Plastic litter accumulation on high-water strandline of urban beaches in Mumbai, India

H. B. Jayasiri · C. S. Purushothaman · A. Vennila

Abstract Today, almost every beach on every coastline is threatened by human activities. The inadequate recycling and poor management of waste in developing countries has resulted in considerable quantities of plastic contaminating beaches. Though India has long coastline of 5,420 km along the mainland with 43 % of sandy beaches, data on litter accumulation, particularly the plastics, which are one of the most common and persistent pollutants in marine environment, are scanty. The abundance and distribution of plastic litter was quantitatively assessed in four sandy beaches in Mumbai, India, bimonthly from May 2011 to March 2012. Triplicates of 2×2 m (4 m^2) quadrats were sampled in each beach with a total of 72 quadrats. Overall, average abundance of 11.6 items m^{-2} (0.25–282.5 items m^{-2}) and 3.24 g m^{-2} (0.27–15.53 g m^{-2}) plastic litter was recorded in Mumbai beaches. Plastic litter accumulation significantly varied temporally and spatially at $p=0.05$. Significantly higher plastic litter accumulation was recorded in Juhu beach. Furthermore, the highest abundance by weight was recorded in November and May numerically. More than 80 % of plastic particles were within the size range of 5–100 mm both by number and weight. Moreover, coloured plastics were predominant with 67 % by number of items and 51 % by weight. Probably, the intense use of beaches for recreation, tourism, and religious activities has increased the potential for plastic contamination in urban beaches in Mumbai.

Introduction

Marine and coastal litter can be defined as any item that appears on beaches, or at sea, as a result of human activity (Marine Conservation Society 2002). Littering, however, is a behavioural issue that needs to be addressed primarily through education. More attention and resources need to be devoted to increase the awareness among consumers about the environmental consequences of litter, as this is the most effective solution. Coastal litter can be categorised according to material type (e.g., plastic, glass, metal, cloth, paper, rubber, and wood) and the source can be recreation and tourism, fishing, shipping, and sewage. Classifying beach litter into groups based on the type of material has demonstrated that plastic litter predominates (Derraik 2002; Nakashima et al. 2011). The proportion of plastic litter consistently varies between 60 and 80 % of the total marine debris (Gregory and Ryan 1997). These are inexpensive, lightweight, strong, durable and corrosion-resistant, with high thermal and electrical insulation properties (Thompson et al. 2009). Thus, plastics are one of the most common and persistent pollutants in ocean waters and beaches worldwide (Derraik 2002). The poor management and slow recycling of waste in the developing countries has resulted in considerable quantities of plastic contaminating the beaches. As a consequence, plastics accumulate on beaches and reduce the aesthetic appeal and affect recreational value (Pendleton et al. 2001). These pose considerable threat

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by choking and starving wildlife, distributing non-native and potentially harmful organisms, absorbing toxic chemicals and degrading to microplastics that may subsequently be ingested (Laist 1987; Ryan 1987; Henderson 2001; Cadee 2002; Andrady 2011). These organic polymers degrade slowly via photocatalysis when exposed to UV radiation (Andrady 2003) and thus, stay in the environment for a long period of time. Estimates for the longevity of plastics are variable but are believed to be in the range of hundreds or even thousands of years depending on the physical and chemical properties of the polymer. Plastic litter accumulates temporarily or permanently on beaches and on the sea bed at locations known as litter sinks. Accumulation rates vary widely with many factors such as proximity of urban settlements, shore use, prevailing wind and ocean currents, and region (Barnes et al. 2009). At high tide, plastic debris moved by waves is commonly stranded along the wrack line of beaches depending on tidal height. Thus, the strandlines of beaches probably have a more significant accumulation of different size fractions of plastic due to their natural characteristics (Costa et al. 2009). There are major inputs of plastic litter from land-based sources in densely populated or industrialised areas (Pruter 1987; Gregory 1991).

The absence of litter has been identified as a desirable beach quality in beach users' priorities (Morgan et al. 1993). Thus, beach cleanups are carried out in beaches investing large amount of revenue. The stability of beach ecosystems is threatened by mechanical beach cleaning operations, carried out by numerous local authorities in amenity beaches, which tend to remove organic material (seaweed and driftwood) as well as litter items, reducing strandline biodiversity and disrupting the food chain (Llewellyn and Shackley 1996). Many of the litter problems associated with marine debris attract considerable media and public attention. Foremost of these is the visual affront of unsightly, discarded, and/or accidentally lost plastics and other manufactured materials that tend to strand and concentrate along shorelines and sandy beaches of considerable recreational importance (Gregory 2009).

