Marine Pollution Bulletin 159 (2020) 111497

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Baseline

Marine macro-litter composition and distribution along the Kenyan Coast: The first-ever documented study

Eric Ochieng Okuku[a,⁎], Linet Imbayi Kiteresi[a,b], Gilbert Owato[a,b], Catherine Mwalugha[a,c], Jill Omire[a], Kenneth Otieno[a,c], Mary Mbuche[a], Annette Nelson[a], Brenda Gwada[a], Lilian Mulupi[a,b]

[a] Kenya Marine and Fisheries Research Institute, P. O. Box 81651, Mombasa, Kenya
[b] Pwani University, P.O Box 195, 80108 Kilifi, Kenya
[c] Technical University of Mombasa, P.O. Box 90420, 80100 Mombasa, Kenya

ARTICLE INFO

Keywords:
Plastics pollution
Macro-litter
Accumulation survey
Brand audit
Accumulation rate

ABSTRACT

Macro-litter accumulation surveys were carried out in six beaches in Kilifi, Mombasa and Kwale Counties. Macro litter were collected, quantified and characterized to determine their composition, distribution and accumulation rates. The results showed that the accumulation rates ranged between 1.53 ± 1.23 and 11.46 ± 7.72 (for dry zones) and 2.69 ± 2.13 and 8.93 ± 7.87 items m^{-1} day^{-1} (for wet zones). Plastics and foam were the most abundant litter categories. Local products constituted about 88% of all the collected litter. Food packaging products constituted about 91.3% of all branded litter types. Marine litter pollution particularly by plastics was widespread in all studied coastal counties. However, a significant amount of litter encountered in the beaches was of local origin, thus a local solution to waste management (that will eliminate leakage into marine environments) will considerably reduce marine litter pollution in Kenya.

Marine litter is a rising global environmental issue that affects both human and ecosystem health. It originates from the sea and land-based activities (Galgani et al., 2015) with the latter contributing an estimate of 80% (Eerkes-Medrano et al., 2015; Jambeck et al., 2015; Li et al., 2016; Ritchie and Roser, 2018; UNEP, 2016). The land-based sources include waste released from dumpsites near the coast or river banks, littering of beaches, ship-breaking yards, tourism, recreational activities, and storm-related events, i.e. flash floods (GESAMP, 2015). The major sea-based sources include: abandoned, lost, or discarded fishing gear, shipping activities and illegal sea-based dumping. Litter in the marine environment may either float and later wash ashore or can sink to the bottom of the ocean. Most marine litter items are buoyant thus their spatial distribution and accumulation are greatly influenced by hydrodynamics, geomorphology (Barnes et al., 2009), prevailing winds and current conditions, anthropogenic activities- how they are released (Ramirez-Llorda et al., 2013) and coastline geography (Arias and Marcovecchio, 2017). These factors create a different spatial distribution, with localized accumulation zones, with varying litter densities (Eriksen et al., 2014; Mansui et al., 2015; Williams et al., 2016).

Marine litter can be defined as manufactured or processed items that are subsequently discarded, disposed of, or abandoned thus ending up in the coastal and/or ocean environments (UNEP, 2011; Buhl-Mortensen and Buhl-Mortensen, 2017). Some of the common litter include food wrappers, cigarette butts, cigar tips, fishing line, ropes and nets, diapers and nappies, six-pack rings, beverage bottles, disposable syringes, as well as pre-production resin pellets (Sheavly and Register, 2007). The most common materials that make up marine litter are plastics, glass, metal, paper, cloth, rubber, and processed wood with plastics forming the major part (UNEP, 2016). Plastics comprise a diverse group of synthetic polymers that have their origins in the late 19th century but became popular in the mid-twentieth century (Law, 2017). They play an important role in modern life in the manufacturing industries due to their low densities, durability, resilience and affordability. These desirable attributes have resulted in a significant increase in their global production and the resultant post-consumer waste of about 3.7 billion metric tonnes, a figure that is projected to double by 2025 (Plastics Europe, 2013; Galgani et al., 2019). The same properties that make plastics useful also make the mismanaged post-consumer plastic waste a significant environmental threat (Ryan et al., 2009). In 2010, an estimate of 12.7 million metric tonnes of plastic waste found its way into the oceans (UNEP, 2016), with approximately 227,000 metric tonnes floating freely on the sea surface (NCEAS, 2013).

Plastics can persist in the environment for many years due to their resistance to microbial and other degradation processes thus creating

⁎ Corresponding author.
E-mail address: eokuku@kmfri.go.ke (E.O. Okuku).

https://doi.org/10.1016/j.marpolbul.2020.111497
Received 30 March 2020; Received in revised form 8 July 2020; Accepted 19 July 2020
Available online 29 July 2020

an increasing concern on their risks and possible adverse effects to organisms (Wright et al., 2013; Gall and Thompson, 2015). Marine organisms can be impacted by plastics through entanglement (Thompson et al., 2009; Ryan, 2018; Thiel et al., 2018), ingestion (van Franeker et al., 2011; Ryan, 2016), suffocation (Kühn et al., 2015), bioaccumulation of pollutants (Andrady, 2011; Murray and Cowie, 2011), modification of benthic communities (Katsanevakis et al., 2007), the introduction of non-native marine species into new habitats (Rech et al., 2016) and change in physical conditions of the seafloors (Akoumianaki et al., 2008). Consequently changing the integrity and functioning of habitats (Vegter et al., 2014) as well as impacting human health through food safety issues (Gregory, 2009; Lusher et al., 2017). In addition to impacting aquatic ecosystems (Rochman et al., 2016), plastics pollution also affects societies and the economies (UNEP, 2014) through impacts on shipping, fishing, aquaculture, tourism and recreation.

Developing countries (which mostly have inadequate waste management infrastructure) are undergoing rapid urbanization (estimated at 24% in 2014 by World Bank, 2016) which provides a large consumer market for plastic goods, most of which are single-use plastics (UNEP-WCMC IU, 2018). Plastics have been used in Africa since the late 1950s, long before adequate recycling infrastructure and policies were put in place (Jambeck et al., 2018). The consumption of plastics in Africa is further predicted to increase as the population of the middle class continues to expand (Deloitte, 2014; Jambeck et al., 2018). To combat the plastics pollution crisis, many African countries have become signatories to several international treaties and made commitments regarding the regulation and reduction of marine litter (including the UN 2030 Agenda for Sustainable Development). The Sustainable Development Goals (SDGs) address marine litter through Goal 14 (target 14.1), with a particular focus on sources from land-based activities. Similarly, Goals 11 -addresses municipal and other litter management (target 11.6), and 12 -addresses environmentally sustainable management of chemicals and litter (target 12.4), and overall litter reduction (target 12.5). This is echoed further by the Call for Action Declaration of the 2017 UN Ocean Conference on the commitment of all its member states to address marine plastic pollution (Blidberg et al., 2015; UNIDO, 2019).

In Kenya, Mombasa County generates 1000 tons of solid waste per day (Mombasa County, 2019) while Kilifi County generates 400 tons per day (Kilifi County, 2019), whereas no estimates of solid waste generated in Kwale County exist. These counties have inadequate and poorly implemented policies on plastic waste management as well as inadequate human, technical and financial capacity to effectively manage waste, thus a fraction of the waste is discharged into the marine environment (Okuku et al., 2011). Such leakage of plastics into the environment coupled with its buoyancy and durability has made plastics to be distributed across all oceans (Eriksen et al., 2014).

