Journal of Agriculture and Ecology Research International

Volume 25, Issue 6, Page 127-139, 2024; Article no.JAERI.126893
ISSN: 2394-1073

Seasonal Abundance and Types of Microplastics in Surface Waters of River Sabaki Estuary, Kenya

Moses Kamau [a*], Mwakio Tole [a] and Simon Mbuvi Muti [b]

[a] *Department of Environmental Sciences, Pwani University, Kenya.*
[b] *Department of Agriculture, Pwani University, Kenya.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jaeri/2024/v25i6646

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/126893

Original Research Article

Received: 10/09/2024
Accepted: 13/11/2024
Published: 25/11/2024

ABSTRACT

Increased demand for plastics has resulted in the generation of plastic waste, which poses a threat to the environment in general, and ultimately the marine environment. Estuaries and deltas are the main filters of marine ecosystem pollutants from inland sources. There have been limited studies on temporal variations in microplastic (MP) pollutants in tropical estuaries of Africa. In 2022, a twelve-month sampling survey study was conducted at Sabaki river estuary, in Kenya. A bucket was used to collect water samples, that were sieved through a 225µm sieve. A stereo microscope was used to identify microplastics and their polymer confirmed using FTIR spectroscopy. Data analysis on seasonal difference in abundance of microplastics in surface waters was performed using Minitab software at $\alpha \leq 0.05$. The results indicated that the April-June (A-J) long rains season had significantly ($P \leq 0.05$) higher levels of MPs due to rainfall runoff, compared to other seasons, namely January –March (J-M), July-October (J-O) and November –December (N-D). The (J-M), (J-

**Corresponding author: E-mail: m.kamau@pu.ac.ke; moseskamau2@gmail.com;*

***Cite as:** Kamau, Moses, Mwakio Tole, and Simon Mbuvi Muti. 2024. "Seasonal Abundance and Types of Microplastics in Surface Waters of River Sabaki Estuary, Kenya". Journal of Agriculture and Ecology Research International 25 (6):127-39. https://doi.org/10.9734/jaeri/2024/v25i6646.*

O) and (N-D) seasons had similar levels of MPs, which were lower compared to those observed during (A-J) long rains season by 44.3%, 54% and 25% respectively, compared to the highest concentration of 264 MPs m^{-3} observed during the A-J season. Fragments type of MPs were higher during the wet season, while fiber type of MPs dominated during the dry season. Film and form type of MPs were least abundant. Seasons significantly ($P \leq 0.05$) influenced distribution of the different sizes of MPs. Small and medium sized category of MPs occurred and dominated during the dry season, while larger particles dominated during the wet season. Seven (7) differently colored MPs were observed during the study. White colored MPs were most prevalent (33%), followed by blue (23%), black (17%), brown (12%), yellow (5%), red (5%), and green (4%). Five types of plastic polymers were found in surface waters of river Sabaki estuary, namely polyethylene (PE), polypropylene (PP), polystyrene (PS), Polyethylene terephthalate (PET), and Acrylonitrile-butadiene-styrene (ABS).

Keywords: Micro-plastics; types; polymers; estuary.

1. INTRODUCTION

Plastic pollution and climate change are among the leading threats of our environment. Plastic products consume about 10% of global oil production, generating about 381 million tonnes of plastics annually. This is projected to quadruple by the year 2050 (Haas et al. 2022). Generation of plastic wastes, coupled with poor waste management, has led to accumulation of plastic wastes in terrestrial and marine environments (Ayeleru et al. 2020, Lebreton and Andrady 2019, Kibria et al. 2022). Of the 6,300 million tons of plastics ever produced, 79% are still in landfills and dumps sites, while about 12% have been incinerated, and only 9% have undergone recycling (Geyer 2020). In Kenya, over 92% of plastic waste generated is mismanaged, and only 8% is collected for recycling (Massa et al. 2024). Exposure of plastics to various weathering agents and processes such as ultra-violet (UV) light radiation results in fragmentation of these plastics into different sizes. These sizes include: mega (> 1m), macro (25-1000mm), meso (5-25mm), micro (< 5mm) and nano (< 1 µm) particles (Arp et al. 2021). Among these categories, micro-plastics (MPs) are the most abundant in the environment. Micro plastics (MPs) resulting from weathering process, are designated as secondary sourced MPs. However, there are purposefully produced MPs that are used as feed-stock for molding plastic items, air blasting in cleaning of surfaces and/or abrasives incorporated in body care products. These intentionally produced MPs such as nurdles, pellets, powders, and industrial scrubbers are denoted as primary MPs. Intentional use and accidental loss of primary MPs contributes to MPs pollution in the environment (Onyena et al. 2021).

About 10 million tonnes of plastics leak into the ocean each year. Currently, over 5,250 billion plastic particles are found in the marine environment, of which about 80 % emanates from inland sources. Micro-plastics are distributed in all aquatic compartments including sediments, seabed, riverbanks, water columns and surface waters (Onyena et al. 2021). Negative impacts associated with plastic pollution in aquatic ecosystems include: ingestion by aquatic organisms, release of toxic chemicals, and introduction of invasive and alien species (Onyena et al. 2021), while socio - economic hazards of MPs and plastic pollution include: reduced cultural and aesthetic values of aquatic ecosystems and loss of income from fishing, aquaculture and tourism (Kumar et al. 2021). Organisms living in aquatic ecosystems confuse MPs for their natural food, thereby ingesting MPs that results in physical abrasion and/or obstruction of the gastrointestinal tract, leading to reduced food intake (Au 2017, Lusher et al. 2017, Grigorakis et al. 2017). In addition, MPs have large surface area to volume ratio, and may adsorb toxic chemicals from polluted waters, especially in estuaries (Cássio et al. 2022). Consumption of toxins-laden MPs negatively affects physiological functions of the organisms with such effects as impairment of neurocognitive and cardiovascular systems. This compromises the immune system, fecundity, hormonal balance, memory and behavior of the organism (Lusher et al. 2017). Bio-magnification of these toxins among the higher trophic level predators which includes humans, has raised food safety concerns, especially among seafood consumers (Wang et al. 2019).

