Marine Pollution Bulletin 77 (2013) 107–112

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Quantitative analysis of plastic debris on recreational beaches in Mumbai, India

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ARTICLE INFO

Keywords:
Plastics
Microplastics
Abundance
Beaches
Debris
Mumbai

ABSTRACT

Plastic litter was quantified on four sandy beaches in Mumbai. The mean abundance of 7.49 g and 68.83 items per square metre was recorded. The abundance of plastics significantly varied among the beaches showing an increasing trend in the southern part. The abundance of plastics by weight in Dadar was significantly higher than that in Aksa. The size fractionation of plastics proved that small particles (1–20 mm) are predominant with 41.85% microplastics (1–5 mm) which emphasizes the high risk to marine organisms due to possible ingestion. The highest quantity of microplastics was seen in Juhu beach (55.33%) followed by Versova, Aksa and Dadar. The major contributing factors for the abundance are beach usage for different activities such as recreational, religious and fishing which suggest that the land-based sources provide major inputs to plastic pollution in these beaches.

Plastic debris in aquatic ecosystems is a rapidly increasing long-term and widespread threat that represents a great challenge for remediation (Derraik, 2002; Zarfl et al., 2011). The poor management of waste in developing countries has resulted in considerable quantities of plastics contaminating the beaches. Plastics typically make up the major category in most litter surveys in terms of both weight and number (Takashi and Michio, 2003). As a consequence, plastics accumulate on the beaches, reduce the aesthetic appeal as well as cause harm to wildlife which may either ingest the plastic or become entangled in it (Cadee, 2002). The longevity of plastics in the environment is variable and depends on the physical and chemical properties of the polymer (Barnes et al., 2009). The dynamic environment of many beaches leads to potential changes in plastic litter composition and quantity on a frequent basis. Land-based sources in densely populated or industrialized areas (Gregory, 1991) are major inputs of plastic litter and are responsible for 70–80% of the plastics in the marine environment (Sheavly, 2005).

The risk of magnification of microplastics (<5 mm) and their impacts on the marine ecosystem received more attention (Endo et al., 2005) recently, although size fractions are not normally distinguished in the majority of reports dealing with marine debris, probably due to sampling difficulties associated with large-scale surveys (Moore, 2008). Therefore, their sources, fate and further environmental consequences are poorly understood (Sheavly and Register, 2007). Cole et al. (2011) extensively reviewed the microplastics in the marine environment. These microplastics (pre-production pellets and post-production fragments) enter the marine environment through direct introduction with runoff and weathering of large plastics (Andrady, 2011). It is not possible to obtain reliable estimates of the quantity of plastic debris that reaches the marine environment, but the quantities are nevertheless quite substantial (Derraik, 2002). Only a few studies have been conducted on plastic accumulation in beach sediment (Williams and Tudor, 2001; Kusui and Noda, 2003). The accumulation of both macro- and micro-plastics has consistently increased on shores and in sediments, respectively, for the last four decades (Thompson et al., 2004; Barnes, 2005). India has a long coastline of about 5423 km along the mainland with 43% of sandy beaches (Kumar et al., 2006). However, there are no published reports with respect to beach litter on Indian beaches. Thus, this paper quantifies the accumulation of plastic debris on sandy beaches, and determines if there are differences in the abundance and size fractions of debris among beaches and seasons.

There are nine beaches from the southern end of Mumbai to the northern end. The beaches (Aksa, Versova, Juhu and Dadar) selected for the present study represent a wide geographical coverage of Mumbai (Fig. 1). Bimonthly sediment samples were collected during May 2011 to March 2012 from the top 2 cm at the high-tide mark on shore, from areas of $50 \times 50\ cm^2$ on the beaches to quantify the plastic debris in sediment in triplicates. The sampling was carried out just after the high tide and before the clean-up operation as plastic is predominantly accumulated in this zone. The sediment samples were air-dried and sieved (1-mm). The material retained was introduced into a glass tank containing sodium chloride ($140\ g\ l^{-1}$) solution (Martins and Sobral, 2011). The floating

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0025-326X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpolbul.2013.10.024