Monitoring marine litter accumulation in marine ecosystems is critical in the assessment of the effectiveness of litter management and reduction measures (Ryan, 2018). However, there is scarce data on marine litter production, litter loads and composition in Africa (Jambeck et al., 2018). The available information lacks rigour as it is based on assumptions drawn from correlations with population size, demographic patterns, socio-economic information and other surrogates (Ribbink et al., 2019). There is, therefore, an urgent need to determine the baselines of marine litter pollution and monitor changes over time to formulate effective marine litter management strategies. This is in line with the outcome of G7 World leaders' declaration summit of 2016 that recommended marine litter monitoring to establish the baseline quantities, potential impact and commitment to the global action plan in combating marine litter pollution (Ministry of

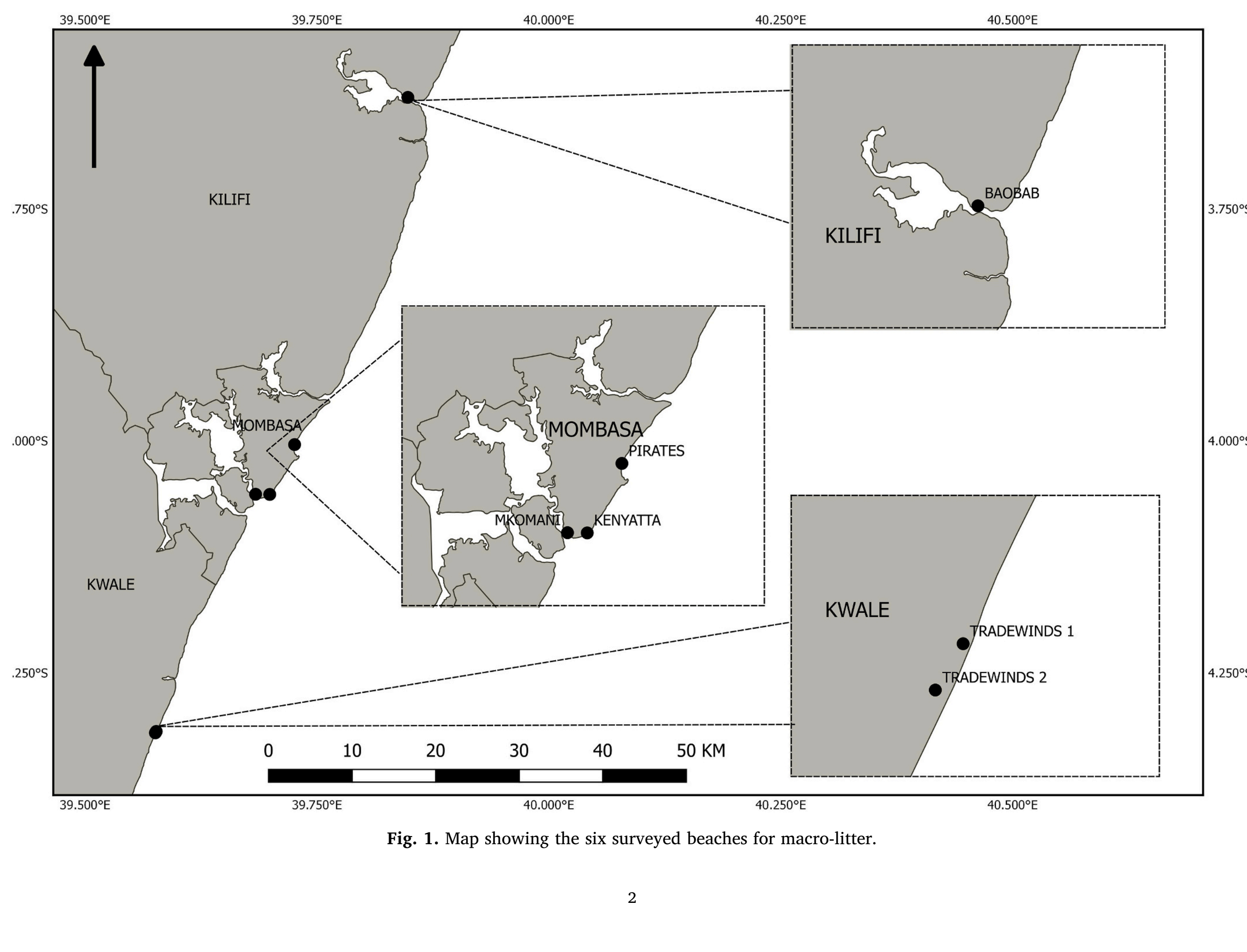
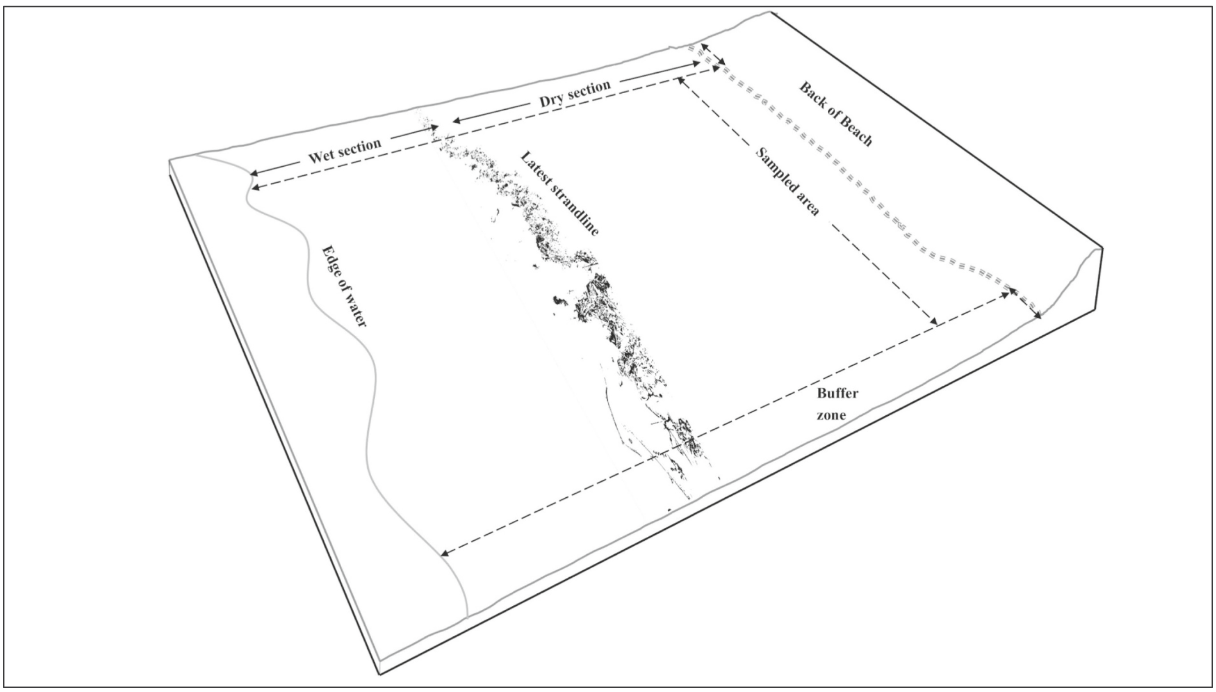


Fig. 1. Map showing the six surveyed beaches for macro-litter.

Foreign Affairs of Japan, 2016). This study aimed to determine the baselines of marine litter pollution along the Kenya coast. Specifically, the study quantified, characterized and determined the distribution and accumulation of marine litter along the Kenyan Coast.

The study was carried out between June and November 2019 in six randomly selected beaches (Fig. 1), namely: Mkomani, Kenyatta and Pirates beaches (Mombasa county), Baobab (Kilifi county) and Tradewinds 1 and 2 beaches (Kwale county). The beaches were randomly selected to cover the heterogeneous nature of Kenyan beaches occasioned by different environmental, demographic and Socio-economic aspects. Other factors considered included: openness to the sea, accessibility, nature of the back of the beach, slope and adequacy of beach length i.e. ≥100 m (Vlachogianni et al., 2018). The survey team ensured that all selected sites were undisturbed by beach cleaning activities during the entire period of the survey as suggested by Schernewski et al. (2018).