Rivers are the main sources of land sourced marine plastic pollution, as they receive runoff and effluent from their catchments (Marwick et al.

2018). However, in estuaries and deltas, the velocity of the waters decreases as a result of reduced gradient and interactions of fluvial flow with marine waters. The sluggishly flowing waters enhance MPs flocculation and biofouling, thus increasing MPs density and sedimentation. Ebb currents, coupled with fluvial flow result in flushing out of the MPs into the ocean. Therefore, estuaries may act as temporary storage or/and permanent burial sites for MPs (Horton et al. 2018). There has been limited studies and documentation on temporal variation of MPs pollution in tropical estuaries of Africa, despite their variability. It is in this regard that it was found necessary to assess variation of plastic pollution in Sabaki river estuary, given that it is the most polluted river in Kenya, and it discharges it's water in Ungwana bay, a rich fishing ground in Kenyan coastal marine waters (Munga et al. 2016, Kitheka 2016, Kitheka et al. 2018).

2. MATERIALS AND METHODS

2.1 Description of Study Site

Athi–Galana–Sabaki River is the second longest permanent river in Kenya after the Tana River, and flows toward Southern-Eastern Kenya, discharging its waters into the Indian Ocean just north of Malindi. The river catchment extends from Aberdare ranges in Central Kenya to the Northern slopes of Mt. Kilimanjaro. The total length of the river is about 390 km, with a drainage basin of about 69,930 km^2. The catchment covers about 12% of the land in Kenya, and generates 4% of runoff in the country. The river flow rate ranges between 0.5 ms^1 - 49 ms^1, with discharge rate of about 380- 600 m^3s^{-1} during March-June long rains season, and about 60-80 m^3s^{-1} during the short-rains (Kitheka and Mavuti 2016).

Fig. 1. Map of the study area and location of the sampling station

Sabaki estuary is located at longitude: 3.2ºS and latitude 40.15º E, about 10 Km North of Malindi town and it discharges its waters at Malindi Bay **(**Fig. 1). In its upper region, the Sabaki estuary measures between 250 to 300m wide, but widens to about 750 to 1000m at river mouth, within a short distance of 2.5 Km.

2.2 Study Period

Seasons within the River Sabaki estuary are well defined by the catchment rainfall pattern. Thus, data collected from Baricho river gauge of Sabaki river, for the year 2022 was used to categorize the dry and wet seasons. The two dry seasons were experienced between January-March (J-M) and July-October (J-O) respectively, while the long and short rains seasons were experienced between April-June (A-J) and November-December (N-D), respectively.

2.3 Water Sampling

Sampling of water was done from January to December 2022 (12 months). The samples were collected during low tides, to avoid sampling ocean salty waters. A 10-liter steel bucket was used to draw the water for sampling, and 100 liters of this water was sieved onsite, through a 225µm steel sieve, as described by Cox. The filtrates were then washed into glass jugs using ultra-filtered water, and the jugs closed using a metallic lid. In laboratory, samples were filtered through Whatman filter paper (0.7µm nominal). After filtration, the filter papers were submerged in glass jug containing 10 % Potassium hydroxide (KOH) solution for 24 hours, to digest the organic materials, and then oven dried for 3 hours at 40º C. MPs from each filter paper were identified and counted using a microscope, and their polymers confirmed using FTIR spectroscopy (Lusher et al. 2017).

3. RESULTS

3.1 Abundance of MPs in River Sabaki Estuary Surface Waters

For quality control, MPs contamination that occurred during fields sampling was about 0.003% MPs of particles collected from a container left open during sampling and about 0.001% MPs, of particles collected during laboratories operation This contamination was considered negligible during the quantification of MPs in the water and sediment samples from river Sabaki estuary. Considering seasonal variations of MPs, two peaks of abundance of MPs were observed. The first peak occurred between the months of April to June (the long rain season), while the lower peak occurred during the months of November to December (the short rain season) (Table 1). A total of 1,574 MPs particles were extracted from surface waters.

Between these two peaks there were low levels of MPs in surface waters observed during the dry seasons (J-M and A-O). In river Sabaki basin there are two main seasons that were considered to influence the abundance of MPs in surface waters of the estuary. The findings indicated that seasons had significant effect on abundance of MPs in surface waters ($P \leq 0.05$) (Table 1). The A-J long rain season had significantly ($P \leq 0.05$) higher levels of MPs compared to other seasons, namely J-M, J-O, and N-D that had similar levels of MPs (Table 1). During J-M, J-O, and N-D seasons, abundance of MPs was lower by 44.3%, 54% and 25% respectively, from the highest concentration of 264 MPs m^{-3} observed during the A-J season.

3.2 Types of MPs in River Sabaki Estuary Surface Waters

The following characteristics of MPs found in surface waters were investigated: type, shape, size, color and polymer composition. The types of MPs found in river Sabaki estuary surface waters were categorized as: fragments, foam, filaments and fiber based on their morphology. All types of MPs namely, fiber, film, foam, and fragments were found during all the four seasons (J-M, A-M, J-O and N-D) (Fig. 2).

During the J-M dry seasons, the hierarchal order of MPs-types found in surface waters was: Fiber (63%), film (13%), fragments (12%) and foam (12%), respectively. During the J-O dry season, the order was: fiber (90%), fragments (3%), foam (1%) and film (1%), respectively (Fig. 2). During the A-J long rains, the order from the most abundant to the least abundant MPs-type was; fragments (60%), film (20%), fiber (14%) and foam (6%). During the N-D short rains, the study revealed that fragments (at 38%) were the most abundant followed by fiber (28%), film (23%) and foam (11%), indicating that fragments were higher during the wet season, and fibers were dominant type of MPs during the dry season, while form and film were least abundant (Fig. 2).

