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Quantifying plastics waste accumulations on coastal tourism sites in Zanzibar, Tanzania

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ABSTRACT

Plastic pollution is becoming a growing concern on coastal tourism sites. Unquantified amounts of plastic materials are discharged into coastal waters with detrimental effects on local marine environments. With the expansion of the tourism industry, waste increasingly originates from tourism activities and ends up into the ocean due to poor management of solid waste post-consumption. This study explores the sources, abundance, and type of litter in Zanzibar, Tanzania by surveying four coastal tourism sites. The analysis illustrates the contributions to plastic pollution of four sectors of Zanzibar's economy (residential households, building and construction, tourism, and commercial sector). Findings suggest that plastic accounted for almost half (48.5%) of the waste inflow to the environment, and single-use packaging was the dominant litter item on all sampled sites.

1. Introduction

Plastic debris is among the most documented beach and marine litter in Africa (Jambeck et al., 2018). It has been estimated that Africa as a whole discharged nearly 4.4 million metric tons of plastics into surrounding oceans in 2010, and these estimates could reach up to 10.5 million metric tons in 2025 if no actions are taken to curb plastic pollution (Jambeck et al., 2018).

Marine debris is defined as "*any persistent, manufactured, or processed solid material discarded, disposed of or abandoned in the marine and coastal environment*" (UNEP, 2009). Plastic debris often originates on land and enters the ocean via direct deposit, loss, abandonment, rivers or wastewater outflows, or transport by wind and tide (Jambeck et al., 2015). Primary land-based sources of beach and marine plastic litter include residential households (e.g., packaging, household supplies, consumer goods), commercial activities (e.g., single-use packaging), tourism and restoration (e.g., single-use packaging, consumer goods) (UNEP, 2016).

Plastic litter on African coastal sites and its impacts on marine life have drawn scholarly attention since the 1980s (e.g., Ryan, 1987; Ryan, 1988). This period is consistent with an increase in import and consumption of plastics, with approximately 172 million tons of plastic consumed between 1990 and 2017 (Babayemi et al., 2019). While demand for plastic had increased, local waste management systems developed at a much slower pace, resulting in consistent leakages into the environment (Yhdego, 1995; UNEP, 2018).

Increased consumption of plastic, and especially single-use plastics, was also driven by the unprecedented growth of coastal tourism (Honey and Krantz, 2007). Coastal tourism refers to beach-based recreation activities (e.g., beach visits, surfing, snorkeling), land-based activities in the coastal area (all other recreation activities that take place in the proximity of the beach), and commercial or manufacturing businesses associated with these activities (ECORYS, 2013; ECORYS, 2016). All activities can be linked to increased beach accumulation of plastic, that puts local coastal development at risk (e.g., Do Sul et al., 2011; Zhao et al., 2015; Camilleri-Fenech et al., 2018; Chaabane et al., 2019).

Coastal tourism is both contributing to a large share of marine plastic pollution and is negatively affected by it (Newman et al., 2015), hence the dual value of surveying plastics waste accumulation on coastal tourism sites. The most documented effects of marine pollution on tourism sites are ingestion of plastics debris from marine organisms (Cózar et al., 2014; Zhao et al., 2015), degradation of reef areas (Lamb et al., 2018), and reduction of mariculture (Wang et al., 2019). In addition to ecological damages, marine pollution presents several consequences for local economies. It can impoverish local communities by reducing the expansion and investments in the tourism sector (McIlgorm et al., 2011), cause the loss of tourism revenues due to environmental degradation (Jang et al., 2014), and result in the decline of coastal-

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dependent activities such as fishing and recreational activities (Mohammed, 2002; Staehr et al., 2018).

The role of coastal tourism in plastic pollution is especially critical on small islands that heavily rely on tourism activities and extraction of marine resources for their development (Monteiro et al., 2018; Dunlop et al., 2020), as is the case of the Zanzibar archipelago, Tanzania. Like most tropical islands, Zanzibar underwent a ten-time increase in the number of tourism activities since the 1990s, with nearly 400 hotels and guesthouses (equivalent to over 15,000 bedspaces) and related infrastructure located across the archipelago (Sharpley and Ussi, 2014; Zanzibar Commission for Tourism, 2018). Together with increased revenues, the tourism sector also brought an enormous increase in the island's waste generation, that shifted from organic and green refuse to more diversified outputs. In particular, large tourism enterprises introduced recyclables and hazardous wastes, increasing the burden on the local waste management infrastructure (Gössling, 2002; Lange, 2015). As a result, Zanzibar faces several environmental challenges, including those related to poor management of refuse due to the inability of local infrastructure to cope with increased waste production.