The detrimental consequences of plastic debris contamination for animal inhabitants and human usage of the coastal zone have been variously documented (Ribic et al. 1992; Walker et al. 1997). However, the assessment of plastic accumulation has been relatively neglected (Goldberg

1994). Furthermore, household plastic items are now chiefly made in South Asia and their use in that area, where there is a very large human population density in contact with a large coastline, results in disposable plastic items entering the surrounding seas. The small particles consist of both preproduction plastic pellets and postproduction plastic fragments of unknown origin. Since they are organic polymers, they sorb organic (Karapanagioti and Klontza 2008) and inorganic (Ashton et al. 2010) pollutants into their matrix. Also, organic compounds are used as additives in polymers to improve the properties of the resulting products. The microplastic particles (less than 5 mm in size) are potentially dangerous to marine species due to the risk of magnification over the food chain (Endo et al. 2005) and they may accumulate in plankton-consuming animals and could be passed up the food chain (McDermid and McMullen 2004).

Many of the human impacts are focused at the world's coastlines, which are dominated by sandy shores (McLachlan and Brown 2006) due to amplified population. Sandy shores provide a wide range of ecosystem services, many of which are essential to support the human uses of sandy coasts. Recreational seashore activities are overwhelmingly concentrated on sandy beaches. Beach management, therefore, customarily focuses on maximising the recreational experience for beach users. However, impacts caused directly by recreational activities are emerging as significant environmental issues (Schlacher et al. 2008). Strandline surveys are now organised in many countries and provide information about temporal and spatial trends of plastic accumulation. India is endowed with a long coastline of about 5,420 km along the mainland with 43 % of sandy beaches (Kumar et al. 2006). However, no studies have been carried out with respect to beach litter, particularly plastic debris accumulation in beaches, except the one by Ganesapandian et al. (2011) along a 50-km stretch of shoreline in the northern Gulf of Mannar region of southeast coast of India. This paper quantifies the accumulation of plastic debris in environments on sandy beaches and determines if there are differences in the abundance, distribution and characteristics of debris between beaches using data gathered on bimonthly interval over a 1-year period.

Material and methods

Study area

Mumbai (18°55′N 72°54′E) is the most populous metropolitan city on the west coast of India and the capital of the state of Maharashtra (Census 2011). The state of Maharashtra accounts for 653 km long coastline with 17 % sandy beaches and many of these are lying within Mumbai city (Kumar et al. 2006). Four sandy beaches, named Aksa, Versova, Juhu, and Dadar, were selected for this study (Fig. 1). Daily beach cleanups are carried out in Mumbai coast investing large amount of revenue by the Municipal Corporation of Greater Mumbai. Beach cleanups are carried out by raking the debris, particularly on high-water strandline, during the study period. The cleanups remove most of the large items; a fraction of smaller items may remain on the beach and some may be buried in sand. The width of the continental shelf varies from about 340 km in the north to less than 60 km in the south.

Maximum tidal range in Mumbai coast is about 5 m (Unnikrishnan 2010).

Mumbai has two main climates, humid and the dry, owing to its location along the coast. The humid season includes summer (March to May) and monsoon (June to September). During this time, the atmosphere is highly humid and the temperature rises above 30 °C. Summer is hot and temperature can go beyond 42 °C. Monsoon is accompanied by heavy rainfall. The dry season, basically the winter, is between the months of November and February. Winter is characterised by medium level of humidity and warm and cool weather during day time and night, respectively. During winters, minimum temperature can go below 10 °C (Fig. 2; http://www.mustseeindia.com/Mumbai-weather). Mumbai beaches are popular destinations for both domestic and foreign tourists, where tourists gather in large numbers especially on weekends, splashing and playing in the water for hours. Some beaches are unfit for bathing due to high pollution levels and thus, infested with pathogens (Anon 2010).