Table 1. Seasonal variation of MPs in surface waters of river Sabaki estuary

Season	Concentration of MPs particles /m^3
J-M Dry	147.33b
A-J Wet	264a
J-O Dry	119.75b
N-D Wet	196.5ab
Mean	181.9
P-Value	0.024

Means with the same letter in the same column are not significantly different at α = 0.05

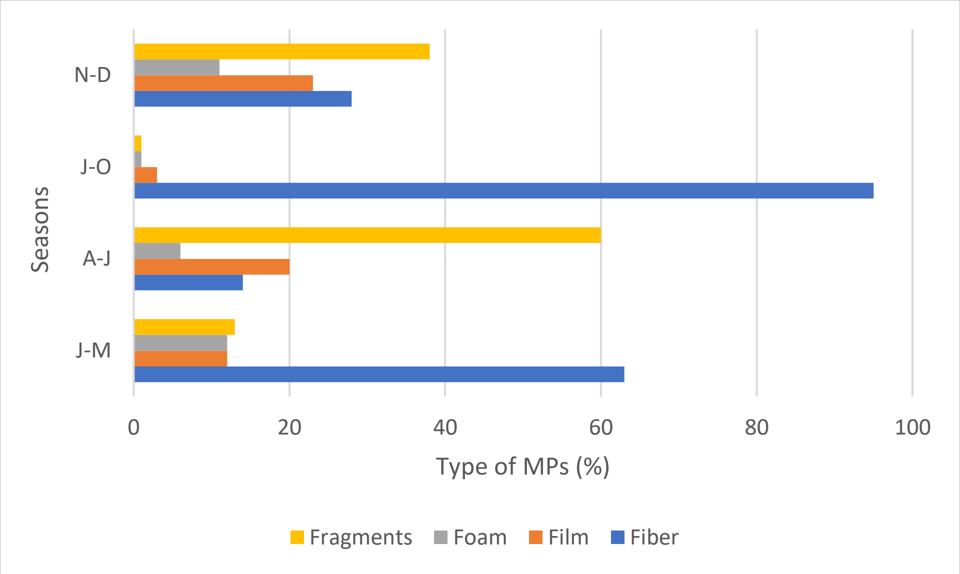

Fig. 2. Distribution of type of MPs in J-M, A-J, J-O and N-D seasons

Table 2. Seasonal variations of MPs based on sizes

	Number of particle m^{-3}/ size category		
Season	**≤ 2000µm (small)**	**2000-3500µm (small)**	**3500-5000µm (large)**
J-M	87.8a	36.17ab	23.33a
A-J	55.5a	96.3a	82.8a
J-O	87.67a	17.17b	5.50a
N-D	81.8a	79.0ab	35.75a
P-Value	0.491	0.036	0.346

Means with the same letter in the same column are not significantly different at α = 0.05

3.3 Seasonal distribution of MPs sizes in River Sabaki Estuary Surface Waters

The results showed significant differences (P ≤ 0.05) in seasonal distribution of 2000-3500µm size, category of MPs (Table 2). However, seasons had no significant influence on distribution of ≤ 2000µm and 3500-5000µm sizes of MPs (Table 2). MPs in the 2000-3500µm category declined by 62.4%, 82.2%, and 18% during the J-M, J-A and N-D seasons, respectively, from the highest concentrations observed in A-J season of 96.3 MPs particles m^{-3}. Although, seasons had no significant influences in the distribution of ≤ 2000µm and 3500-5000µm category of MP particles, there was a noticeable pattern in distribution of MPs particles in relation to seasons. Higher loads of small MPs of ≤ 2000µm increased by 36% during the J-M dry season, while larger MPs of 3500-5000µm size category increased by 60% during A-J wet season, indicating dominance of small sized MPs during the dry season, while larger particles dominated in the wet season (Table 2).

3.4 Colors of MPs in River Sabaki Estuary Surface Waters

Seven (7) different colors of MPs particles were observed in the sampled MPs particles. White colored MPs were more prevalent, followed by blue, black, brown, yellow, red, and green, at 33%, 23%, 17%, 12%, 5%, 5% and 4%, respectively (Fig. 3).

3.5 Types of MPs polymers in River Sabaki Estuary Surface Waters

The results revealed five types of plastic polymers were found in surface waters of river Sabaki estuary, namely polyethylene (PE), polypropylene (PP), polystyrene (PS), Polyethylene terephthalate (PET), and Acrylonitrile- butadiene- styrene (ABS) (Table 3).

There was seasonal variation in frequencies of plastic polymers in surface waters (Table 3). During the J-M season, the order of most dominant to least abundant polymers was: PP (32.7%) >, PE (27.1%) >, PS (16.2 %) >, PET (14.6 %) > ABS (9.4 %). In A-J season, the order of frequency was; PP (19 %) >, PE (24%) >, PS (5 %) >, PET (33%) > ABS (9%), while J-O season, the order of frequency was PP (29%) >, PE (30%) >, PS (11%) >, PET (19 %) >, ABS (0%), and in N-D season, the order of frequency was PP (25 %) >, PE (30%) >, PS (0 %) >, PET (42%) >, ABS (3%) (Fig. 4).

The order of mean percentage of MPs polymers observed in Sabaki river Surface waters was; Polyethylene (PE) (30%), Polyethylene terephthalate (PET) (27%), polypropylene (PP) (26%), Polystyrene (PS) (10%), and Acrylonitrile-butadiene-styrene (ABS) (4%) (Fig. 4).