The study was conducted by well-trained volunteers from Kenya Marine and Fisheries Research Institute (KMFRI) following guidelines provided in WIOMSA marine litter monitoring manual (Ribbink et al., 2019). The beaches were thoroughly cleaned up for one or two days (by picking all visible macro-litter on the surface) prior to the start of the survey, after which the accumulation survey was carried out for 10 consecutive days (starting the same time, 10 am, every day). Onsite characterization of the surveyed beaches was done to establish the substrate type, weather, slope aspect and back of shoreline. Land use characteristics were captured detailing the location and major land-use e.g. recreation or fishing and the mode of access to the site (whether by vehicle or by foot). Ocular inspection for potentially confounding litter sources such as informal waste disposal pits, rivers and streams were carried out.

The start and end points for the surveyed beach was established and geo-referenced using Garmin GPS Map 2S and additional features such as unique structures benchmarked to ensure that the same sampling sites were monitored. Buffer zones of between 10 and 50 m (depending on the size of the beach) were designated either side of the survey site and cleaned every day of the survey to minimize litter movement into the litter survey areas. There were no buffer zones in Mkomani beach since it has walls built at the start and end of the surveyed area acting as buffers. The litter densities were expressed per unit length of the beach (and not per unit areas) as such the survey was not affected by the tidal cycle. The survey was carried out in both the wet and dry beach zones to estimate the oceanic and terrestrial inputs of litter to the beach. The wet zone was defined by the edge of water up to the recent highest watermark and line, whereas the dry section was defined by the recent highest watermark/ strand line up to the back of the beach. The back of the beach was defined as two meters into the vegetation (Abu-Hilal and Al-Najjar, 2004) or at the foot of built construction (Prevenios et al., 2018).

All macro litter (> 25 mm size) from the dry and wet sections was collected separately and thereafter sorted based on litter categories (plastic, glass, metal, processed wood, foam, textiles, rubber, construction material and ceramics, fishing-related gears and others). Litter counting and weighing were done per item type (lollipop sticks, diapers, aluminum cans etc.). Smaller litter items that could not be weighed by the digital scales were put in separate labeled bags, taken to the laboratory and weighed using an analytical balance. All the litter from the dry zones were scrutinized for any visible sediment and any organic materials. The litter that had these materials were cleaned and dried before weighing. All the litter from the wet zones were cleaned and dried before weighing. The data collected (after quantification of marine litter from each beach) were then used to calculate the mean accumulation rates (± SD) for both counts and weights and to test significant differences in accumulation rates in the six surveyed beaches for ten days.

A brand audit was conducted in addition to the quantification and characterization of marine litter. This was done by identifying brand name, manufacturer, country of origin, type of packaging and type of product. Different types of products which included household products (detergent cleansers, cleaning tools etc.), food packaging (food wrappers, beverage bottles etc.) and personal care products (soap, shampoo packaging, toothpaste etc.). Items were then classified further into the type of material such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), polypropylene (PP), polystyrene (PS), single layer (SL) or (Multiple Layers (ML) and other

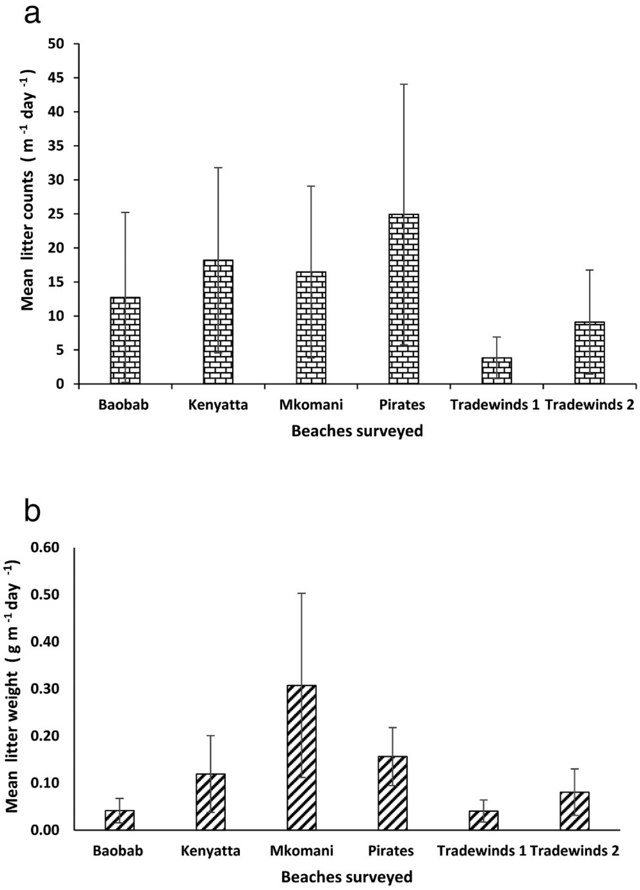


Fig. 2. Mean (± SD) litter accumulation rate of items (items m^{-1} day^{-1}) in the six surveyed beaches.

materials (O). Magnifying lenses were used to read illegible labels on the litter and data recorded on datasheets. The brand audit was used to determine the top ten most polluting brands, manufacturers and countries, types of packaging and type of product. The volunteers were under the senior scientists' supervision at every stage of sampling and data collection. Sorting and data capture was undertaken through strict adherence to the standard protocol.

The mean accumulation rates of marine litter in the six surveyed beaches (by counts) ranged between 3.8 ± 3.1 and 24.9 ± 19.1 items m^{-1} day^{-1}. The order of the beaches based on item counts accumulation rates were: Pirates > Kenyatta > Mkomani > Baobab > Tradewinds-2 > Tradewinds-1 (Fig. 2a). Whereas marine litter is seldom reported in terms of weight (Hengstmann et al., 2017), for this study, the mean accumulation rate of the six surveyed beaches (by weights) ranged between 0.31 ± 0.20 and 0.04 ± 0.02 g m^{-1} day^{-1} (Fig. 2b). A different trend was observed in the accumulation rates by weights as follows: Mkomani > Pirates > Kenyatta > Tradewinds-2 > Tradewinds-1 > Baobab (Fig. 2a). The differences in the amount of litter from the six sites were however not significant both for counts ($F = 0.357$, $p > 0.05$) and weight ($F = 1.194$, $p > 0.05$).

The accumulation rates of marine litter in the dry and wet beach zones ranged from 1.54 ± 1.23 to 11.46 ± 7.72 items m^{-1} day^{-1} and from 2.69 ± 2.13 to 8.93 ± 7.87 items m^{-1} day^{-1}, respectively, suggesting high accumulation rates in the dry beach zone (Fig. 3). Influence by land-based activities, such as the evident dumping at the back of the beach, could have resulted in the observed higher accumulation rates in the dry zone. The recreational use of beaches such as Pirates is an example of land-based contributor to litter accumulation as described elsewhere by Galgani et al. (2015). The wet zones had higher (mean range; 0.03 ± 0.019 to 0.18 ± 0.11 g m^{-1} day^{-1}) marine litter accumulation rates (by weight) compared to the dry zones (mean range; 0.007 ± 0.004 to 0.090 ± 0.080 g m^{-1} day^{-1}). The higher accumulation rates in the wet zones could be originating from litter in the nearshore waters. Carson et al. (2013) similarly reported that nearshore and tidal dynamics play an important role in the retention of pollutants in coastal areas. There were higher accumulation rates in the wet zones (by weight) whereas the accumulation rates (by count) were higher in the dry zones compared to the wet zone. This could be contributed to the presence of a few but heavy items on the wet side (shoes, fishing nets, clothes) which could easily be deposited when the wave energy is reduced (as opposed to lighter litter that is continuously in suspension) whereas the dry zones had predominantly lighter items (plastic fragments, food wrappers, cigarette butts, lollipop sticks and straws) which were mainly windblown as reported by Hengstmann et al. (2017) on the beaches of the Isle of Rügen in the Baltic Sea.