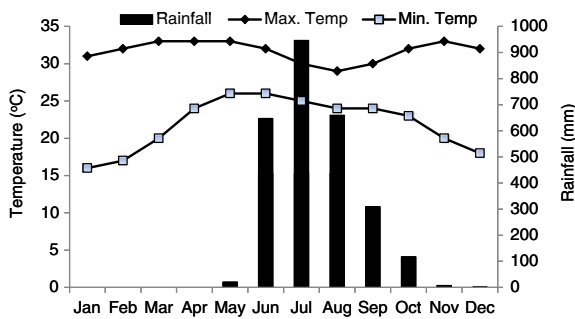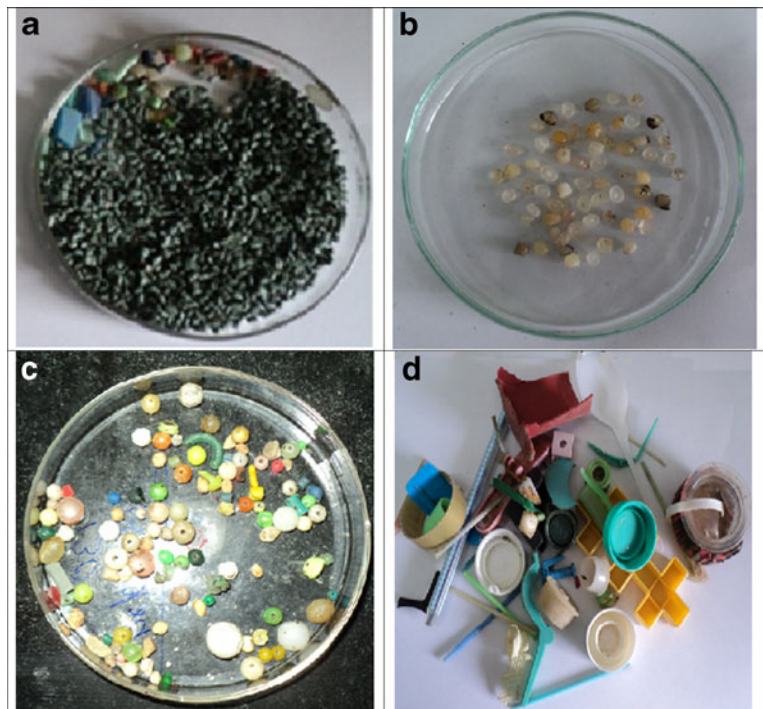**Fig. 1** Map of the study area showing sampling sites
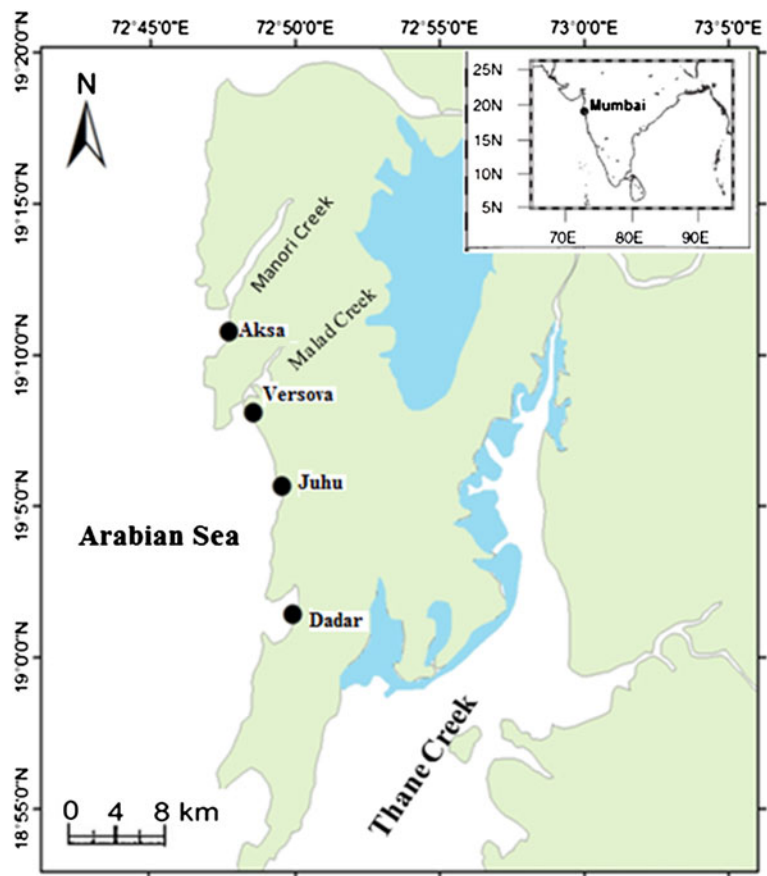
Fig. 2 Average monthly rainfall and air temperature (minimum and maximum) for Mumbai (data source: Mumbai Weather)