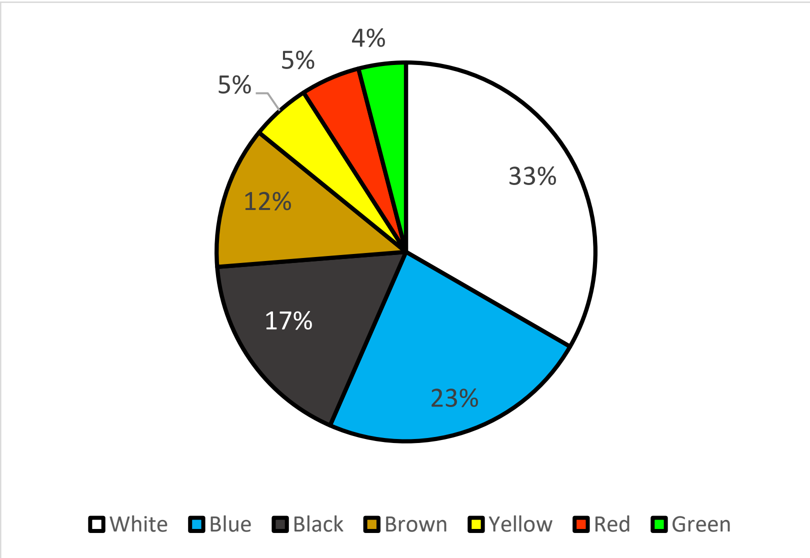

Fig. 3. Percentages distribution MPs particles according to color in surface waters of river Sabaki estuary

Table 3. MPs polymer types found in surface water during wet and dry seasons

	% MPs polymer types per season				
Polymer	**J-M**	**A-J**	**J-O**	**N-D**	**% Mean**
PP	32.7	19	29	25	26.4%
PE	27.1	24	41	30	30.5%
PS	16.2	15	11	0	10.6%
PET	14.6	33	19	42	27.2%
ABS	9.4	9	0	3	5.4%
Total particles (Random selected)					100%

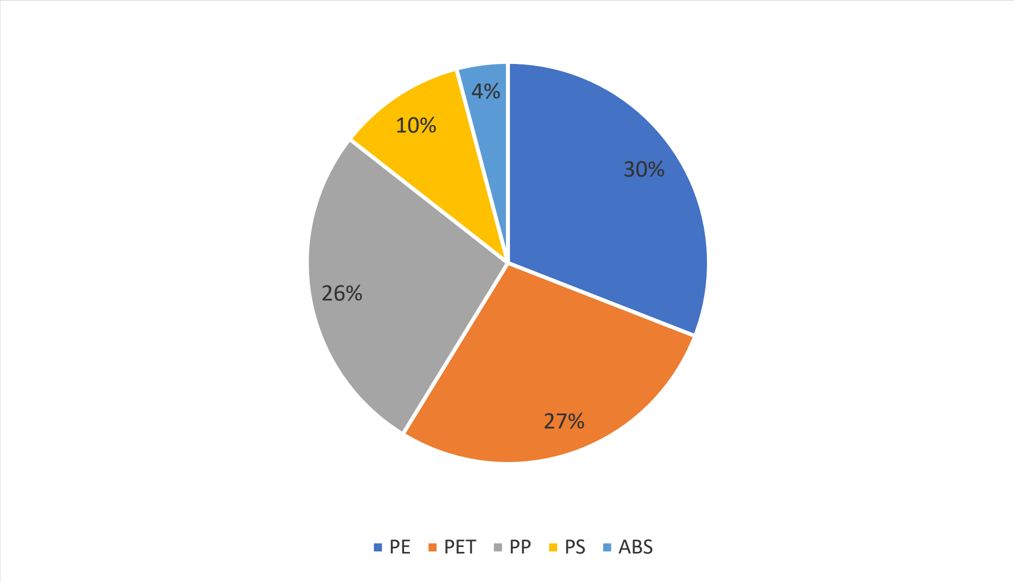

Fig. 4. Pooled percentage seasonal means of MPs polymers

4. DISCUSSION

4.1 Abundance of MPs in River Sabaki Surface Waters

Seasonal distribution of MPs in surface waters: The findings of this study revealed that seasons significantly influenced abundance of MPs particles in the surface waters of river Sabaki estuary. There were more MPs in the surface waters, during the rainy season than during the dry season. This suggests that rainfall runoff introduced MPs into the river. These observations are consistent with similar studies by Strady who reported positive correlations between river discharge and plastic loads during rainy seasons. Linked to increase of MPs in river during the rainy season was associated with increased capacity of floods to erode and mobilize MPs from the river catchment, and bursting of sewer systems that are a major source of MPs in Rivers (Strady et al. 2020). During the long rains season, abundance of MPs increased 2.7 folds compared the low levels recorded during the short rains season and J-M and J-O dry seasons. Similar results have been reported by Hitchcock, who observed that floods increased level of MPs by 40-fold in Cooks estuary, Australia (Hitchcock 2021).

In comparison with other studies, the level of MPs observed in this study in river Sabaki surface waters were relatively low, ranging between 375-504 MP particles m^{-3}. Higher levels of 342.2 billion particles m^{-3} have been reported in Nakdong river in Hong Kong, Korea (Felismino et al. 2021), while lower ranges of 6.3-160.1 items m^{-3} in surface waters have been reported in Bloukrans River, South Africa (Nel et al. 2018). This suggests that river Sabaki estuary is moderately contaminated with MPs. This may have been attributed to a number of factors:

i) The low per capita plastic consumption in Kenya of 0.03 kg per person per day (kg/ppd) as compared with other countries such as Sri Lanka at 5.0 kg/ppd, U.S.A at 2.59 kg/ppd, South Africa at 2.0 kg/ppd) and China at 1.10 kg/ppd, that have high per capita plastic consumption and more abundance of MPs in their rivers (Castro-Jiménez et al. 2019).

ii) Increased velocity of flowing water in rivers is associated with increased shear stress and turbulence that consequently suspends buried MP particles in sediments into surface waters. This phenomenon may have contributed to seasonal variation in MP particles observed in this study. River turbulence continuously suspends and fragments plastic debris into smaller MPs particles thereby increasing the levels of MP particles in the river surface waters (Castro-Jiménez et al. 2019). Catchment characteristics namely human population density, solid waste and sewer management systems also influence the level of MPs loads entering rivers and estuaries during rainy seasons (Zhao et al. 2019).