As other small islands, Zanzibar too offers a rich topic of research for studying plastic pollution within a naturally bounded system. Small islands, in fact, can present several challenges related to the management of waste and recyclables. Some barriers related to environmental management account for limited physical space for storing and treating waste, lack of resources to implement efficient waste infrastructure, high waste management costs, small markets for recycled plastics, and difficulty of implementing plastics circularity locally (Eckelman et al., 2014). Finally, the generation of plastic waste can vary greatly between high (June–October) and low (March–May) tourism season, bearing implications for the need of addressing different material flows.

Several protocols have been developed for quantifying beach accumulation (e.g., NOWPAP, 2007; JRC, 2013; Lippiatt et al., 2013). For this study, we conducted coastal surveys for macro-debris to quantify the amounts of mismanaged plastics waste leaked into the environment to advance the understanding of plastic pollution on coastal tourism sites in Zanzibar. Investigation of the input beach accumulations has valuable applications: from the perspective of material flows, it links the generation of plastics waste with its source to understand which sector more heavily contributes to marine pollution on coastal tourism sites (Eckelman et al., 2014). Second, it can address the challenges of limited data on waste composition for small developing states (Ally et al., 2014; Millette et al., 2019).

2. Materials and methods

2.1. Study area

The archipelago of Zanzibar is located approximately 30 km off the coast of Tanzania, in the Western Indian Ocean (WIO) region. Unguja is the largest and most densely populated island of the archipelago and has a population of 1.5 million, mostly concentrated in the city of Stone Town.

Unguja's urban areas generate over 96,000 metric tons of waste annually; out of the total amount of urban wastes generated in Stone Town, between 45 and 50% are managed by municipal solid waste management (MSWM) services (Ally et al., 2014). MSWM primarily handles household waste and refuse produced by small businesses (Ally et al., 2014), while tourism waste is mainly tackled by private companies (Zanrec, 2020). In particular, the Zanrec Plastics Company Ltd., a privately owned waste management company, carries out collection and separation of waste and recycling of plastic materials from hotels and tourism facilities, while preventing abandonment of plastics on tourism beaches (Zanrec, 2020).

Data were obtained over three consecutive days in June 2018 (27th–29th June). This period is consistent with the high tourism season, thus enabling examination of the management of solid waste during its generation peak. Four coastal tourism sites were selected in Stone Town for the litter survey: (1) Zanzibar's port, (2) Forodhani Gardens, (3) Shangani beach, and (4) the beach's adjacent areas (e.g., access roads, parking lot, public green area surrounding the beach) (Fig. 1).

2.2. Survey method

Data were collected at each sampling location using the survey methodology for macro-debris as prescribed by National Oceanic and Atmospheric Administration (NOAA) for the monitoring and assessment of beach debris (Lippiatt et al., 2013). Litter surveys were conducted during low tides (approximately 9:00 AM-12:00 PM EAT) to increase the survey's rigor and enable safe access to the shoreline sites (Lippiatt et al., 2013).

Upon arrival at the sampling location, the site boundaries were marked using flag markers. Site's boundaries were identified with physical barriers (e.g., separating walls) or primary substrate change (e.g., shoreline/road, road/green), consistently with NOAA (Lippiatt et al., 2013) and UNEP (IOC (Intergovernmental Oceanographic Commission), 2009) operating guidelines. Within the boundaries, transects ran perpendicular to the primary adjacent road (sampling location 2) or the shoreline (sampling locations 1, 3, 4). Between 2 and 4 transects with 10 m $\times$ 20 m (transect area $\sim$ 200 mq) were delimited at all sites. In each transect, debris sized 2.5 cm or larger were surveyed, following the guidance of NOAA (Lippiatt et al., 2013).

A total of 859 observations were recorded. For each observation, we reported GPS coordinates in decimal degree format, litter composition, source, type of polymer for the plastic debris, and amount of plastic on data sheets. The survey's methodology is reported in Table 1 and exact information for each observation is provided in Table S1.