Sampling

Plastic litter sampling survey was carried out in four beaches, named Aksa, Versova, Juhu, and Dadar, in Mumbai coast on bimonthly intervals from May 2011 to March 2012. For the quantification of plastics stranded along the high-tide line, the 2×2 m quadrats ($4\ m^2$) were sampled in triplicate along the most recent high water strandline (Martins and Sobral 2011). The strandline is wide (~2 m) in these beaches due to low steepness, varying wave action, and large tidal range. Tide predictions were obtained from online admiralty charts (http://easytide.ukho.gov.uk/easytide/EasyTide/

SelectPort.aspx) for Bandra tide station which is located just north of Dadar beach. At each beach, 3 quadrats were marked along the strandline transect and plastic litter within each quadrant was collected by hand and placed in a labelled plastic bag and carried to the laboratory. Only items of plastics that were visible on the beach surface were included in this survey.

Sorting, classification, and quantification of plastic debris

In the laboratory, the plastic debris was washed with freshwater to remove sand, shells and other debris, and air dried for 24 h to remove the moisture. Then, the plastic debris was sorted and classified into classes. The dry weights of individual plastic particles were determined and recorded to the nearest 0.0001 g on an electronic balance. The particles were classified into four weight classes (<0.05, 0.05–0.1, >0.1–1, >1 g), four size classes based on length measurements of the longest dimension of each particle such as micro (≤5 mm), meso (6–20 mm), macro (21–100 mm), and mega (>100 mm; Barnes et al. 2009; Ryan et al. 2009; Thompson et al. 2009) and four colour

Fig. 3 Plastic items found in samples: **a** Unidentified microplastics on Juhu in May, **b** virgin plastic pellets, **c** plastic beads, **d** plastic fragments
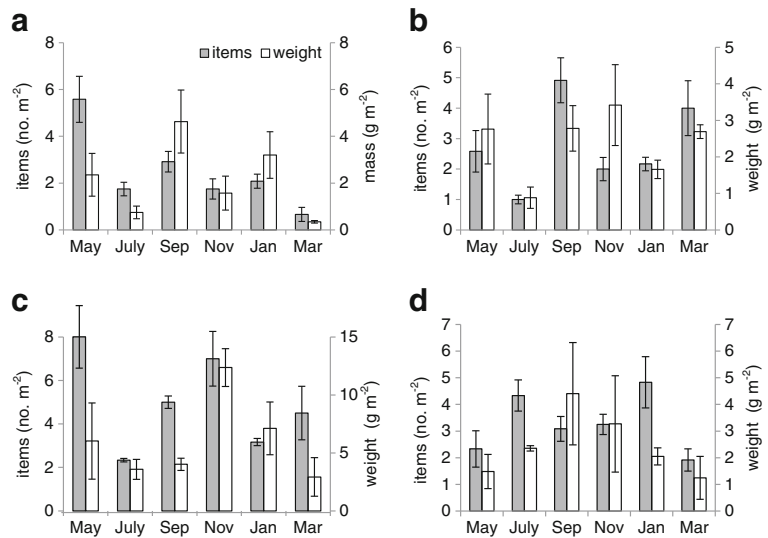
Fig. 4 Distribution of plastics (mean±SE) in beaches of Mumbai from May 2011 to March 2012: **a** Aksa, **b** Versova, **c** Juhu, **d** Dadar

classes such as white, black, coloured, and transparent were made. In each class, the plastic items were counted and weighed. Plastic litter abundances of beaches were expressed in terms of number and weight of items per square metre (Martins and Sobral 2011). The overall percentage of each size, colour, and weight category contributing to the total abundance was then estimated. The analysis of variance was carried out for the effect of month, beach, and their interactions at the significance level of $p < 0.05$ for the abundance by weight and number of total plastics. For significant effects, the mean separation was carried out by Duncan grouping at $p = 0.05$. Pearson correlation analysis of weight, the number of plastics, and size fractions was also carried out. The abundance of plastics in all the categories is expressed as mean±SE.