iii) Considering the fact that coastal flooding is associated with storm surge, coastal flooding may suspend and transport buried MPs from near shore waters into proximate estuaries. This observation agrees with reports by and Zhao and. Luca, who reported that tides have a role in creating temporal flushing and re-entrainment of MPs buried in riverbeds thereby increasing MP loads into river surface waters (Zhao et al. 2019, Luca Nizzetto et al. 2016). In contrast, Maozhou and Yellow rivers in China registered higher loads of MPs during the dry season, which was associated with reduced river flow (Han et al. 2020). This observation differs with observations in this study where the levels of MPs were noted to decrease during the dry season. This can be explained by the fact that rainfall runoff may initially introduce high levels of MPs particles into the river, but subsequently they get diluted by runoff (Wang et al. 2021). Over 70% decline in MPs has been reported, after floods, (Watkins et al. 2021) associated this decline to reduced plastics waste particles from dumps sites after prolonged rains.

Characteristics of MPs found in river Sabaki estuary surface waters:

Seasonal distribution of MP types in river Sabaki surface waters: The study found seasonal variations in the types of MPs found in surface waters of Sabaki river estuary. These types of MPs were fiber, fragments, foam, and film. This suggests that MPs found in the estuary may have originated from different sources and propagated through various pathways, such as storm water runoff and effluent from domestic and upcountry waste water treatment plants (Wwtps). Occurrence of different types of MPs depends on catchment characteristics namely: hydrology, anthropogenic activities, and MPs physical properties (Zhao et al. 2023). The upper section of river Sabaki traverses Nairobi, Athi River and all the way to Voi town and Galana catchments and has both point and diffused sources of propagating MPs pollutants. During the rainy seasons, the main pathway of MPs getting propagated into a river is through runoff that collects MPs from dumpsites, agricultural farms and forests. However, during the dry season effluent discharged from residential areas, industries and waste water treatment plants are the main pathways and sources through which MPs get propagated into rivers.

Fiber type of MPs were also found in river Sabaki waters. Most fiber type of MPs originate from effluent from domestic laundry of synthetic clothing that may have been discharged through waste water treatment plants into river Sabaki. Discharge of effluent from Nairobi, Athi river, Voi and other peri-urban areas found along river Sabaki catchment towns, might have increased the levels of fiber type of MPs in the estuary. In addition, among the tributaries of Sabaki river is Nairobi river, that receives effluent from waste water treatment plant at Ruai. This waste water treatment plant is used to treat effluent from Nairobi City, which has a population of over 4.5 million people. Also, the Export processing zone (EPZ) at Athi River town manufactures apparels that are made of fiber. Effluent from these industries may contain fiber type of MPs that end up in Sabaki river. This may explain the source of high levels of fiber type of MPs found in river Sabaki estuary. According to Liliya, fiber is the most dominant type of MPs in waste water treatment plant effluent at 62%, followed by film (31%), fragment (6.7%) and beads (0.6%) (Heléne Österlund et al. 2022). Waste water treatment plants have an efficiency of 70-90% in reducing fiber types of MPs in the effluent. Thus, inefficiency of waste water treatment plants along river Sabaki to remove fiber type of MPs might have contributed to their propagation into the river (Borges et al. 2019).

The study revealed presence of fragments type of MPs in Sabaki estuary surface waters. This suggests that the fragments type of MPs found in the estuary may have originated from dump sites that handle municipal solid wastes from residential areas, including plastic containers such as water bottles. These observations are in agreement with those made by Chen, and Schmid, who linked presence of fragments type of MPs in estuaries to collection, fragmentation and transportation of plastic waste into rivers, by storm waters especially during the flooding seasons (Liliya Khatmullina 2017, Chen et al. 2021 and Schmid et al. 2021).

Film type of MPs were found in river Sabaki waters. These types of MPs may have been propagated into the river through runoff originated from agricultural farms that use plastic bags (made from vinyl polymer) (Luca Nizzetto et al. 2016 and Heléne Österlund et al. 2022). These vinyl plastic bags were probably used for bagging farm inputs such as fertilizers and agricultural farm produce along river Sabaki catchment areas. The heterogeneity of these types of MPs increases their bioavailability posing a wider range of risks to estuarine species (He et al. 2022). According to Ziajahromi small types of MPs such as fibers pose a higher threat to aquatic organisms than fragments, films and micro beads, since fibers may end up coiling into clumps, blocking the gastrointestinal track, while large and irregular shaped MP particles induce physical damage as they move along the gastrointestinal tract (Ziajahromi et al. 2017). Equally, MPs texture, hydrophobicity and chemical additives influences biofilm formation, while irregularly surfaced MPs provides more points for attachment and colonization by microbes. These factors may increase MPs density and enhance their sinking into sediments thereby reducing levels of MPs in surface waters (Mu et al. 2019).

Sizes of MPs in river Sabaki estuary surface waters: MPs of all sizes were found in all surface water samples during the four seasons of the study. Large sized MP particles of 3500-5000μm dominated Sabaki river estuary during the rainy season, while smaller sized MP particles of ≤ 2000μm dominated during the dry seasons. This suggests that seasonal rainfall patterns influenced dominant size of MPs found in the river. This observation agrees with similar findings by Geyer, who positively correlated occurrence of larger MPs particles with wet seasons, and attributed their increase energy of the river water during the wet season, and therefore larger plastic particles are easily mobilization and broken down by the river flow depending on its geomorphology (Geyer et al. 2017).

