$ -value = 0.002, respectively). The mean concentration of films was relatively low across sites and did not show significant differences ( $p > 0.05$ ).

Within the stations, fibres were most abundant in Dabaso ( $5.8 \pm 0.1 \text{ mp m}^{-3}$ ), Mayonda ( $5.2 \pm 0.3 \text{ mp m}^{-3}$ ) and Mwache SGR ( $5.4 \pm 1.6 \text{ mp m}^{-3}$ ) and lowest in Mwache-Tsunza ( $0.9 \pm 0.2 \text{ mp m}^{-3}$ ). Fragments were most abundant in Mwache-SGR ( $0.8 \pm 0.2 \text{ mp m}^{-3}$ ) and lowest in Kirepwe, Mayonda, Mwache-Tsunza and KMC, at  $0.1 \pm 0.03 \text{ mp m}^{-3}$ , while films were highest in

Mayonda ( $0.2 \pm 0.1 \text{ mp m}^{-3}$ ) and none were encountered in Mwache-Tsunza ( $0 \text{ mp m}^{-3}$ ). The differences in the mean concentrations of fibres, fragments and films between stations were significant (ANOVA:  $\text{Chisq}_{8,39} = 20.69$ ,  $p$ -value = 0.008;  $\text{Chisq}_{8,29} = 17.95$ ,  $p$ -value = 0.02;  $\text{Chisq}_{2,29} = 18.9$ ,  $p$ -value = 0.02) respectively (Table 3).

Unlike the small sized MPs, only six colours were encountered in this size with purple and grey totally missing. Overall, white colour was most abundant ( $2.1 \pm 0.3 \text{ mp m}^{-3}$ ) followed by black ( $0.5 \pm 0.1 \text{ mp m}^{-3}$ ) and blue ( $0.3 \pm 0.1 \text{ mp m}^{-3}$ ). By site, the percentage proportion of the white MPs was almost the same across the sites at 70 % (Fig. 4) with that of MPs of other colours being only 30 %. Green colour was encountered in small proportions in Mida Creek while it was nearly missing in the other two sites (Fig. 4).

#### Large size (500 $\mu\text{m}$ - < 5 mm) microplastics category

The concentrations of the large size MPs category were generally less than 1 MPs particle per  $\text{m}^3$  in all the sites. Overall, mean concentration of the large size MPs was  $0.6 \pm 0.1 \text{ mp m}^{-3}$  of water. There was a significant difference ( $F_{1,46} = 41.82$ ,  $p < 0.05$ ) in the MPs concentrations between sampling periods. During the first sampling campaign the overall concentration was

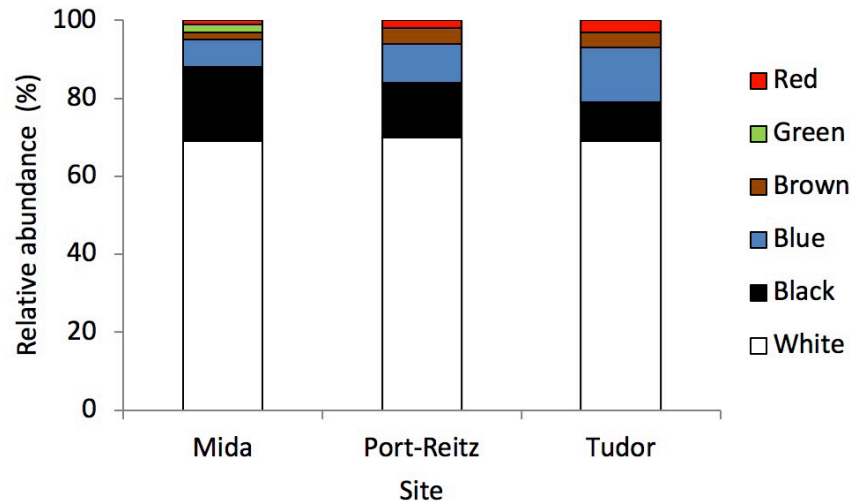


Figure 4. Mean percentage proportions of microplastic particles of different colours in the medium size category in different sites.