Results

In total, 72 quadrats were sampled at the high water strandline of the urban beaches of Mumbai to quantify the prevalence of plastic litter accumulated on the beach surface. A sample of some of the plastic items found during the study is shown in Fig. 3. The overall average abundance of 11.67±8.83 items m^{-2} (0.25–282.5 items m^{-2}) by items and 3.24±0.92 g m^{-2} (0.27–15.53 g m^{-2}) by weight was recorded in the beaches of Mumbai coast. The highest plastic abundance was recorded in Juhu beach in May by number of items

(207.00±49.14 items m^{-2}) and by weight in November (12.36±1.62 g m^{-2}). The lowest abundance by weight and number was recorded in Aksa beach (0.67 items m^{-2}, 0.35 g m^{-2}) in March (Fig. 4). However, surprisingly, a high number of microsize (2 mm in length and light blue in colour) particles were recorded on Juhu beach in May (Fig. 3a). Thus, the greatest quantity of plastic litter was reported in Juhu beach in the month of May. This can be an obvious outlier which is clearly seen in Fig. 4. Thus, we removed this fraction of microplastics (outlier) with similar properties (194.33±46.32 no. m^{-2}; 1.80±0.43 g m^{-2}) reported on Juhu beach in May for all statistical analysis.

The two-way ANOVA revealed that the weight and number of plastics significantly varied among months, beaches and their interactions at $p = 0.05$ (Table 1). The temporal variation revealed that the plastics' abundance by number of items was significantly higher in

Table 1 Summary of two-way ANOVA for total plastic debris (weight and number) among months and beaches, and their interactions

Source	df	Number		Weight	
		MS	F	MS	F
Month	5	17.96	5.60*	20.16	4.47*
Beach	3	40.89	12.75*	51.71	11.46*
Month* beach	15	14.17	4.42*	10.82	2.40*
Error	48	3.21		4.51	

*$p = 0.05$, significant difference

May (5.79 ± 1.55 no. m^{-2}) than that of other months while by weight, significantly higher abundance was observed in November (5.16 ± 1.04 g m^{-2}) than in May, July, and March (Fig. 5). Among the beaches, significantly higher abundance by weight and number of items (5.71 ± 1.02 g m^{-2}; 5.78 ± 1.03 no. m^{-2}) was found in Juhu beach than in other beaches (Fig. 6).

Colour fractionation of plastics revealed that coloured plastics are predominant with 67 % by the number of items and 51 % by mass followed by white. Transparent fractions were less than 1 % by items; however, they were 16 % by weight, which was due to a single plastic bottle (Fig. 7).

Size fractionation revealed that macroplastics are dominant in Mumbai by number of items (45 %) and by weight (65 %). More than 80 % of plastic particles were within the size range of 5–100 mm both by number and weight. Megaplastics were the least abundant fraction by number while microplastics were the least abundant by weight (Fig. 8).

The fractionation of plastic debris for four weight classes showed that the majority of plastic items by number are within the weight class of >0.1–1.0 g which accounted for 47 % followed by >1.0 g (28 %). However, by weight, 67 % of plastic litter were of the weight class >1.0 g followed by >0.1–1 g (30 %; Fig. 9).

The multiple correlation analysis performed with high-water height, total number of items and weight, and weight and number of four size fractions at the significance level of 0.05 is shown in Table 2. The highly significant correlations are reported for the total items with weight and number of microsize particles
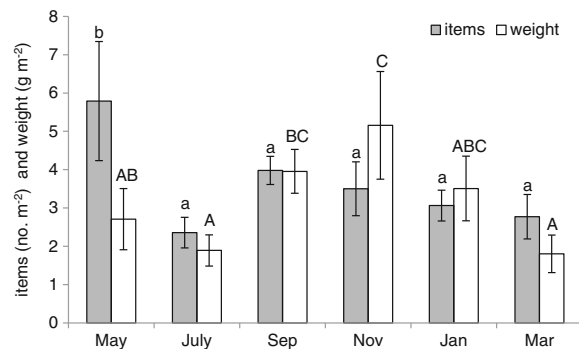