Color of MPs in river Sabaki estuary surface waters: Different colored MPs particles were found in river Sabaki estuary. This suggests that MPs found in the estuary may have originated from commonly used plastic items. Presence of various colors of MP particles indicates that they may have originated from fragments of larger plastic items found in the catchment areas (Geyer 2024). The most prevalent colors of MPs found in surface waters of river Sabaki were white at 33% and blue at 23%, accounting for 56% of the total MPs. White and transparent colored MPs tend to be the most abundant type of MPs found in surface waters, while green was the least in abundance. Other studies have reported blue as the most abundant color in MPs particles found in estuaries surface waters (Wang et al. 2021).

Different colored MPs found in an estuary may be attributed to interaction of plastics and the environment. Estuary environmental conditions such as high temperatures and UV light affects the physical and chemical properties of MPs, causing changes in their surface texture and structure. Exposure of plastic items to ultra violet radiation affects their color, and plastics with pigment of longer wavelength and lower lightness are resistant to UV radiation which slows down their rate of degradation (Wang et al. 2021). Strongly pigmented plastics such as black colored plastic items limit light attenuation (Zhao et al. 2019). These UV resistant plastics are highly desired and recommended in production of plastic items and materials, explaining their abundance in the market. In contrast, light-pigmented plastics allow more light penetration, thereby enhancing their ageing and fragmentation, and eventual dominance in environmental pollution (Sathish et al. 2020). Changes in the color of MP particles can be used to assess the aging process of plastics and ecological health of an ecosystems (He et al. 2020). Degradation of MPs by ultra violet (UV) light and staining by sediments may result in overlapping of colors of MPs, thus limiting classification of MPs based on color (Castro-Jiménez et al. 2019).

Plastic additives have been used to enhance plastic properties such as durability, appearance, density and tensile strength (Zhao et al. 2019). In this study blue, green, and other colored MPs were found at various levels of abundance. However, some of the additives used for pigmentation of plastics such as lead are toxic although they are used to produce bright colored plastics. These colored and toxin laden MPs may be mistaken for natural food by some visual predators, posing threats to aquatic organisms and health risks to humans consuming these aquatic organisms (Geyer et al. 2017).

Types of MPs polymers in river Sabaki estuary surface waters: Six types of plastic polymers were present in the estuary in various proportions, namely Polyethylene (PE) (27%), Polyethylene terephthalate (PET) (25%), Polystyrene (PP) (24%) and low-levels of Polystyrene (PS) (13%), and Acrylonitrile-butadiene-styrene (ABS) (9%). This suggests that MPs polymers found in Sabaki river estuary are indicators of aging and breakdown of common plastic products. Globally, about 80% of plastics consist of polyethylene (PE) (both low and high density), polypropylene, polyvinyl chloride, polyurethane, polyester and polyethylene terephthalate. PE, PP and PS are the dominant plastic polymers in the environment, while ABS is among the least (Wenyu Zhao et al.2024). PE and PP were the most dominant polymers in Sabaki estuary (Borges et al. 2019). PE and PP accounts for 50% in the plastic industry (Prata et al. 2020). It is conceivable that the dominance of PE and PP in plastics used in every day human life, may be linked to their contribution in plastic waste (Leal Filho et al. 2019). In 2019, Japan Plastic Industrial Federation (JPIF) revealed that PE, PP, PS, PET, Nylon (PA) and (PVA) contributed 61.1% of total plastic production in Japan. PE, PP, PS, and PET constituted 65.2% of produced and consumed plastic items (Leal Filho et al. 2019). Five major plastic polymers (PE, PP, PS, PET, and PVC) accounted for most of municipals solid waste in Europe (Leal Filho et al. 2019, Pucino et al. 2020). In Kenya, PE and PP contributes most of the plastic waste (Kerubo et al. 2021). PE are hard with low strength while PP is resistant to high temperatures (55-70^{o}C) and relatively cheaper. These factors have contributed to their dominance in plastic industry which is also reflected in their contribution to plastics waste.

Considering plastic density, polyethene (PE) is the least dense, while polypropylene (PP), Polystyrene (PS), Polyamide (PA), are among the lighter polymers (Sun et al., 2020). PP and PE tend to float in water owing to their low density and this may explain their dominance in estuary surface waters especially during rainy seasons (Wenyu Zhao et al. 2024). Polypropylene (PP) has a density of 0.88-0.91 g cm^{-3} while polyethylene (PE) has a density of 0.093-0.98 gm^{-3} both of which have their densities being lower than that of sea water (Zhang et al. 2021, Dube and Okuthe 2024).

5. CONCLUSION

The surface waters were found to be more contaminated with MPs during the wet season than during the dry season. With regard to characteristics of MPs present in surface waters, fiber, films, fragments and foam types were the most dominant. While higher loads of larger MPs particles were present during the wet season, small sized particles dominated during the dry season. Five MPs polymers were found in the waters of river Sabaki estuary, namely PE, PP, PS, PET, and ABS. Different polymers polluted the Sabaki estuary, and to protect species living in such water bodies there is need for broad based plastic pollution mitigating measures in Kenya.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Arp, H. P. H., Kühnel, D., Rummel, C., MacLeod, M., Potthoff, A., Reichelt, S., Rojo-Nieto, E., Schmitt-Jansen, M., Sonnenberg, J., Toorman, E., & Jahnke, A. (2021). Weathering Plastics as a Planetary Boundary Threat: Exposure, Fate, and Hazards. *Environmental Science & Technology*, *55*(11), 7246–7255. https://doi.org/10.1021/acs.est.1c01512

Au, S. (2017). *Toxicity of microplastics to aquatic organisms* [PhD Thesis, Clemson University]. https://search.proquest.com/openview/d2a05cc0949cc912947e50bcfd8e4f74/1?pq-origsite=gscholar&cbl=18750

Ayeleru, O. O., Dlova, S., Akinribide, O. J., Ntuli, F., Kupolati, W. K., Marina, P. F., Blencowe, A., & Olubambi, P. A. (2020). Challenges of plastic waste generation and management in sub-Saharan Africa: A review. *Waste Management*, *110*, 24–42.