2.3. Debris classification and quantification

The classification and quantification of litter were conducted on-site and no material was removed from the sampling locations. Samples were processed following four main steps. The first step was the visual inspection of specimens to record the material composition. The sampled materials were classified into three main groups: plastic debris, organic debris, and other materials (e.g., paper, aluminum, glass, cigarette butts, and e-waste). No further material classification was conducted for organic debris and other materials, falling outside of the study's scope.

Following, specimens of each material group were linked to their source, intended as the human activity or sector of the local economy from which the debris originated (Veiga et al., 2016). The sources included in the analysis were residential household, building and construction sector, commercial sector, and tourism sector, consistently with the four major categories of waste generators defined by Zanrec (2020). Sources were assigned based on linear distance (proximity of the transect to a potential source), observed littering practices (conducted at the sampling locations over a three-week period between June–July), and were cross-validated post-survey during interviews with stakeholders from the waste and tourism sectors (Maione, 2019). The cross-validation was conducted to reduce uncertainties, especially for those observations where the other two criteria could suggest a number of potential sources.

Step three and four were only conducted on plastic debris, with the purpose of assessing which source more heavily contributed to the leakage of plastic waste into the natural environment, with detrimental repercussions on marine plastic pollution.

During step three, we classified the plastic debris by polymer type: polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), polystyrene or Styrofoam (PS), and other (miscellaneous plastics) (Plastics Industry Association, 2021). Plastic identification was conducted through visual inspection (e.g., product

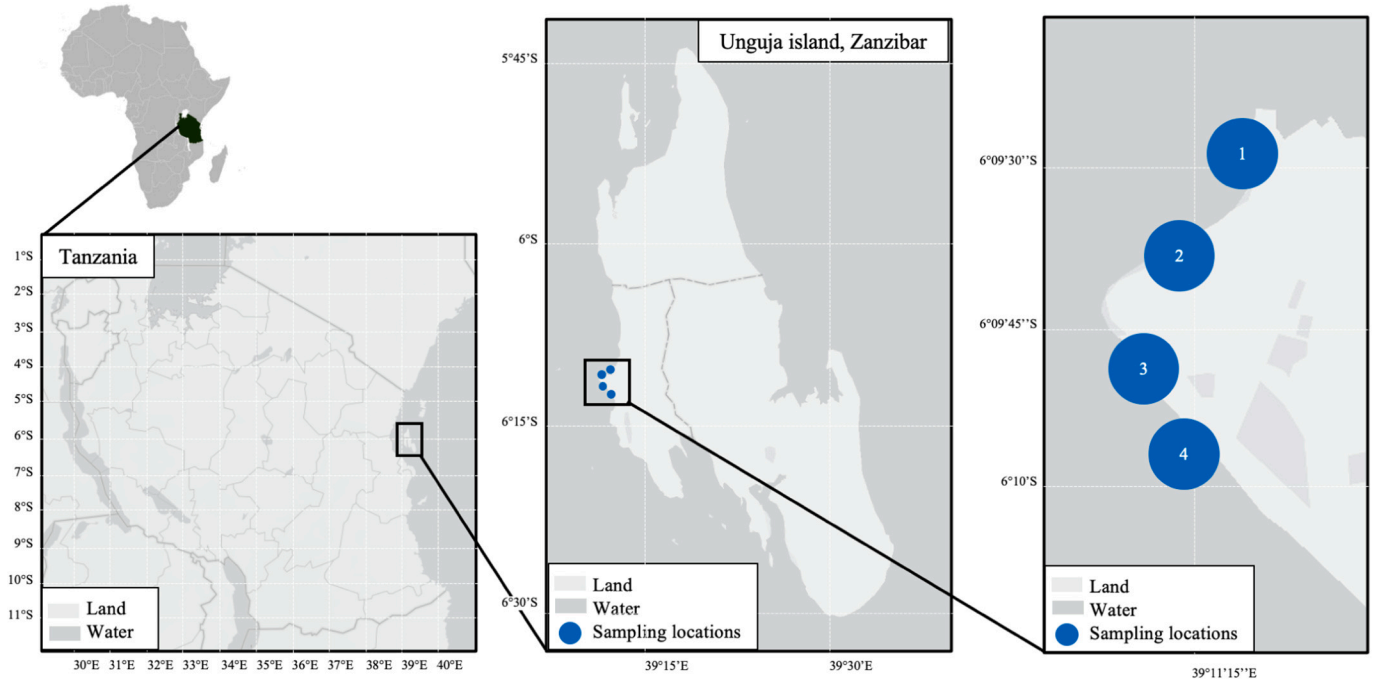

Fig. 1. Map of sampling locations along the coastal tourism sites in Zanzibar, Tanzania.