Marine litter accumulation rates showed the following trends in the dry zone of the beach: Kenyatta > Pirates > Mkomani > Baobab > Tradewinds 2 > Tradewinds 1, with the mean litter amounts ranging between 1.53 ± 1.23 and 11.46 ± 7.72 items m^{-1} day^{-1} (Fig. 3). An almost similar trend was observed in the wet zone (Kenyatta > Baobab > Mkomani > Pirates > Tradewinds 2 > Tradewinds 1), except for Baobab (7.27 ± 7.11 items m^{-1} day^{-1}) that had higher accumulation rate than Mkomani (6.92 ± 6.25 items m^{-1} day^{-1}) and Tradewinds 2 (4.45 ± 4.02 items m^{-1} day^{-1}) (Fig. 3). The difference in accumulation rates in varied beaches has similarly been reported

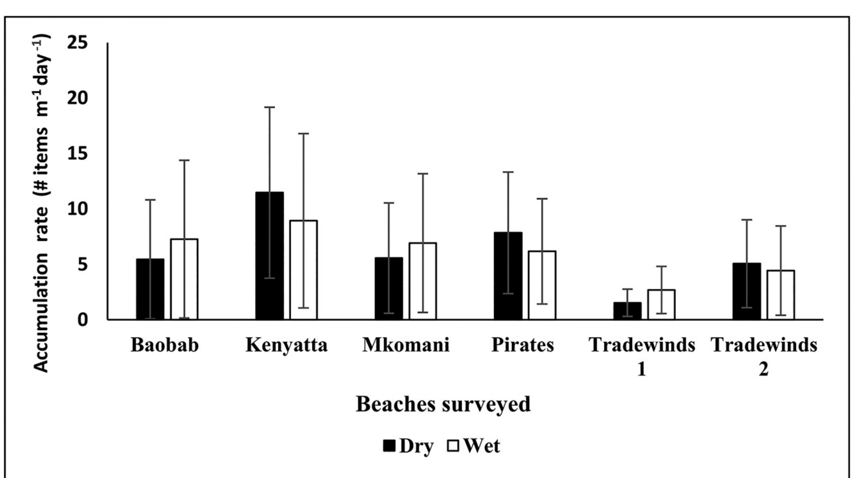


Fig. 3. Mean (± SD) litter accumulation rate of items (g m^{-1} day^{-1}) in the six surveyed beaches.

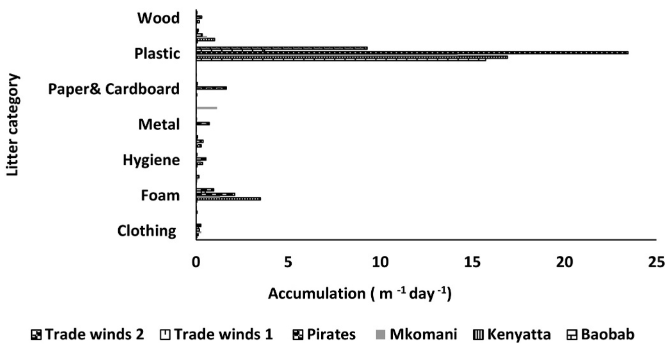


Fig. 4. Mean (± SD) litter accumulation rate (items m^{-1} day^{-1}) in the dry and wet zones of the six surveyed beaches.

elsewhere by Debrot et al. (1999) who attributed the differences to beach topography which results in patchiness especially for smaller and lighter items that are easily dispersed or buried. Similar studies carried out along the Gulf of Oman also showed that litter often varies among different parts of an individual beach (Claereboudt, 2004) with higher amounts frequently found at high-tide or storm-level lines (Oigman-Pszczol and Creed, 2007). Even though there were varied marine litter accumulation rates (both weights and counts) in the two intertidal zones, these differences were not statistically significant ($F = 0.37$, $p > 0.05$). The marine litter type with high accumulation rates were plastics (11.15 ± 4.49 items m^{-1} day^{-1}) and foam (1.04 ± 1.30 items m^{-1} day^{-1}) (Fig. 4). Laglbauer et al. (2014) and Lopes da Silva et al. (2015) similarly reported plastic among the most frequently encountered litter types in Slovenian and Brazilian beaches, respectively. Lopes da Silva et al. (2015) identified the culture of poor waste disposal and currents and tides action as the main forces responsible for the high number of plastic waste on Itacoatiara beach. They additionally attributed the high counts to inefficient collection and disposal of litter, presence of kiosks and numerous food sellers and lack of dustbins. According to Laglbauer et al. (2014) the possible sources of plastics that may have contributed to the large proportion of plastics in Slovenia beaches include wastewater release, pollution from the port of Koper, tourism, sea traffic and agriculture.

During the study period, styrofoam fragments were evident in the beaches as they are used for packaging or from wrecked boats which could have contributed to its high counts. Veiga et al. (2016) similarly alluded that it's quite difficult to quantify foams originating from consumer packaging materials (i.e. to-go containers, cups, plates, coolers, and commercial packing material).

In general, high accumulation rates in terms of litter type in both the dry and wet zones were from plastic and foam (Table 1). Clothing litter (0.086 ± 0.033 items m^{-1} day^{-1}), Foam 0.191 ± 0.236 items m^{-1} day^{-1}), Paper & Cardboard (0.179 ± 0.366 items m^{-1} day^{-1}), plastic (5.161 ± 2.440 items m^{-1} day^{-1}) had higher accumulation rates in the wet zone compared to the dry zone. The latter was dominated by plastics, foams, glass, marine and fishing gear, metal, paper and cardboard, personal care, rubber and wood (Table 1).

Table 1
Litter accumulation rate (number of items m^{-1} day^{-1}) in the dry and wet beach zones by litter category in the six coastal beaches surveyed.

	Litter category	Intertidal beach zone	
		Wet	Dry
1.	Clothing	0.051 ± 0.056	0.086 ± 0.033
2.	Construction materials & ceramics	0.003 ± 0.006	0.008 ± 0.017
3.	Foam	0.846 ± 1.338	0.191 ± 0.236
4.	Glass	0.022 ± 0.025	0.016 ± 0.018
5.	Hygiene	0.040 ± 0.041	0.138 ± 0.149
6.	Marine & fishing gear	0.085 ± 0.085	0.048 ± 0.057
7.	Metal	0.059 ± 0.133	0.040 ± 0.083
8.	Other	0.003 ± 0.004	0.034 ± 0.075
9.	Paper& cardboard	0.179 ± 0.366	0.018 ± 0.032
10.	Personal care	0.001 ± 0.001	
11.	Plastic	5.161 ± 2.440	5.988 ± 2.403
12.	Rubber	0.184 ± 0.212	0.106 ± 0.141
13.	Wood	0.048 ± 0.053	0.031 ± 0.036

The brand audit of marine litter in the six surveyed beaches revealed that products from Kenya were the highest contributor (88%) followed by Tanzania (4.7%), India (1.8%), USA (1.0%), South Africa (0.9%), China (0.7%), Thailand (0.7%), UK (0.4%), Uganda (0.3%) and Egypt (0.2%). The significant contribution of locally produced products to marine litter is consistent with the findings of a study done by Jang et al. (2018) that reported an insignificant amount (only 0.9%) of the large debris from foreign sources.