Borges, A. V., Darchambeau, F., Lambert, T., Morana, C., Allen, G. H., Tambwe, E., Toengaho Sembaito, A., Mambo, T., Nlandu Wabakhangazi, J., Descy, J. P., & Teodoru, C. R. (2019). Variations in dissolved greenhouse gases (CO_2, CH_4, N_2O) in the Congo River network overwhelmingly driven by fluvial-wetland connectivity. Biogeosciences, 16(19), 3801–3834.

Cássio, F., Batista, D., & Pradhan, A. (2022). Plastic interactions with pollutants and consequences to aquatic ecosystems: What we know and what we do not know. *Biomolecules*, *12*(6), 798.

Castro-Jiménez, J., González-Fernández, D., Fornier, M., Schmidt, N., & Sempéré, R. (2019). Macro-litter in surface waters from the Rhone River: Plastic pollution and loading to the NW Mediterranean Sea. *Marine Pollution Bulletin*, *146*, 60–66.

Chen, X., Huang, G., & Dionysiou, D. D. (2021). Editorial Overview: Emissions of Microplastics and Their Control in the Environment. Journal of Environmental Engineering, 147(9), 01821002. https://doi.org/10.1061/(ASCE)EE.1943-7870.0001897

Cox, K. D., Covernton, G. A., Davies, H. L., Dower, J. F., Juanes, F., & Dudas, S. E. (2019). Human Consumption of Microplastics. *Environmental Science & Technology*, *53*(12), 7068–7074. https://doi.org/10.1021/acs.est.9b01517

Dube, E.; Okuthe, G.E. (2024). Plastic and Micro/Nanoplastic Pollution in Sub-Saharan Africa: Challenges, Impacts, and Solutions. World 2024, 5, 325–345. https:// doi.org/10.3390/world5020018

Felismino, M. E. L., Helm, P. A., & Rochman, C. M. (2021). Microplastic and other anthropogenic microparticles in water and sediments of Lake Simcoe. *Journal of Great Lakes Research*, *47*(1), 180–189.

Geyer, R. (2020). Production, use, and fate of synthetic polymers. In *Plastic waste and recycling* (pp. 13–32). Elsevier. https://www.sciencedirect.com/science/article/pii/B9780128178805000025

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, *3*(7), e1700782. https://doi.org/10.1126/sciadv.1700782

Grigorakis, S., Mason, S. A., & Drouillard, K. G. (2017). Determination of the gut retention of plastic microbeads and microfibers in goldfish (Carassius auratus). *Chemosphere*, *169*, 233–238.

Haas, V., Wenger, J., Ranacher, L., Guigo, N., Sousa, A. F., & Stern, T. (2022). Developing future visions for bio-plastics substituting PET–A backcasting approach. *Sustainable Production and Consumption*, *31*, 370–383.

Han, M., Niu, X., Tang, M., Zhang, B.-T., Wang, G., Yue, W., Kong, X., & Zhu, J. (2020). Distribution of microplastics in surface water of the lower Yellow River near estuary. Science of the Total Environment, 707, 135601.

He, B., Liu, A., Duan, H., Wijesiri, B., & Goonetilleke, A. (2022). Risk associated with microplastics in urban aquatic environments: A critical review. Journal of Hazardous Materials, 439, 129587.Ziajahromi, S., Neale, P. A., Rintoul, L., & Leusch, F. D. (2017). Wastewater treatment plants as a pathway for microplastics: Development of a new approach to sample wastewater-based microplastics. *Water Research*, *112*, 93–99.

He, B., Wijesiri, B., Ayoko, G. A., Egodawatta, P., Rintoul, L., & Goonetilleke, A. (2020). Influential factors on microplastics occurrence in river sediments. *Science of The Total Environment*, *738*, 139901.

Hitchcock, J. N. (2020). Storm events as key moments of microplastic contamination in aquatic ecosystems. *Science of the Total Environment*, *734*, 139436

Horton, A. A., & Dixon, S. J. (2018). Microplastics: An introduction to environmental transport processes. *WIREs Water*, *5*(2), e1268. https://doi.org/10.1002/wat2.1268

Kerubo, J. O., Onyari, J. M., Muthumbi, A. W., Andersson, D. R., & Kimani, E. N. (2021). Microplastic polymers in surface waters and sediments in the creeks along the Kenya coast, western Indian Ocean (WIO). *European Journal of Sustainable Development Research*, *6*(1), em0177.

Khatmullina, L., & Isachenko, I. (2017). Settling velocity of microplastic particles of regular shapes. Marine Pollution Bulletin, https://doi.org/10.1016/j.marpolbul.2016.11.024

Kibria, G., Nugegoda, D., & Haroon, A. K. Y. (2022). Microplastic Pollution and Contamination of Seafood (Including Fish, Sharks, Mussels, Oysters, Shrimps and Seaweeds): A Global Overview. In M. Z. Hashmi (Ed.), *Microplastic Pollution* (pp. 277–322). Springer International Publishing. https://doi.org/10.1007/978-3-030-89220-3_14

Kitheka, J., & Mavuti, K. (2016). Tana Delta and Sabaki Estuaries of Kenya: Freshwater and Sediment Input, Upstream Threats and Management Challenges. In S. Diop, P. Scheren, & J. Ferdinand Machiwa (Eds.), *Estuaries: A Lifeline of Ecosystem Services in the Western Indian Ocean* (pp. 89–109). Springer International Publishing. https://doi.org/10.1007/978-3-319-25370-1_6

Kumar, R., Sharma, P., Verma, A., Jha, P. K., Singh, P., Gupta, P. K., Chandra, R., & Prasad, P. V. (2021). Effect of physical characteristics and hydrodynamic conditions on transport and deposition of microplastics in riverine ecosystem. *Water*, *13*(19), 2710.