$0.33 \pm 0.04$  mp  $m^{-3}$  while during the second the concentration was  $0.80 \pm 0.05$  mp  $m^{-3}$  of water. Mida had the highest mean concentration ( $0.8 \pm 0.1$  mp  $m^{-3}$ ), followed by Port-Reitz ( $0.6 \pm 0.1$  mp  $m^{-3}$ ), then Tudor ( $0.5 \pm 0.1$  mp  $m^{-3}$ ). The Kruskal Wallis test showed significant difference ( $F_{2,45} = 4.97$ ,  $p$ -value = 0.01) in mean microplastic concentration between sites. The Post hoc test showed that the mean concentration in Mida was different from that in Port-Reitz and Tudor but the latter two were not different.

## Discussion

The presence of MPs in marine surface waters along the Kenyan Coast clearly provides evidence for widespread MPs pollution in these waters. Seasonal changes affect MPs distribution in surface water differently. The average monthly rainfall in the January/February sampling period was low (6.1-9.8 mm), and relatively high (36.3 mm) in September 2018 (Kenya Meteorological Department, 2018). Mean concentrations of  $3365.1 \pm 431.2$  and  $2539.3 \pm 223.5$  mp  $m^{-3}$  were encountered in the first and second sampling seasons respectively, but the concentrations were not significantly different ( $p > 0.05$ ). The lack of significant difference between the sampling campaigns may mean that land-based sources may not be the major sources of MPs in the creeks with little new input through runoff or wind (Veerasingam *et al.*, 2016). This could be attributed to the calm ocean conditions with low wind, wave intensity and similarity in physico-chemical factors (Maes *et al.*, 2017) that prevailed during the sampling seasons leading to uniform distribution of MPs in the sites. High salinity of 34.2 ppt during sampling periods could have increased water density making MPs buoyant and resulting in high concentrations in the surface waters.

Microplastics recovery from different studies are different due to varied sampling protocols adopted. Lusher *et al.* (2015) recovered between 0.02 and 100 particles  $m^{-3}$  from the Northeast Atlantic Ocean by pumping and sieving surface water with a 250  $\mu m$  sieve. Lucia *et al.* (2014) recovered 0.11-119 MPs particles  $m^{-2}$  from surface water in the Mediterranean Sea using a 333 $\mu m$  manta net. Kosore *et al.* (2018) recovered an average of 110 MPs particles  $m^{-3}$  in the Indian Ocean along the Kenyan Coast in the central EEZ by sieving water samples through a 250  $\mu m$  stainless steel mesh. In this study, an estimated average of 2897 MPs particles  $m^{-3}$  of the small size MPs were recovered by sieving surface water samples through a 20  $\mu m$  net. These levels are high as expected due to the high population densities and the many anthropogenic activities around the creeks. The recoveries of MPs from 250  $\mu m$  and 500  $\mu m$  neuston nets were very low estimated at 3.1 MPs and  $<1$  MPs particle  $m^{-3}$  of water respectively. This points to the possibility of there being much lower concentrations of large and medium MPs particles in the water surface compared to the small size MPs. Thus, the manta trawl with 300  $\mu m$  mesh size that has been proposed for sampling of MPs in the water column (Viršek *et al.*, 2016) and used in many studies (Tamminga *et al.*, 2018) may be underestimating the MPs in the water column (Dai *et al.*, 2018). On the other hand, there is the possibility that the effect of currents generated by towing the nets could be causing the MPs to be pushed out of the nets through the large mesh size. Kang *et al.* (2015) found that MPs less than 2 mm were two orders of magnitude higher in concentration in a hand net compared to the trawl.