Results of the brand audit focusing on the top ten manufacturers on individual beaches mirror the general outcome of the overall audit; based on country of origin whereby local manufacturers contributed the highest in all the surveyed beaches. Marine litter with the recent manufacture date labels on the foreign brands was an indication of the products' relatively young age implying that they might have been consumed locally and disposed of by beach users. The brands of litter were observed to be varied in the surveyed beaches, reflecting the heterogeneous nature of marine litter along the Kenyan coast. Findings on the studied beaches particularly Tradewinds 1, Tradewinds 2 and Pirates that are popular and frequented by both locals and foreign tourists revealed the relatively low occurrence of foreign products despite fairly high tourism activities on the beach. This could be an indication that beach hotels are running a relatively efficient waste management system. The brand audit on marine litter also revealed that the top ten polluters were Mars Wrigley's (36.1%), Mzuri Sweets (9%), Unilever (5.5%), Asilia Enterprises (3.5%), Bakhresa Food Products Limited (2.4%), Brookside Dairy Limited (1.9%), Mjengo Limited (1.9%), Kenya Sweets Limited (1.8%), Coca-Cola Company (1.7%) and Highlands Company (1.3%) most of which are locally manufactured in Kenya. The large proportion of Mars Wrigley's chewing gums encountered could be attributed to most local recreational beach users who habitually chew Khat in combination with the chewing gum in most of the beaches surveyed. Notably, Coca-cola, quoted as the "Top Global Polluter" (International Coastal Cleanup, 2019) for two years in a row, was not among the top five polluters and only contributed (1.7%) during this study. This could be attributed to most of their brands being packed in returnable glass bottles and extensive reuse of their PET bottles by local communities for packaging informally produced juice.

Food packaging products (FP) were the most abundant (91.3%) followed by Personal Care products (PC) and Household products (HP) with 6.2 and 2.0%, respectively (Fig. 5). The cross-cutting dominance of FP was observed in both dry and wet beach sections and generally in all the surveyed beaches (Fig. 6). These concur with findings by Thiel et al. (2013) and Andrades et al. (2016) where food-related packaging materials accounted for about 50–80% among seven categories of beach debris in Brazil beaches.

Most of the marine litter encountered in the beaches consisted of packaging material with 39.2% of the branded litter being Multiple Layer-ML (milk packets, sachets, candy wrappers, etc.), while 32.7% were Single Layer-SL (clear flexible plastic film wrappers and polythene bags). PET (clear or tinted plastic drink bottles) contributed to 16.0% of the branded litter while HDPE, PP, PVC and others accounted for 3.3%, 3.0%, 0.6% and 5.1%, respectively (Fig. 5). Nakashima et al. (2011) and Isobe et al. (2014) similarly reported PE (ML and SL), PET and PP as the main types of plastics in marine litter. The high number of ML and SL litter items could be attributed to the high use of items with flexible plastic packaging for sweets and chewing gum commonly consumed in the beaches. Additionally, these categories are made from light polymers that are among the high windage items which can easily be carried by wind and ocean currents over long distances (Nakashima

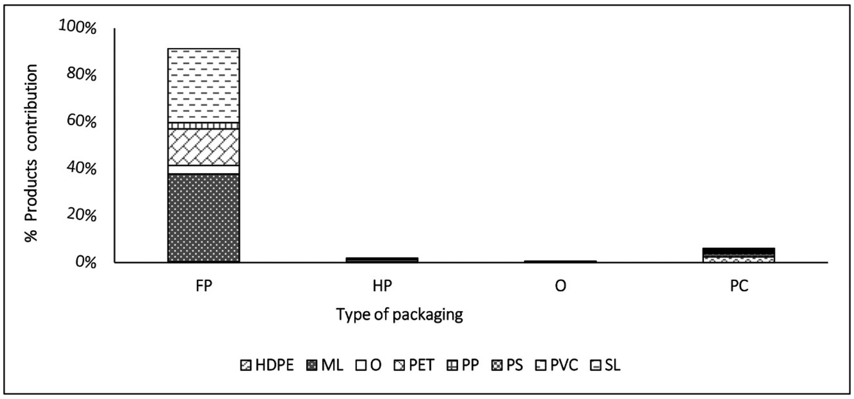


Fig. 5. Litter accumulation rate (items m^{-1} day^{-1}) by litter category in the six coastal beaches surveyed.

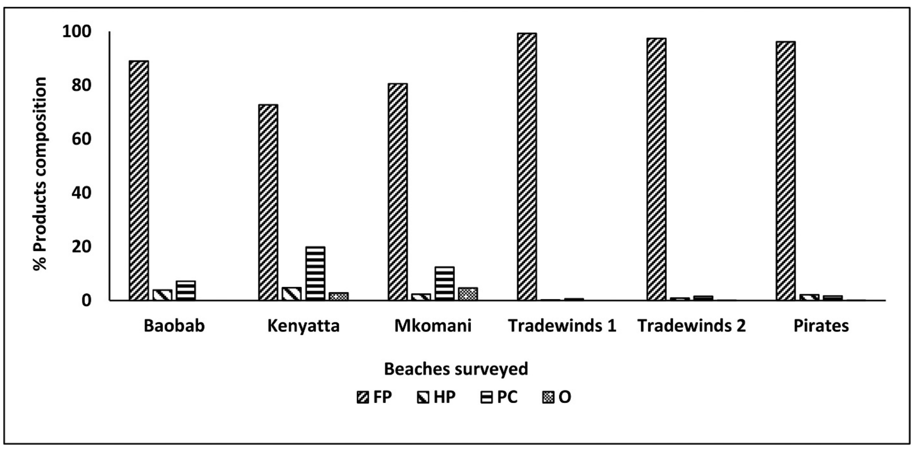


Fig. 6. % products packaging type audited from the beaches surveyed.

et al., 2011). When considering only the packaging prodcuts, food packaging (FP) constituted a highers (Fig. 7)

The distribution of the type of packaging varied across the surveyed beaches. The dominance of the polymers was also observed to vary across the beaches. However, ML and SL were the most conspicuous. In the wet beach section, SL was dominant in four beaches (Pirates, Tradewinds 1, Mkomani and Baobab) while ML was the dominant type of packaging in dry beach section of popular public beaches i.e. Tradewinds 1, Tradewinds 2 and Pirates (Fig. 7).

A total of 1190 PET bottles were encountered from the 6 survey sites over the 10 days accumulation surveys. One hundred and forty-six (146) of these PET bottles were from Bakhresa Foods Products manufacturers– (Tanzania) making it the highest contributor (12.3%) compared to other companies. This can be attributed to its wide distribution network along the Kenyan Coast in addition to the relative affordability of their drinks compared to the other locally available energy drinks. It is also popularly used among local recreational beach users as an accompaniment for chewing khat. Other major contributing

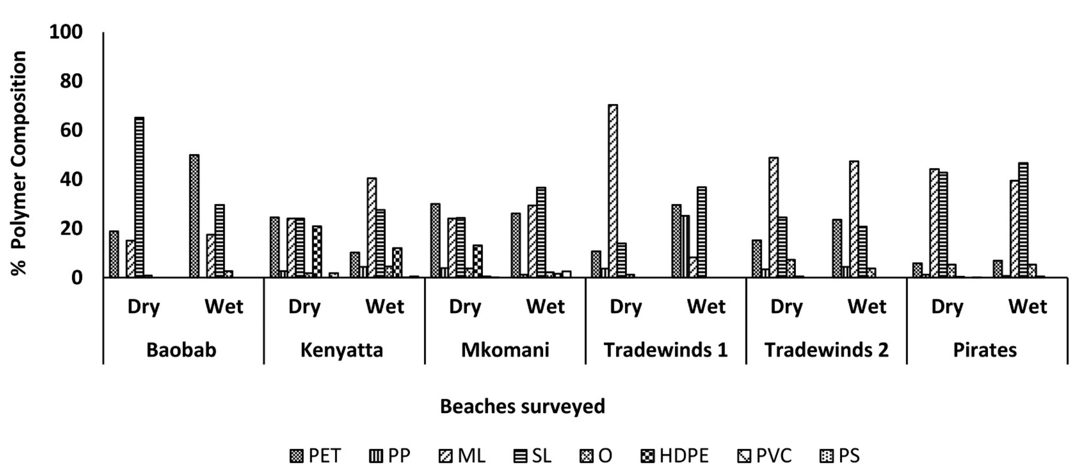


Fig. 7. % contribution of litter product type (Food products [FP], Household Products [HP], Personal Care products [PC] and Others [O]) to the overall litter collected from the beaches surveyed.