Fig. 5 Temporal variation of plastic abundance (mean±SE) by weight and number of items in four beaches of Mumbai coast from May 2011 to March 2012. *Bars with different letters in lowercase vary significantly among the months for number and uppercase for mass* ($p<0.05$)
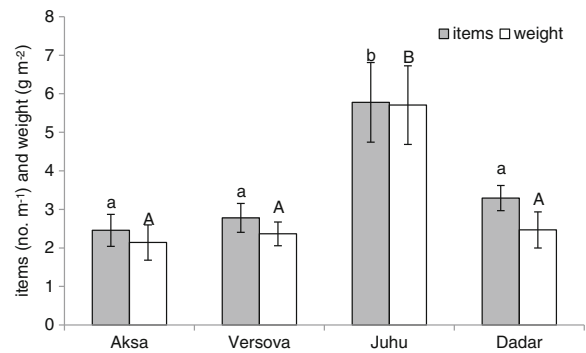

Fig. 6 Spatial variation of plastic abundance (mean±SE) by items and weight in Aksa, Versova, and Juhu beaches from May 2011 to March 2012. *Bars with different letters in lowercase vary significantly among the beaches for the number of items and uppercase for mass* ($p<0.05$)

and weight of macroparticles. The total weight of plastics has highly significant correlation with weight of macrosize particles. Further, weight of microplastics is highly correlated with number of microplastics ($r=0.91$), while the weight of macrosize fraction has highly significant correlation with the number of macroplastics. Moreover, high-water height is significantly correlated with the total items, and the number and weight of microsize particles.

Discussion

Marine debris could have impacts on marine organisms, habitats, and human economies (Derraik 2002; McDermid and McMullen 2004; Sheavly and Register 2007; Moore 2008; Hinojosa and Thiel 2009; Santos et al. 2009). Since plastics are buoyant (floatable) material, these tend to be more harmful than elements that are able to settle due to their ability to be transported throughout the water body and ultimately to the marine environment. Most of the beach litter surveys confirmed the predominance of plastic litter in terms of the number of items (Golik and Gertner 1992; Madzena and Lasiak 1997; Derraik 2002; Santos et al. 2009). However, most of the reports have presented plastic as a percent of total beach litter (Kusui and Noda 2003; Ganesapandian et al. 2011). Furthermore, the different authors have reported different size categories of plastics. Most of the reports are related to micro or small plastic debris (McDermid and McMullen 2004; Ng and Obbard 2006). In this study, we report the plastic debris (~1 to >100 mm) stranded

Fig. 7 Average percentages of colour fractions of plastic debris in beaches of Mumbai coast; **a** by the number of items and **b** by mass
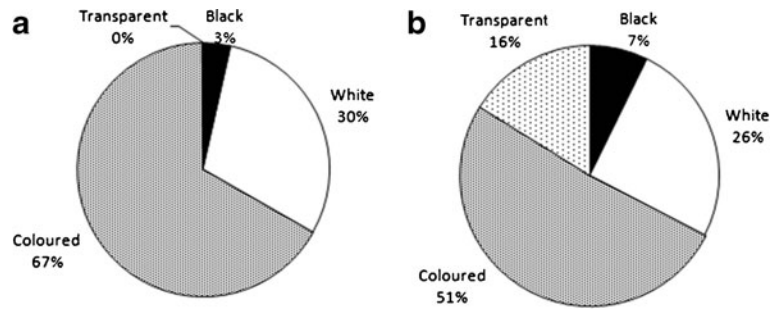
on high-water line. Thus, direct comparisons with other surveys are difficult. This difficulty also is largely owing to the differences in sampling protocols and the type of data recorded (Ryan et al. 2009). The similar work carried out by Martins and Sobral (2011) in beach sediment reported the preponderance (88 %) of 1–10 mm particles.

Substantially high overall average abundance of plastic litter in the beaches of Mumbai coast was observed. Though, daily beach cleanups are carried out, some small particles may remain in the strandline of the beach. Oigman-Pszczol and Creed (2007) estimated significantly low litter abundance of 13.76 items/100 m^2 (0.14 items m^{-2}) for seven litter types including plastics on the beaches along Armacao dos Buzios, Rio de Janeiro, Brazil, and reported significantly low plastic abundance (~0.05 items m^{-2}) during a 4-day study. But Moore et al. (2001) reported 99 % of the total abundance and 51 % of the total weight of three plastic categories (preproduction plastic pellets, foamed plastics, and hard plastics) along the Orange County shoreline. Kusui and Noda (2003) reported stranded litter on Japanese and Russian beaches which accounts for 341 and 20.7/100 m^2 with 40–80 % of the plastics items in terms of weight and number. Thus, it does not support to the overall abundance of plastics.