Table 1
Survey methodology.

	Site preparation	Litter composition analysis	Source identification	Polymer composition analysis	Plastic debris weighing
Activities	•Marking site boundaries •Setting transects	•Recording GPS coordinates •Debris classification by material type (plastic, organic, other)	•Measuring distance from potential sources	•Visual inspection of plastic debris	•Weighing of plastic debris
Materials	•Flag markers •20-m measuring tape •Strip transect •Digital camera	•Hand-held GPS unit •Digital camera •Datasheets •Pencils	•20-m measuring tape •Datasheets •Pencils	•Datasheets •Pencils	•Portable scale (5 kg load capacity, 0.1 kg accuracy) •Datasheets •Pencils

and packaging labels) or by application (GESAMP, 2015; Li et al., 2016; UNEP, 2016).

Finally, we recorded the amount of plastic debris for each polymer type. Litter was weighted using a portable scale, with a load capacity of 5 kg and an accuracy of 0.1 kg.

3. Results

3.1. Litter composition and source

A total of 859 observations were made on four coastal sites; out of these 417 observations (48.5%) weighing approximately 296.7 kg were plastics. At most of the locations, plastic debris was the most prevalent litter type (Fig. 2). A total of 172 observations were recorded at the Zanzibar's port, of which 76 (44.2%) contained plastic debris, 15 (8.7%) organic debris, and 81 (47.1%) other materials. We recorded 221 observations at the Forodhani Gardens, including 110 (49.8%) plastic debris, 11 (5.0%) organic debris, and 100 (45.2%) other materials. A total of 223 observations were collected at Shangani beach, of which 111 (49.8%) plastic debris, 17 (7.6%) organic debris, and 95 (42.6%) other materials. Finally, 243 observations were made in the area adjacent to Shangani beach, including 120 (49.4%) plastic debris, 14 (5.8%) organic debris, and 109 (44.9%) other materials.

The litter composition by source is reported in Fig. 2. In general, residential households and the tourism sector were the main producers of plastic litter, with an average of 51.8 observations/site and 29 observations/site, respectively, followed by the commercial sector (14 observations/site average count) and the building and construction sector (9.5 observations/site average count).

3.2. Source, abundance, and type of plastic litter

The weight of the total plastic litter at the four sampling locations was found to be 296.7 kg, with a mean weight of 74.2 kg/site. The sources and amounts of plastic litter at the four sites are reported in Table 2.

Our results show that plastic litter surveyed at the Forodhani Gardens was primarily linked to tourism consumption, that represented 41.3% of the total by weight, equivalent to 47.9 kg. Plastic litter samples included beverage bottles, tableware, food wrapping, takeaway containers, and plastic shopping bags associated with both daily (e.g., visitors) and night (e.g., food and restoration) tourism activities. The building and construction sector was found to be the secondary source of plastic litter on the site, weighing 40.7% (47.2 kg) of the total plastic amount, followed by commercial plastics (17.8%), and residential households plastics (0.2%).

For the other three sampling sites, the count of plastic debris showed a larger composition of domestic plastic refuse. Residential households plastics at Zanzibar's port were found to be 63.4% of the total plastic sampled on the site, equivalent to 26.8 kg. Sampled litter items included