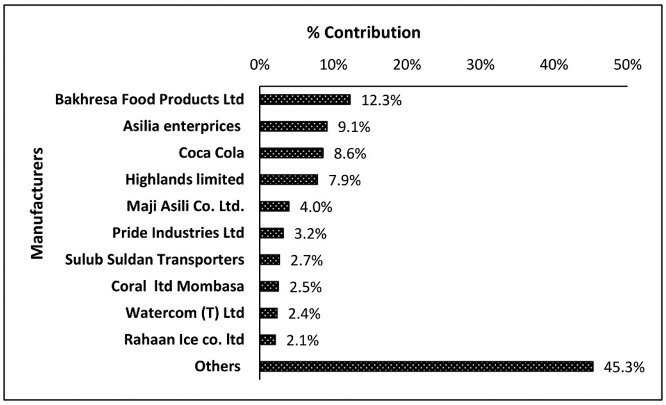


Fig. 8. The % top ten PET bottles contribution by manufacturers from the beaches surveyed.

manufacturers were Asilia enterprises-Kenya 109 PET bottles (9.1%) and Coca Cola-Kenya with 102 PET bottles (8.6%), Highlands LTD-Kenya 93 PET bottles (7.9%), Maji Asili-Kenya 47 PET bottles (4.0%), Pride Industries LTD-Kenya 37 PET bottles (3.2%), Sulub Suldan Transporters-Kenya 31 PET bottles (2.7%), Coral LTD Mombasa-Kenya 30 PET bottles (25%), Watercom (T) LTD-Kenya 28 PET bottles (2.4%) and Rahaan Ice co. LTD-Kenya 25 PET bottles (2.1%) (Fig. 8). Other PET bottles not featured in the top 10 polluting PET bottles included 161 different brands contributing 45% of the total PET bottles collectively.

Noteworthy, the contribution of PET by manufacturers was found to be higher with the presence of the distribution stores or bottling plants in the County of the surveyed beach. For instance, Asilia Enterprises has a large depot in Ukunda (Kwale County) making it the main water supplier in the area hence its high contribution of PET bottles in Tradewinds 1 and Tradewinds 2 beaches. This observation was consistent in most of the top polluting drinking water brands such as Pride Industries, Maji Asili, Coral LTD and Rehaan Ice Co Limited in Mombasa County.

The accumulation rate of packaging materials ranged between 0.01 for PS to 1.3 items m^{-1} day^{-1} for ML (Fig. 9). Whereas only 4.75% of collected litter was brandable; it was observed that Pirates beach had the highest influx of branded litter between the wet and dry sections of the beaches surveyed (Fig. 10). The high rate of daily accumulation is occasioned by the popular use of the beach by the public which has attracted small scale traders selling packaged food material to the beach users. Whereas high rates of accumulation were expected in the dry beach section, higher rates were observed in the wet beach section. This observation could be due to the influx of food packaging material brought in by winds and surface runoff experienced during the survey.

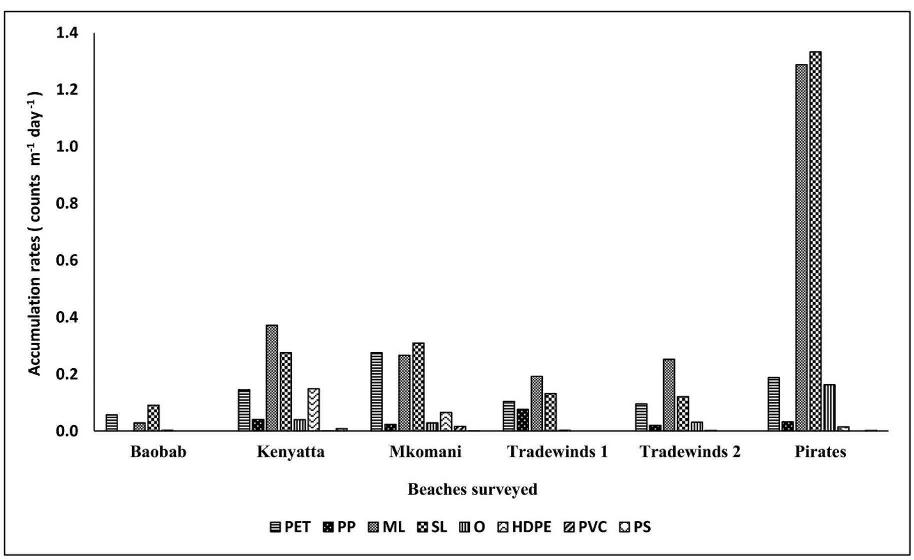


Fig. 9. The accumulation rate of packaging materials in the surveyed beaches (items m^{-1} day^{-1}).

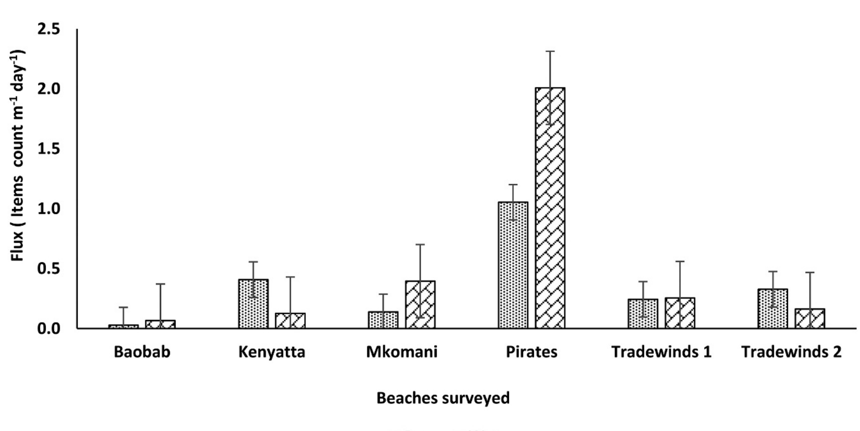


Fig. 10. The influx (items m^{-1} day^{-1}) of branded litter between the wet and dry sections of the surveyed beaches.

The branded litter forms a significant amount of the overall amount of all the litter items on the beaches. This is an indication that a significant amount of litter leakage to the environment can be reduced through manufacturers' responsibility i.e. through return program or by cleaning their products that leak into the environment.

In conclusion, higher amounts of plastic were encountered on the surveyed beaches relative to other litter types. There is a need for management measures that specifically target plastics and innovations that utilize plastics upstream to prevent their leakage into the environment. The easily accessible beaches such as Pirates, Kenyatta and Mkomani which were frequently used for recreation had high mean litter accumulation rates. This emphasizes the need to install waste receptors at the beaches and sensitize beach users against littering. Local products contributed the bigger proportion of marine litter confirming that a local solution could greatly reduce marine litter pollution. PET similarly contributed a significant proportion of packaging products encountered. Promotion of a circular economy and the enforcement of polluter pays principle to encourage return policy will provide a long-lasting solution to plastic menace along the Kenya coast.

CRediT authorship contribution statement

E.O. Okuku: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Writing - original draft, Writing - review & editing. **L.I. Kiteresi:** Funding acquisition, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing - original draft, Writing - review & editing. **G. Owato:** Funding acquisition, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing - original draft, Writing - review & editing. **C. Mwalugha:** Funding acquisition, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing - original draft, Writing - review & editing. **J. Omire:** Data curation, Formal analysis, Methodology, Investigation, Validation, Writing - original draft, Writing - review & editing. **K. Otieno:** Data curation, Formal analysis, Investigation, Validation, Writing - original draft, Writing - review & editing. **M. Mbuche:** Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. **A. Nelson:** Data curation, Formal analysis, Investigation, Writing - original draft, Methodology. **B. Gwada:** Data curation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **L. Mulupi:** Data curation, Formal analysis, Investigation, Methodology, Writing - original draft.