In this study MPs concentrations of three size categories (large, medium and small MPs) were estimated using different net mesh sizes and sampling strategies. Although the small size MPs samples were collected by scooping water using a bucket, the concentrations were several orders of magnitude higher compared to the medium and large sizes. The medium and large size MPs samples were collected by towing plankton nets for ten minutes where less than 10 MPs and less than 1 MPs particles per cubic meter were recovered, respectively. However, owing to the heterogeneous distribution of MPs on the sea surface (Eriksen *et al.*, 2018) towing nets on the sea surface helps to overcome the heterogeneity. Owing to the great contrast in mean concentrations of MPs between the small size and the others, it may be critical to test the efficiency of bulk sampling vis-a-vis use of towed plankton or manta trawl nets for all sizes of MPs and compare the recovery. The challenge of heterogeneity of MPs distribution can be overcome by taking several replicate samples at different points. It is also worth noting that bulk sampling can take much less time compared to towing of nets and thus is less costly in terms of sea time.

Some of the risks associated with marine microplanktons is the incorporation of the particles and the adsorbed chemicals into the food web through trophic transfer (Setälä *et al.*, 2018). The smaller the MPs particle the more the likelihood of being ingested by marine animals and being transferred in food webs (Botterell *et al.*, 2019). It is therefore prudent that assessment of MPs considers those less than 300µm (normal size of the manta trawl net mesh size) as well. Small MPs have a large surface area and can thus adsorb much more POPs which accumulate on the MPs and are transferred to many marine organisms (Hermabessiere *et al.*, 2017) where they could become toxic at high levels.

Microplastic categories by shape were similar to those found in other regions of the world with fibres being the most dominant category (>90%) (Dai *et al.*, 2018). This could be as a result of release from fishing nets and ropes or washing of synthetic textiles (Napper and Thompson, 2016), while few were fragments and films from packaging material (Kowalski *et al.*, 2016).

A greater proportion of MPs in this study were white, followed by coloured MPs. This is in line with earlier research findings in the Hawaii islands (Alan and James, 2016), the North Pacific Ocean and Bering Sea (Boerger *et al.*, 2010). Colour is used for preliminary

identification of MPs. Plastic pellets and polypropylene (PP) pellets are transparent (Ismail *et al.*, 2009), high density polyethylene (PE) pellets white, low density PE opaque, while ethyl vinyl acetate corresponds to clear and almost transparent pellets (Ismail *et al.*, 2009). However, MPs colour inherited from their plastic products can change due to weathering. Currently, there is no scheme for colour designation for plastic litter hindering its use in identifying the source of plastics in the marine environment. The results from this study imply that plastics in the Indian Ocean waters along the Kenyan coast are from sea-based activities such as fishing and tourist activities and could be transported from distant areas.

Microplastics were found in all the sites including Mida Creek, a National Marine Reserve thought to be safe from pollution by industrial effluents, sewage disposal and fishing activities. The relatively high concentration of MPs in this site suggests that the source may not necessarily only be from activities on the adjacent land. The higher concentration of the large size microplastics category in Mida compared to Tudor and Port-Reitz suggests that the microplastics were entering the system close to their source and could mainly originate from the tourists to the Marine National Park, and the inhabitants of Dabaso village and Kirepwe Island, backing up findings from earlier research linking human population density and plastic pollution (Dai *et al.*, 2018). The human inhabitants release domestic effluent into the ocean and dispose off plastic waste which could be seen floating on the water surface (personal observation) thereby contributing to the pollution. This also suggests that plastic debris has not stayed within the creek waters for long as little degradation has occurred, probably due to the regular cleaning done to remove anthropogenic litter from the creek waters (personal observation). The trend of MPs distribution is similar to those observed for the Mediterranean Sea, the Northeast Pacific Ocean and the open ocean waters (Goldstein *et al.*, 2013; Cozar *et al.*, 2015). Extensive boat and dhow fishing activities go on in the creek waters (personal observation) which could be contributing to the high concentration of MPs in the waters.