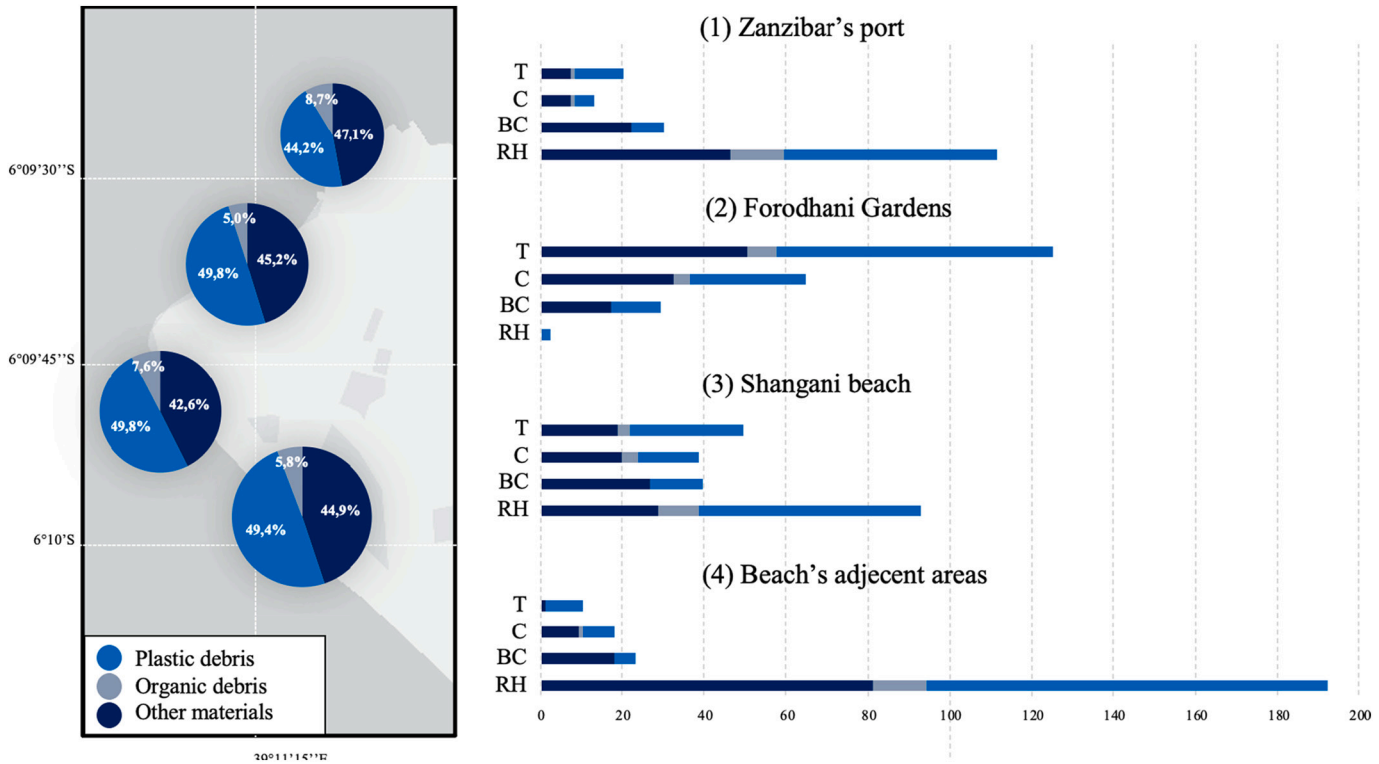

Fig. 2. Percentage (left) and count (right) of litter composition by source at the four sampling locations (T = tourism sector, C = commercial sector, BC = building and construction sector, RH = residential households).

plastic shopping bags, flip flops, rubbers, cleaning supplies containers, tyres, and fishing equipment. A secondary source of plastic litter was the building and construction sector, weighing 22.0% (9.3 kg) of the total plastic amount, followed by tourism plastics (11.3%), and commercial plastics (3.3%). Shangani beach and its adjacent areas showed a similar composition, with domestic plastics weighing respectively 30.8% (20.8 kg) and 70.3% (49.8 kg) of the total sampled plastics.

At all sites, LDPE was the most abundant polymer type, with a mean weight of 38.9 kg/site. Sampled LDPE items included plastic shopping bags and wrappings, and were linked to all sources. The highest abundance of LDPE plastics was recorded at the Forodhani Gardens (72.2 kg), followed by Shangani beach (32.1 kg), its adjacent areas (31.5 kg), and Zanzibar's port (19.7 kg).

PET was the second most abundant polymer type, with a mean weight of 16.8 kg/site. At almost all sites, PET plastics were associated with the tourism sector and residential households consumption. The most common PET items among sampled debris were beverage bottles and cleaning supplies containers, respectively.