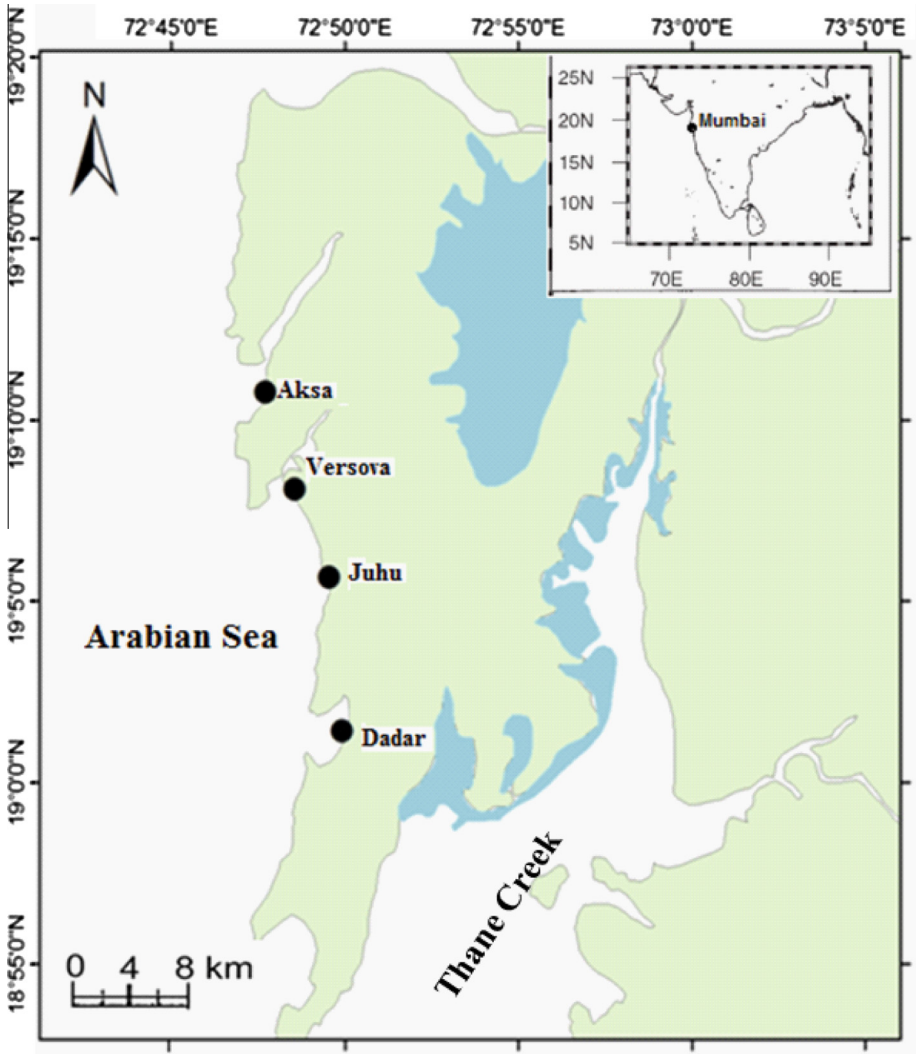

Fig. 1. The map showing sampling sites in Mumbai Coast.

plastic particles were recovered and washed with freshwater to remove salt. Then, the plastic debris was air-dried and individual plastic particles sorted, weighed to the nearest 0.0001 g on an electronic balance and the length measured to the nearest millimetre along the longest axis according to the structure of the particle and classified as micro- (<5 mm), meso- (5–20 mm), macro- (21–100 mm) and mega- (>100 mm) debris (Barnes et al., 2009). Plastic particles of size less than 1 mm were not considered in this survey. Also, styrofoam and films were not collected due to their buoyancy, and related floating and stranding characteristics as windblown material. Plastic abundances are expressed in numbers and weight per square metre in the sediment of 2-cm thickness in beaches.

The mean abundance of plastics was found to be 7.49 g (0.17–56.27 g) and 68.83 items (12–960 items) per square metre. The results conclusively prove that plastic litter predominates in Mumbai beaches. Martins and Sobral (2011) found a higher abundance of plastic debris (185.1 items m^{-2}; 36.4 g m^{-2}) in the Portuguese coastline when compared to Mumbai beaches, while Costa et al. (2009) reported a much higher density (0.29 items per square centimetre) in the sediment of a Brazilian beach. Significant variation in abundance by weight and number of items was observed for months, beaches and their interaction except abundance by weight among the months (Table 1). The plastic abundance by number in the sediment collected in May (204.33 ± 93.13 m^{-2}) was significantly higher than that of the other months (Fig. 2a). The abundance by weight in Dadar sediment was significantly higher than that of Aksa while those of Versova and Juhu were intermediate (Fig. 2b). In general, the abundance of plastics in sediment on beaches at the high tideline increased towards the south. Kumar et al. (2006) pointed out that the long-shore current along the west coast of India is mostly towards the south. Thus, the long-shore current may affect the distribution of plastics on beaches. In addition, the number of beach visitors or usage of the beach and proximity to population centre could be the other most important factors for the abundance and distribution of plastics on Mumbai beaches. Except for Aksa, all the beaches studied are located in the highly populated urban area. Among the beaches, Juhu showed significantly higher number (155.33 ± 63.48 m^{-2}) of plastics than other beaches (Fig. 2b). The greatest abundance of plastics by weight was found at Dadar (29.17 ± 14.21 g m^{-2}) in September followed by Versova (16.36 ± 8.91 g m^{-2}) and Juhu (14.78 ± 7.20 g m^{-2}) in May and July, respectively. The least abundance by weight (0.47 ± 0.27 g m^{-2}) was observed at Aksa in March 2012 and by number at Aksa and Juhu in January (Fig. 3). In May, the highest number of microplastics was observed at Juhu. Thus, the greatest abundance of plastics by number was at Juhu (716.00 ± 126.51 m^{-2}) in May followed by Dadar in January (Fig. 3). The high abundance in May might be due to the increase of beach visitors and therefore, the high recreational activities during summer holidays in Mumbai. Thornton and Jackson (1998) also