Leal Filho, W., Saari, U., Fedoruk, M., Iital, A., Moora, H., Klöga, M., & Voronova, V. (2019). An overview of the problems posed by plastic products and the role of extended producer responsibility in Europe. *Journal of Cleaner Production*, *214*, 550–558.

Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. *Palgrave Communications*, *5*(1), 1–11

Lusher, A., Hollman, P., & Mendoza-Hill, J. (2017). *Microplastics in fisheries and aquaculture: Status of knowledge on their occurrence and implications for aquatic organisms and food safety*. FAO. https://oceanrep.geomar.de/id/eprint/49179/1/Microplastics%20in%20fisheries%20and%20aquaculture.pdf

Marwick, T. R., Tamooh, F., Ogwoka, B., Borges, A. V., Darchambeau, F., & Bouillon, S. (2018). A comprehensive biogeochemical record and annual flux estimates for the Sabaki River (Kenya). *Biogeosciences*, *15*(6), 1683–1700.

Massa, G. M., & Archodoulaki, V.-M. (2024). An Imported Environmental Crisis: Plastic Mismanagement in Africa. *Sustainability*, *16*(2), 1–20.

Mu, J., Zhang, S., Qu, L., Jin, F., Fang, C., Ma, X., Zhang, W., & Wang, J. (2019). Microplastics abundance and characteristics in surface waters from the Northwest Pacific, the Bering Sea, and the Chukchi Sea. *Marine Pollution Bulletin*, *143*, 58–65.

Munga, C. N., Kimani, E., Ruwa, R. K., & Vanreusel, A. (2016). Species Composition of Fisheries Resources of the Tana and Sabaki Estuaries in the Malindi-Ungwana Bay, Kenya. In S. Diop, P. Scheren, & J. Ferdinand Machiwa (Eds.), *Estuaries: A Lifeline of Ecosystem Services in the Western Indian Ocean* (pp. 27–38). Springer International Publishing. https://doi.org/10.1007/978-3-319-25370-1_2

Nel, H. A., Dalu, T., & Wasserman, R. J. (2018). Sinks and sources: Assessing microplastic abundance in river sediment and deposit feeders in an Austral temperate urban river system. *Science of the Total Environment*, *612*, 950–956.

Nizzetto, L., Bussi, G., Futter, M. N., Butterfield, D., & Whitehead, P. G. (2016). A theoretical assessment of microplastic transport in river catchments and their retention by soils and river sediments. Science of the Total Environment.

Onyena, A. P., Aniche, D. C., Ogbolu, B. O., Rakib, M. R. J., Uddin, J., & Walker, T. R. (2021). Governance strategies for mitigating microplastic pollution in the marine environment: A review. *Microplastics*, *1*(1), 15–46.

Österlund, H., Blecken, G., Lange, K., Marsalek, J., Gopinath, K., & Viklander, M. (2022). Microplastics in urban catchments: Review of sources, pathways, and entry into stormwater.

Prata, J. C., da Costa, J. P., Lopes, I., Duarte, A. C., & Rocha-Santos, T. (2020). Environmental status of (micro) plastics contamination in Portugal. *Ecotoxicology and Environmental Safety*, *200*, 110753.

Pucino, M., Boucher, J., Bouchet, A., Paruta, P., Zgola, M., Pucino, M., Paruta, P., Bouchet, A., & Zgola, M. (2020). Plastic Pollution Hotspotting and Shaping Action: Regional Results from Eastern and Southern Africa, the Mediterranean, and Southeast Asia. *International Union for the Conservation of Nature: Gland, Switzerland*, 78.

Sathish, M. N., Jeyasanta, I., & Patterson, J. (2020). Occurrence of microplastics in epipelagic and mesopelagic fishes from Tuticorin, Southeast coast of India. *Science of the Total Environment*, *720*, 137614.

Schmid, C., Cozzarini, L., & Zambello, E. (2021). A critical review on marine litter in the Adriatic Sea: Focus on plastic pollution. Environmental Pollution, 273, 116430.

Strady, E., Kieu-Le, T.-C., Gasperi, J., & Tassin, B. (2020). Temporal dynamic of anthropogenic fibers in a tropical river-estuarine system. *Environmental Pollution*, *259*, 113897.

Wang, C., Zhao, J., & Xing, B. (2021). Environmental source, fate, and toxicity of microplastics. Journal of Hazardous Materials, 407, 124357.

Wang, M. H., He, Y., & Sen, B. (2019). Research and management of plastic pollution in coastal environments of China. *Environmental Pollution*, *248*, 898–905.

Watkins, L., Sullivan, P. J., & Walter, M. T. (2021). What You Net Depends on if You Grab: A Meta-analysis of Sampling Method's Impact on Measured Aquatic Microplastic Concentration. Environmental Science & Technology, acs.est.1c03019. https://doi.org/10.1021/acs.est.1c03019

Zhang, K., Hamidian, A. H., Tubić, A., Zhang, Y., Fang, J. K., Wu, C., & Lam, P. K. (2021). Understanding plastic degradation and microplastic formation in the environment: A review. *Environmental Pollution*, *274*, 116554.

Zhao, S., Wang, T., Zhu, L., Xu, P., Wang, X., Gao, L., & Li, D. (2019). Analysis of suspended microplastics in the Changjiang Estuary: Implications for riverine plastic load to the ocean. *Water Research*, *161*, 560–569.

Zhao, W., Li, J., Liu, M., Wang, R., Zhang, B., Meng, X., & Zhang, S. (2024). Seasonal variations of microplastics in surface water and sediment in an inland river drinking water source in southern China. Science of the Total Environment, 2023, 168241. https://doi.org/10.1016/j.scitotenv.2023.168241

Zhao, X., Niu, Z., Ma, Y., Zhang, Y., & Li, Y. (2023). Metagenomic insights into the potential risks of representative bio/non-degradable plastic and non-plastic debris in the upper and lower reaches of Haihe Estuary, China. Science of The Total Environment, 887, 164026.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/126893