Other polymer types encompassed: PP (6.1 kg/site mean weight), in the form of houseware; PS (6.1 kg/site mean weight) from take-away containers; HDPE (2.6 kg/site mean weight), including cleaning supplies and other containers; PVC (2.1 kg/site mean weight) from small plastic components; and other plastics (1,6 kg/site mean weight). Classification and abundance of sampled polymers is presented in Fig. 3.

4. Discussion

All surveyed sites in Zanzibar had plastic debris present. This confirms the findings of previous studies that plastic is a major contributor to beach and marine litter in the archipelago (O'Brien, 2018; Staehr et al., 2018). This trend also aligns with that of other coastal and island countries in Africa, that are considered top generators of land-based plastic debris entering the ocean every year (Jambeck et al., 2015; Jambeck et al., 2018; Babayemi et al., 2019).

The high concentration of plastic debris on coastal sites has similarly been found in other small islands with high tourism potential (e.g., Shamshiry et al., 2011; Schmuck et al., 2017; Lavers et al., 2019; Rey et al., 2021). One of the possible reasons for this may be a poor enforcement of solid waste management policies and services in these areas (Shamshiry et al., 2011). Similar studies on Zanzibar's tourism landscape have shown a lack of specific waste regulations for the tourism sector (O'Brien, 2018; Staehr et al., 2018).

This is also coupled with poor enforcement of plastic bans. The Government of Zanzibar passed a ban on the import, distribution, and sale of plastic shopping bags in November 2006 (UNEP, 2018), further extended to the mainland Tanzania as well as all visitors entering the country on June 1, 2019 (Government Communication Unit, 2019). Despite monetary penalties for the transgressors, plastic shopping bags continued to circulate across the archipelago and were heavily documented on its coastlines (O'Brien, 2018; Staehr et al., 2018). Similarly, we recorded the presence of plastic shopping bags at all sampling locations.

Furthermore, Zanzibar presents the challenges of other small developing islands with underdeveloped waste management infrastructure. This absence of a proper waste collection and treatment system is reportedly correlated to the persistence of illegal disposal practices, such as dumping and littering (Mohee et al., 2015). In addition, studies have shown that several tourism sites and facilities (e.g., hotels, resorts) in Zanzibar are excluded from municipal waste collection (Blomstrand and Silander Hagström, 2014), and only a few plastic companies, such as Zanrec and ZASEA (Zanzibar Scraps and Environment Association), handle the plastic waste generated on coastal tourism sites (Zanrec, 2020).

Another reason for plastic abundance is that mass tourism brought about overexploitation of beach and coastal environments by both tourist groups and locals, with consequent increased waste generation on these sites (Mohammed, 2002; Lange, 2015). In particular, the high tourism season has been linked with greater abundance of plastic litter

Table 2
Source and amount of plastic litter at the four sampling locations.

Sampling location	Source	Amount (kg)	Contribution in weight (%)	Examples of litter items
Zanzibar's port	Residential households	26.8	63.4	Plastic shopping bags, flip flops, rubbers, cleaning supplies containers, tyres, fishing equipment
	Building and construction sector	9.3	22.0	Wrapping, containers, small plastic components
	Commercial sector	1.4	3.3	Plastic shopping bags, food wrapping, supplies containers
	Tourism sector	4.8	11.3	Beverage bottles, plastic shopping bags
Forodhani Gardens	Residential households	0.2	0.2	Cleaning supplies containers
	Building and construction sector	47.2	40.7	Wrapping, containers, small plastic components
	Commercial sector	20.7	17.8	Plastic shopping bags, containers, small plastic components
	Tourism sector	47.9	41.3	Beverage bottles, tableware, food wrapping, takeaway containers, plastic shopping bags
	Residential households	20.8	30.8	Plastic shopping bags, food wrapping, houseware, flip flops, rubbers, cleaning supplies containers, tyres, fishing equipment, clothing
Shangani beach	Building and construction sector	18.3	27.1	Wrapping, containers, small plastic components
	Commercial sector	10.9	16.1	Plastic shopping bags, containers, small plastic components
	Tourism sector	17.6	26.0	Beverage bottles, tableware, food wrapping, containers, plastic shopping bags, flip flops, fishing equipment, sporting equipment
Beach's adjacent area	Residential households	49.8	70.3	Plastic shopping bags, food wrapping, houseware, flip flops, rubbers, cleaning supplies containers, tyres, fishing equipment, clothing
	Building and construction sector	7.2	10.2	Wrapping, containers, small plastic components
	Commercial sector	11.1	15.7	Plastic shopping bags, containers
	Tourism sector	2.7	3.8	Beverage bottles, plastic shopping bags

(Grelaud and Ziveri, 2020). Unsurprisingly, our study has shown that plastic was a persistent pollutant on all sites during the high tourism season. However, more studies to compare our results with sampling during the low tourism season are needed to further assess the total contributions of tourism activities to marine plastic pollution.