The plastic abundance can be varied with month and season. We found the significantly high abun-

dance plastic accumulation in Juhu beach compared to the other beaches. Though we have not correlated the abundance with beach visitors, Juhu beach, which is easily accessible to visitors, attraction to tourists and recreational activities, might have resulted in high plastic density. The blue colour microplastics (1.5 mm in diameter and 2 mm in length) reported in May at Juhu, which was an outlier, might be due to the spill out from a ship during transportation or plastic industry. Excluding this fraction, significantly high number of plastic particles in May might also be due to the summer holidays in Mumbai resulting in high beach usage and recreational activities.

Plastic litter loads are greater close to urban areas (Garrity and Levings 1993; Willoughby et al. 1997), increasing with the numbers of visitors to beaches (Frost and Cullen 1997) which is consistent with our study. Though, we have not classified the items by function, items such as toys, cups, pharmaceutical items, bottles, beads of necklaces, dress material, bangles, etc. suggest that the major source for plastic items in these urban beaches is land based. As such, recreational and tourism activities might have contributed more in these beaches. The high plastic accumulation by weight was recorded in November. The most pleasant weather period of Mumbai is between October and February. So we may expect high plastic accumulation within this period due to the high usage

Fig. 8 Average percentages of size fractions of plastic debris in beaches of Mumbai coast: **a** by items and **b** by weight
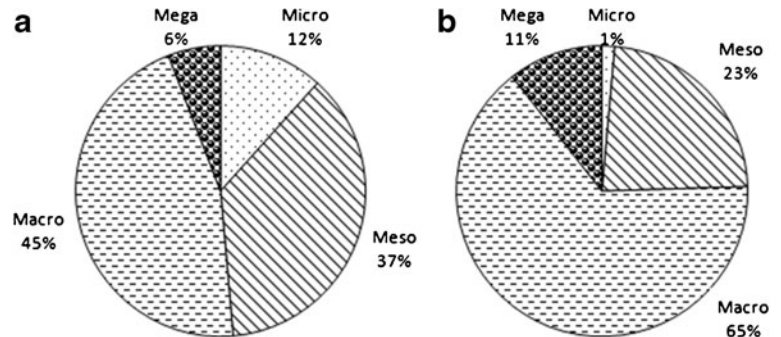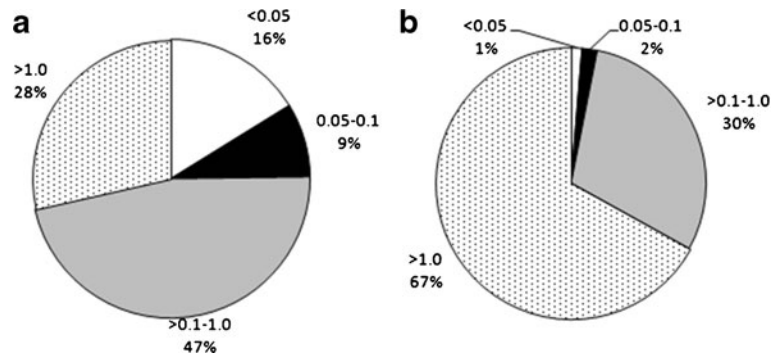
Fig. 9 Average percentages of four weight classes (<0.05, 0.05–0.1, 0.1–1, and >1 g) of plastic debris in four beaches: **a** by items and **b** by weight

for recreational activities such as horse riding, playing games (cricket, soccer, etc.). However, beach activities could be less in January due to the cold sea breeze, particularly in the evening, affecting low accumulation of plastics by weight compared to November. Also macro- and mega-plastic accumulation is possible because of the calm sea condition during this season. However, the second highest accumulation in September might be due to gathering of Hindus in beaches to celebrate the Ganesh Chaturthi festival, which is one of the most important Hindu festivals in India.