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.

Acknowledgment

We thank the Western Indian Ocean Marine Science Association (WIOMSA) for providing research funds, Kenya Marine and Fisheries Research Institute for infrastructure and technical support, and our project counterpart Kenya Wildlife service staff for support in Pirates beach surveys. A very big thank you to volunteers from KMFRI particularly Benard Oketch, Joy Ndwiga, Quinter Aketch and Purity Chepkemboi for your continued support during the surveys. Patrick Otuo, your efforts in mobilizing survey teams is appreciated. Amina Makori, your GIS support is appreciated.

References

Abu-Hilal, A.H., Al-Najjar, T., 2004. Litter pollution on the Jordanian shores of the Gulf of Aqaba (Red Sea). Mar. Environ. Res. 58 (1), 39–63.
Akoumianaki, I., Kontolefas, P., Katsanevakis, S., Nicolaidou, A., Verriopoulos, G., 2008. Subtidal littering: indirect effects on soft substratum macrofauna? Mediterr. Mar. Sci. 9 (2), 35–52.
Andrades, R., Martins, A.S., Fardim, L.M., Ferreira, J.S., Santos, R.G., 2016. Origin of marine debris is related to disposable packs of ultra-processed food. Mar. Pollut. Bull. 109 (1), 192–195.
Andrady, A.L., 2011. Microplastics in the marine environment. Mar. Pollut. Bull. 62, 1596–1605.
Arias, Andrés Hugo, Marcovecchio, J.E., 2017. Marine debris: problems and solutions of the changing ocean. In: Marine Pollution and Climate Change. 9781315119243, pp. 336. https://doi.org/10.1201/9781315119243.
Barnes, D.K., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 364 (1526), 1985–1998. https://doi.org/10.1098/rstb.2008.0205.
Blidberg, E., Bekken, A.L., Bäckström, A., Hakksi, H., Hansen, L.-M., Skogen, M.H., Frandsen, B.L., Thernström, T., Ångström, J., 2015. Marine Littering and Sources in Nordic Waters. (Denmark).
Buhl-Mortensen, L., Buhl-Mortensen, P., 2017. Marine litter in the Nordic seas: distribution composition and abundance. Mar. Pollut. Bull. 125, 260–270.
Carson, H.S., Lamson, M.R., Nakashima, D., Toloumu, D., Hafner, J., Maximenko, N., McDermid, K.J., 2013. Tracking the sources and sinks of local marine debris in Hawaii. Mar. Environ. Res. 84, 76–83. https://doi.org/10.1016/j.marenvres.2012.12.002.
Claereboudt, M.R., 2004. Shore litter along sandy beaches of the Gulf of Oman. Mar. Pollut. Bull. 49 (9–10), 770–777.
Debrot, A.O., Tiel, A.B., Bradshaw, J.E., 1999. Beach debris in Curacao. Mar. Pollut. Bull. 38 (9), 795–801.
Deloitte, 2014. The Deloitte Consumer Review Africa: A 21st-century View. (London).
Eerkes-Medrano, D., Thompson, R.C., Aldridge, D.C., 2015. Microplastics in freshwater systems: a review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. Water Res. 75, 63–82.
Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, C., Galgani, F., Ryan, G.P., Julia, R., 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PLoS One 9 (12), e111913. https://doi.org/10.1371/journal.pone.0111913.
Galgani, F., Hanke, G., Maes, T., 2015. Global Distribution, Composition and Abundance of Marine Litter, Marine Anthropogenic Litter. Springer, Cham.
Galgani, L., Beiras, R., Galgani Panti, C., Borja, A., 2019. Impacts of marine litter. Front. Mar. Sci. 6, 208.
Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. Mar. Pollut. Bull. 92 (1–2), 170–179.
GESAMP, 2015. Sources, Fate and Effects of Microplastics in the Marine Environment: A Global Assessment. Reports and Studies GESAMP, London.
Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings - entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos. Trans. R. Soc. B-Biol. Sci. 364 (1526), 2013–2025.
Hengstmann, E., Gräwe, D., Tamminga, M., Fischer, E.K., 2017. Marine litter abundance and distribution on beaches on the Isle of Rügen considering the influence of exposition, morphology and recreational activities. Mar. Pollut. Bull. 115, 297–306.
International Coastal Cleanup, 2019. Branded: Identifying the World's Top Corporate Plastic Polluters. (Philippines).
Isobe, A., Kubo, K., Tamura, Y., Kako, S., Nakashima, E., Fujii, N., 2014. Selective transport of microplastics and meso plastics by drifting in coastal waters. Mar. Pollut. Bull. 89, 324–330.
Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. Science 347 (6223), 768–770.
Jambeck, J., Hardesty, B.D., Brook, L.A., Friend, T., Teleki, K., Fabres, J., Beaudoin, Y., Bamba, A., Francis, J., Ribbink, J.A., Baleta, T., Bouwman, H., Knoxi, J., Wilcox, C., 2018. Challenges and emerging solutions to the land-based plastic waste issue in Africa. Mar. Policy 96, 256–263.
Jang, Y.C., Ranatunga, R.R.M.K.P., Mok, J.Y., Kim, K.S., Hong, S.Y., Choi, Y.R., Gunasekara, A.J.M., 2018. Composition and abundance of marine debris stranded on the beaches of Sri Lanka: results from the first island-wide survey. Mar. Pollut. Bull. 128, 126–131.
Katsanevakis, S., Verriopoulos, G., Nicolaidou, A., Thessalou-Legaki, M., 2007. Effect of marine litter on the benthic megafauna of coastal soft bottoms: a manipulative field experiment. Mar. Pollut. Bull. 54, 771–778.
Kilifi County, 2019. Waste to energy project. Infrastructure and Energy. URL. https://directory.africabusinessportal.com/projects/waste-to-energy-project-89, Accessed date: 12 May 2019.
Kühn, S., Bravo Rebolledo, E.L., van Franeker, J.A., 2015. Deleterious effects of litter on marine life. In: Bergmann, M., Gutow, L., Klages, M. (Eds.), Marine Anthropogenic Litter. Springer, Cham, pp. 75–116.
Laglbauer, B.J.L., Melo Franco-Santos, R., Andreu-Cazenave, M., Brunelli, L., Papadatou, M., Palatinus, A., Grego, M., Deprez, T., 2014. Macro debris and microplastics from