Several sources may contribute to beach and coastal littering. In our study, sampled plastic litter was predominantly related to domestic consumption (32.9%), followed by building and construction (27.6%), tourism (24.6%), and commercial activities (14.9%). However, the state of knowledge around sources of beach and coastal litter is patchy due to difficulties in assessing provenience, pathways, and entry points of the plastic debris. While our source identification methods are arguably reliable for intact waste items, assumptions were made for smaller fragments and may introduce biases in our classification.

Like in other coastal regions (e.g., Jang et al., 2014; Artüz et al., 2021), the expansion of tourism in Zanzibar is held responsible for the introduction of new types of plastic litter that are not typically associated with household waste, as is the case of single-use packaging (Ally et al., 2014). In the current study, we found obvious trends that confirmed this thesis. Beverage bottles were the dominant tourism plastics on all surveyed sites, and could be associated with daily tourism activities (leisure and beach visitors). Furthermore, plastic tableware, such as cups, straws, cutlery, and food containers, were abundant in the Forodhani Gardens, and can be linked to daily and night tourism activities (food and restoration) from the food market and kiosks located in the area.

These accumulations were detected despite frequent beach cleanups (1–3 times a week) conducted by local community groups and daily sweeping of the Forodhani Gardens. In another study conducted in the area, we interviewed waste workers about the role of beach cleanups in preventing plastic leakages into the ocean. The study's participants said that "*beach clean-ups have only been limited to the shoreline and shore waters, while the high tide washes up residual litter,*" and "*the frequency of these clean-ups is not sufficient to educate people, locals and tourists, about how to manage waste*" (Maione, 2019). The perceptions of waste workers suggest the need to implement additional measures to contain plastic inflows and mitigate the risks posed to the marine environment.

As most studies (e.g., Bancin et al., 2019; Rapp et al., 2020; Kukkola et al., 2021), our polymer composition analysis showed a greater abundance of polyethylene on all sampled sites. Single-use packaging was a common source of LDPE, including plastic shopping bags and wrappings; followed by PET beverage bottles. While LDPE bears a low recyclability potential, PET from bottles is currently the most recycled polymer type in Zanzibar (Zanrec, 2020). In this perspective, investigating the polymer composition can provide useful information on the recyclability potential of recovered items.

Because we could not remove sampled waste, plastic debris was weighed on site using a portable scale. This instrument allows for a rough measurement of the litter weight without further laboratory analysis and processing. In addition, it offers a simple and cheap approach to recording the abundance of plastic accumulations. However, the balance's characteristics presented constraints related to the accuracy of the weighing (accuracy of 0.1 kg), introducing some measurement errors that should be taken into account for future