The heavy monsoonal rains in July and humid high temperature in March might have led to low plastic accumulation due to less number of beach visitors and recreational activities (Fig. 2). Thus, plastic litter accumulation can be explained by beach usage for

different activities in relation to weather pattern. However, some other factors such as sea condition, vacations, and other religious festivals (i.e., Dewali festival) may interact for litter accumulation in these urban beaches. During the monsoon season, the beaches have very undefined strandline due to strong waves and winds which might also affect quantification. Marine-based items, particularly fishing-related items such as fragments of nets, ropes, and lines, were also observed, particularly during the monsoon season. Though megaplastics were less, more than 80 % of the items were within the size range of 5–100 mm and visible to naked eye. Also, degradable debris was very common in these beaches which also might have affected the collection of microplatics during the survey which is accounted for less than 12 % by the number of items.

Table 2 Pearson correlation matrix of tidal height, total number and weight of plastic litter per square meter and size fractions of plastics (weight and items) at the significance level of 0.05 (two tailed)

		HW height	Total items	Total wt.	Weight				Items		
					Micro	Meso	Macro	Mega	Micro	Meso	Macro
Total items		0.36[a]									
Total wt.		−0.03	0.48[b]								
Weight	Micro	0.31[a]	0.77[b]	0.19							
	Meso	0.04	0.26[a]	0.44[a]	0.08						
	Macro	−0.00	0.50[a]	0.88[b]	0.21	0.22					
	Mega	−0.09	0.94	0.60[a]	−0.04	0.37[a]	0.26[a]				
Items	Micro	0.36[a]	0.81[b]	0.17	0.91[b]	0.08	0.18	−0.04			
	Meso	0.16	0.65[a]	0.26[a]	0.34[a]	0.51[a]	0.22	−0.05	0.38[a]		
	Macro	0.10	0.77[b]	0.66[b]	0.41[a]	0.23	0.76[b]	0.15	0.39[a]	0.52[a]	
	Mega	0.10	0.31[a]	0.52[a]	−0.01	0.24[a]	0.44[a]	0.52[a]	−0.01	0.16	0.43[a]

HW high water

[a] Correlation is significant

[b] Correlation is highly significant

The pattern of litter dispersal on beaches is often irregular; it can collect at one end or in patches across the beach (Williams and Tudor 2001). Some beaches often have very undefined strandlines with some litter distributed away from these areas due to re-emergence, from beneath the surface as a result of being trapped between surficial sand or as windblown accumulations. Thus, it might have affected our quantification. Further, triplicate of sampling may not be enough to explain the plastic litter accumulation for long beaches. Furthermore, data collected in the study may not be enough to present the overall distribution pattern of plastics in the beaches of India. However, these baseline data will be more beneficial to design future studies on litter accumulation in urban beaches, particularly in South Asian countries, as there are no enough data available on litter accumulation.

Furthermore, miroplastics are composed of preproduction plastic pellets and fragments. Microplastics have been recently identified as marine pollutants of significant concern due to their persistence, ubiquity, and potential to act as vectors for the transfer and exposure of persistent organic pollutants to marine organisms (Karapanagioti and Klontza 2008; Ogata et al. 2009) and are potentially dangerous to marine species due to the risk of magnification over the food chain (Endo et al. 2005). Though pellets were also reported in our samples, more pellets were found buried in beach sediment (Jayasiri, unpublished data). Gregory (1978) found in quite considerable quantities, in counts of over 100,000 raw plastic granules per metre of the coast. The presence of microplastics in sediments and seawater is likely due to ongoing waste disposal practices from industries and recreational activities, and discharge from shipping (Ng and Obbard 2006). There is a considerable variation in the methodology between regions and between investigators, and more valuable and comparable data could be obtained by standardising the monitoring approaches (Ryan et al. 2009).

Conclusion

Plastic litter accumulation was quantitatively assessed in urban beaches of Mumbai and found significantly high spatial and temporal variations with the high abundance of macroplastics. The main source identified on the study area is the land-based source, represented by various beach uses in relation to the weather pattern. This high litter accumulation is more related with the intense use of beaches for recreation, tourism, and religious activities. The abundance and distribution of litter in Mumbai coast seems to be especially influenced by recreational visitors reflecting inadequate disposal practices and littering behaviour. Considering the cost of beach clean-ups and environmental consequences of plastic litter, we recommend that efforts have to be made towards creating awareness among various beach users on the responsible disposal of litter and proper recycling, and the reuse and recovery of energy from plastic debris, which might help reduce the plastic pollution in these beaches.

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