Makupa in Port-Reitz had a high MPs concentration compared to other stations within the site. This could be attributed to the fact that Kibarani dumpsite is near Makupa where municipal waste has been dumped for many years (Eriksen *et al.*, 2014). Water flow within the station is limited hence MPs are not carried away by

ocean currents. High MPs levels have been linked to anthropogenic activities like aquaculture, fishing and coastal tourism in other parts of the world (Frere *et al.*, 2017; Dai *et al.*, 2018). Population density and the level of urbanization and waste infrastructure have also been linked to high accumulation of MPs in different regions of the world (Lebreton *et al.*, 2012; Pedrotti *et al.*, 2016). This could be the case with Port-Reitz Creek which is adjacent to suburban areas on the mainland which host oil refineries and housing estates and are surrounded by densely populated villages such as Dongo Kaya, Dunga Nusa, and Ngala (IAME, 2018). The relatively high concentration of MPs of small and medium size categories in Mwache-SGR in Port-Reitz could be attributed to Port activities as well as high population density. Mwache-Tsunza, also in Port-Reitz, has a high population density (IAME, 2018) but low MPs concentrations, probably because of flushing by the many channels such as the Mwache, Cha Shimba and Mwambone rivers, and frequent ocean waves and currents (Kitheka *et al.*, 1999).

Mikindani in Tudor is an outlying township on the mainland along the Nairobi highway within the heavy industrial areas at Changamwe and accommodates the working population who work in the Port of Mombasa, town centre and in the industries (IAME, 2018). Tudor creek is fed by two major seasonal rivers; Kombeni and Tsalu, which arise near the town of Mariakani (Kitheka *et al.*, 1999). The rivers collect surface runoff with plastic and other waste debris from the mainland and discharge them into the creek. Rapid urbanization has led to the development of informal settlements near the Coast General Hospital and Kenya Meat Commission (Okuku *et al.*, 2011) that may be adding to the MPs brought in by the seasonal rivers and ocean currents through the release of raw domestic waste contributing to the high MPs concentrations observed.

## Conclusion

The creeks along the Kenyan coast are highly polluted with microplastics of the 20  $\mu\text{m}$  - 250  $\mu\text{m}$  size range. Microplastics of the 250 $\mu\text{m}$  - 5000 $\mu\text{m}$  size range occur in low concentrations. Tudor Creek is more polluted with microplastics compared to Port-Reitz and Mida creeks. Makupa in Port-Reitz was the most polluted station, perhaps due to the Kibarani dumping site in the vicinity. Mida Creek which is located within a Marine National Park, is a protected environment considered as a control, but was also contaminated with microplastics.

Microplastics fibres were the most abundant in the creek surface waters accounting for over 90 %, followed by fragments and films accounting for around 10 %. The bulk of the microplastics recovered were white, suggesting that gear from fishing activities may be one of the main sources of MPs in the coastal waters.

The results of this study provide a baseline for future monitoring of the effect of the Kenya Government ban on single use plastic carriers of February 2017. Future assessments can be compared with these results to establish whether the ban is making a difference to the extent of MPs pollution in the coastal waters. Countries bordering the WIO and neighbouring Kenya are likely to be polluted with microplastics and together with other governments in the world should join and support the fight against plastic pollution in the oceans.

There is a need for a critical evaluation of plastic waste disposal policies in Kenya to curb the problem. The Kenyan Government should protect the ocean through legislation on plastic waste management; encourage the development of plastic recycling industries by availing capital to investors. Manufacturers should produce alternative packaging materials to plastics such as sisal bags. The Kenyan Government should also conduct mass education to create awareness on the dangers of MPs to marine ecosystems as well as human health and conduct frequent massive beach cleaning. Recycling of plastics could lead to a closed-loop system where plastics are continuously reused.

It is recommended that the recovery of MPs of all three sizes using the bulk sampling method be tested. Microplastic pollution along the Kenyan coast needs to be monitored to establish the effect of the 2017 ban on the production and use of light plastics. Finally, monitoring during the Northeast and Southeast Monsoon, when fishing activities are different along the Kenyan coast, needs to be conducted.

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