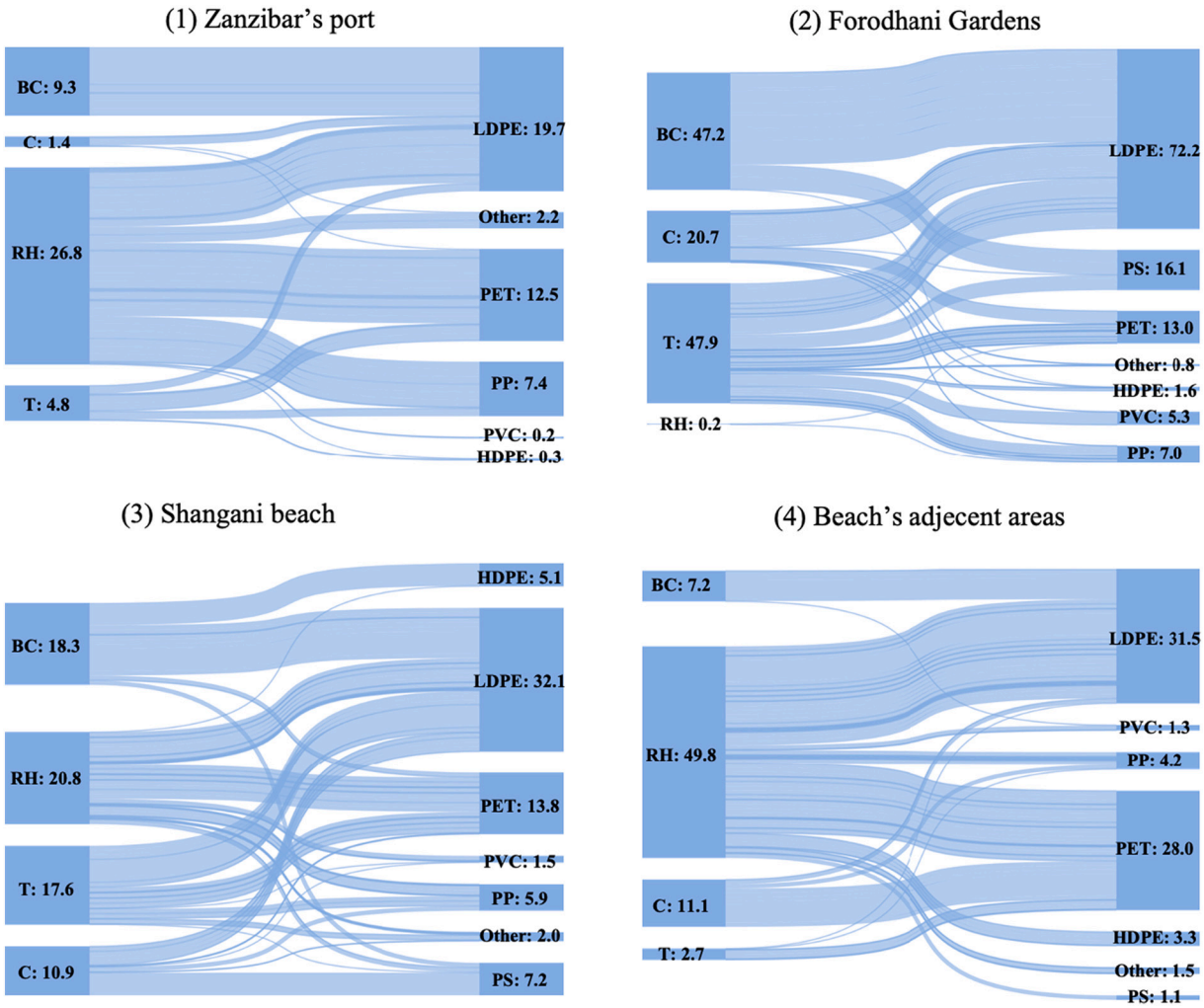

Fig. 3. Classification and abundance (kg) of polymer type by source at the four sampling locations (T = tourism sector, C = commercial sector, BC = building and construction sector, RH = residential households).

comparisons.

5. Conclusions

This is the third study to explore the extent of plastic pollution on Zanzibar's tourism landscape. While the previous two studies focused on stressors and environmental impacts of pollution on the marine ecosystems (Staehr et al., 2018) and amounts of plastic debris in the Zanzibar's port area (O'Brien, 2018), our study provides a baseline analysis of the role of tourism in coastal pollution.

Our findings reveal that plastic was the dominant waste material on almost all surveyed sites, mostly in the form of single-use packaging. Identified sources of plastic waste include domestic consumption, building and construction, tourism, and commercial activities. The current study addresses plastic litter, but the proposed methodology enables inquiry of many other waste materials as well. However, some limitations of the proposed approach are associated with assumptions on the litter sources and approximations in litter quantification.

Analysis of the extent and distribution of coastal plastic pollution can supplement the existing paucity of waste management data for small developing islands. It can also inform decisions on beach and coastal management, based on the initial inquiry of pollution impacts on the marine environment. Future research could investigate litter management strategies and advance solutions to marine littering at a manageable scale.

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CRediT authorship contribution statement

Carol Maione: Conceptualization, Methodology, Investigation, Writing – original draft, Funding acquisition.

Declaration of competing interest

The author declares no conflict of interest.

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