beaches in Slovenia. Mar. Pollut. Bull. 89, 356–366.
Law, L.K., 2017. Plastics in the marine environment. Annu. Rev. Mar. Sci. 9, 205–229.
Li, W.C., Tse, H.F., Fok, L., 2016. Plastic waste in the marine environment: a review of sources, occurrence and effects. Sci. Total Environ. 566–567, 333–349.
Lopes da Silva, M., Vieira de Araújo, F., Oliveira Castro, R., Souza Sales, A., 2015. Spatial–temporal analysis of marine debris on beaches of Niterói, RJ, Brazil: Itaipu and Itacoatiara. Mar. Pollut. Bull. 92, 233–236.
Lusher, A.L., Welden, N.A., Sobral, P., Cole, M., 2017. Sampling, isolating and identifying microplastics ingested by fish and invertebrates. Anal. Methods 9, 1346–1360.
Mansui, J., Molcard, A., Ourmieres, Y., 2015. Modelling the transport and accumulation of floating marine debris in the Mediterranean basin. Mar. Pollut. Bull. 91 (1), 249–257.
Ministry of Foreign Affairs of Japan, 2016. G7 Ise-Shima leaders' Declaration, G7 Ise-Shima Summit. Ise-Shima.
Mombasa County, 2019. Environment, waste management and energy. URL Mombasa Countyhttp://www.mombasa.go.ke/environment-waste-management-and-energy/, Accessed date: 5 December 2019.
Murray, F., Cowie, P.R., 2011. Plastic contamination in the decapod crustacean Nephrops norvegicus (Linnaeus, 1758). Mar. Pollut. Bull. 62, 1207–1217.
Nakashima, E., Isobe, A., Magome, S., Kako, S., Deki, N., 2011. Using aerial photography and in situ measurements to estimate the quantity of macro-litter on beaches. Mar. Pollut. Bull. 62 (4), 762–769.
NCEAS, 2013. Global trends in plastic pollution in the oceans. URL. https://www.nceas.ucsb.edu/news/global-trends-plastic-pollution-oceans, Accessed date: 30 November 2019.
Oigman-Pszczol, S.S., Creed, J.C., 2007. Quantification and classification of marine litter on beaches along Armação dos Búzios, Rio de Janeiro, Brazil. J. Coast. Res. 421–428.
Okuku, E.O., Ohowa, B., Mwangi, S.N., Munga, D., Kiteresi, L.I., Wanjeri, V.O., Okumu, S., Kilonzo, J., 2011. Sewage pollution in the coastal waters of Mombasa city, Kenya: a norm rather than an exception. Int. J. Environ. Res. 5 (4), 865–874.
Plastics Europe, 2013. Plastics – The Facts 2013: An Analysis of European Latest Plastics Production, Demand and Waste Data. Brussels and Wemmel.
Prevenios, M., Zeri, C., Tsangaris, C., Liubartseva, S., Fakiris, E., Papatheodorou, G., 2018. Beach litter dynamics on Mediterranean coasts: distinguishing sources and pathways. Mar. Pollut. Bull. 129 (2), 448–457.
Ramirez-Llorda, E., De Mol, B., Company, J.B., Coll, M., Francesc, S., 2013. Effects of natural and anthropogenic processes in the distribution of marine litter in the deep Mediterranean Sea. Prog. Oceanogr. 118, 273–287.
Rech, S., Pichs, J.B.Y., Garcia-Vasquez, E., 2016. Marine litter as a vector for non-native species: what we need to know. Mar. Pollut. Bull. 113, 1–2.
Ribbink, T., Baleta, T., Martin, S., Mbongwa, N., Bray, D., 2019. Guideline to Marine Litter Monitoring. (Zanzibar).
Ritchie, H., Roser, M., 2018. Plastic Pollution, Our World in Data.
Rochman, C.M., Browne, M.A., Underwood, A.J., van Franeker, J.A., Thompson, R.C., Amaral-Zettler, L.A., 2016. The ecological impacts of marine debris: unraveling the demonstrated evidence from what is perceived. Ecology 97, 302–312.
Ryan, P.G., 2016. Ingestion of plastics by marine organisms. In: Takada, H., Karapanagioti, H.K. (Eds.), Hazardous Chemicals Associated With Plastics in the Marine Environment: Handbook of Environmental Chemistry. Springer, Cham.
Ryan, P.G., 2018. Entanglement of birds in plastics and other synthetic materials. Mar. Pollut. Bull. 135, 159–164.
Ryan, G.P., Moore, J.C., van Franeker, A.J., Moloney, L.C., 2009. Monitoring the abundance of plastic debris in the marine environment. Philos. Trans. R. Soc. B-Biol. Sci. 364, 1999–2012.
Schernewski, G., Balciunas, A., Gräwe, D., Gräwe, U., Klesse, K., Schulz, M., Wesnigk, S., Fleet, D., Haseler, M., Möllman, N., Werner, S., 2018. Beach macro-litter monitoring on southern Baltic beaches: results, experiences and recommendations. J. Coast. Conserv. 22 (1), 5–25.
Sheavly, S.B., Register, K.M., 2007. Marine debris and plastics: environmental concerns, sources, impacts and solutions. J. Polym. Environ. 15 (4), 301–305. https://doi.org/10.1007/s10924-007-0074-3.
Thiel, M., Hinojosa, I., Miranda, L., Pantoja, J., Rivadeneira, M., Vásquez, N., 2013. Anthropogenic marine debris in the coastal environment: a multi-year comparison between coastal waters and local shores. Mar. Pollut. Bull. 71, 307–316.
Thiel, M., Luna-Jorquera, G., Álvarez-Varas, R., Gallardo, C., Hinojosa, I.A., Luna, N., Diego, M.-U., Naiti, M., Nicolas, O., Pacheco, A.S., Matías, P.-T., Zavalaga, C., 2018. Impacts of marine plastic pollution from continental coasts to subtropical gyres-fish, seabirds, and other vertebrates in the SE Pacific. Front. Mar. Sci. 5 (238), 1–16.
Thompson, R.C., Moore, C.J., vom Saal, F.S., Swan, S.H., 2009. Plastics, the environment and human health: current consensus and future trends. Philos. Trans. R. Soc. B-Biol. Sci. 364 (1526), 2153–2166.
UNEP, 2011. Assessment of the Status of Marine Litter in the Mediterranean Sea, UNEP (DEPI)/MED WG.357/Inf.4. Athens.
UNEP, 2014. Valuing Plastics: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry. (Nairobi).
UNEP, 2016. Marine Plastic Debris & Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change. (Nairobi).
UNEP-WCMC IU, 2018. Protected Planet: 2018 Report on the World Database on Protected Areas (WDPA). (Cambridge, UK).
UNIDO, 2019. Addressing the Challenge of Marine Plastic Litter Using Circular Economy Methods: Relevant Considerations. (Vienna).
van Franeker, J.A., Blaize, C., Danielsen, J., Fairclough, K., Gollan, J., Guse, N., Hansen, P., Heubeck, M., Jensen, J., Le Guillou, G., Olsen, B., Olsen, K., Pedersen, J., Stienen, E., Turner, D., 2011. Monitoring plastic ingestion by the northern fulmar Fulmarus glacialis in the North Sea. Environ. Pollut. 159 (10), 2609–2615.
Vegter, A.C., Barletta, M., Beck, C., Borrero, J., Burton, H., Campbell, M.L., Costa, M.F., Eriksen, M., Eriksson, C., Estrades, A., Gilardi, K.V.K., Hardesty, B.D., Ivar do Sul, J.A., Lavers, J.L., Lazar, B., Lebreton, L., Nichols, W.J., Ribic, C.A., Ryan, P.G., Schuyler, Q.A., Smith, S.D.A., Takada, H., Townsend, K.A., Wabnitz, C.C.C., Wilcox, C., Young, L.C., Hamann, M., 2014. Global research priorities to mitigate plastic pollution impacts on marine wildlife. Endanger. Species Res. 25, 225–247.
Veiga, J.M., Fleet, D., Kinsey, S., Nilsson, P., Vlachogianni, T., Werner, S., Thompson, R.C., Dagevos, J., Gago, J., Sobral, P., Cronin, R., 2016. Identifying Sources of Marine Litter: MSFD GES TG Marine Litter Thematic Report. JRC Technical Report, Ispra (VA). https://doi.org/10.2788/018068.
Vlachogianni, T., Fortibuoni, T., Ronchi, F., Zeri, C., Mazziotti, C., Tutman, P., Mandić, M., 2018. Marine litter on the beaches of the Adriatic and Ionian seas: an assessment of their abundance, composition and sources. Mar. Pollut. Bull. 131, 745–756.
Williams, A.T., Randerson, P., Di Giacomo, C., Anfuso, G., Macias, A., Perales, J.A., 2016. Distribution of beach litter along the coastline of Cádiz, Spain. Mar. Pollut. Bull. 107 (1), 77–87.
World Bank, 2016. World Development Report 2016: Digital Dividends. World Bank Publications.
Wright, S.L., Thompson, R.C., Galloway, T.S., 2013. The physical impacts of microplastics on marine organisms: a review. Environ. Pollut. 178, 483–492.