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Characteristics, seasonal distribution and surface degradation features of microplastic pellets along the Goa coast, India

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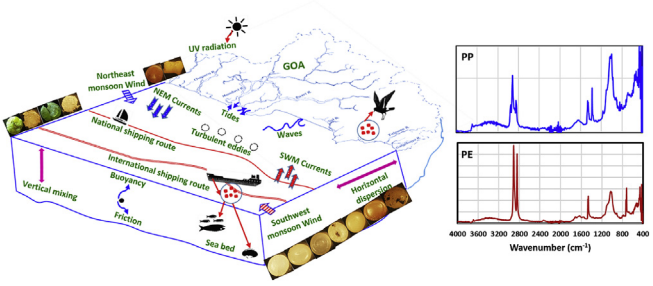
HIGHLIGHTS

- We investigated the spatial and seasonal variations of MPPs at 6 beaches of Goa.
- White MPPs with PE and PP polymer types are abundant in all beaches.
- Weathering of MPPs during the NE is higher than the SW monsoon.
- Sources of MPPs on beaches of Goa coast probably ocean-based.
- SW monsoon winds and currents are the driving forces for deposition of MPPs.

GRAPHICAL ABSTRACT



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ABSTRACT

Microplastic pellets (MPPs) are ubiquitous contaminants, recognised as a serious threat to the biota in coastal, estuarine and marine environment. The distribution, abundance, weathering and chemical characteristics of MPPs on the beaches of Goa, and their transport to the coast during the southwest (SW) monsoon are discussed in this paper. MPP samples collected from six sandy beaches were categorised based on colour and polymer types using Stereoscope microscope and FTIR-ATR spectroscopy, respectively. White colour MPPs were the most abundant, and Polyethylene (PE) and Polypropylene (PP) were the dominant polymer types of MPPs deposited on all the beaches. Carbonyl index values showed that MPPs collected in June 2015 (representing SW monsoon) were 'new', whereas the MPPs collected in January 2015 were 'aged', showing that MPPs are arriving at Goa coast only during SW monsoon due to conducive hydrodynamic conditions. Characteristics of MPPs suggest that they could be originated primarily from ocean-based sources. The winds and surface currents during SW monsoon are the driving forces for the transportation and deposition of MPPs on the Goa beaches. The results of this study will be useful to the National 'Clean India' program for effective plastic debris removal management.

1. Introduction

The global production of plastics has increased from 1.5 million tonnes in 1950 to 299 million tonnes in 2013, representing 4% increase over 2012 (Plastics Europe, 2015). A part of these plastics reaches the ocean through different pathways, and pollute the marine environment due to improper waste management and coastal and marine activities. A recent study by Jambeck et al. (2015) shows that 275 million metric tonnes (MMT) of plastic waste was generated in 192 coastal countries in 2010, with 4.8–12.7 MMT entering the ocean. Microplastics are small plastic

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particles in the environment, generally less than 5 mm in diameter. The following two types of microplastics are currently existing: (i) primary microplastics which are made to carry out certain functions (e.g. toothpaste, skin cleansers and cosmetics) and microplastic pellets (MPPs) used for the manufacturing plastic material and (ii) secondary microplastics, which are generated when macro-sized plastics in the marine environment are physically (wind, wave and current), chemically (UV radiation) and biologically (microbial activity) degraded and fragmented into micro-sized (<5 mm) particles (Cole et al., 2011; GESAMP, 2015). Eriksen et al. (2014) have estimated that there is 5.25 trillion plastic pieces (tremendous amount of microplastics) floating in the world oceans weighing over 250,000 tonnes. At the same time, there is an increase in the global effort taken by the scientific community to better understand the effect of plastic marine pollution (NOAA-UNEP, 2012). Within a short period, the research on microplastics has rapidly evolved, especially related to nomenclature, classification, methodologies, techniques, distribution, occurrence and adverse effects of microplastics to marine organisms (Law and Thompson, 2014; Van Cauwenberghe et al., 2015).

MPPs are ubiquitous and worldwide contaminants that accumulate in estuarine, coastal and marine environment, especially on sandy beaches. MPPs are usually cylindrical, spherical or oval shape and made up of raw polymers of 1–5 mm. MPPs are industrial raw material transported to manufacturing sites for the production of a wide range of plastic products (Ogata et al., 2009). Sources of MPPs are both marine and land based and include spillages during handling and transfer and losses during transportation (Turner and Holmes, 2011). Because of the small size of microplastics, it can be ingested by a variety of marine biota including fish, filter feeders, detritivores and planktivores (Browne et al., 2008; Wright et al., 2013a). Once microplastics are accumulated within the organisms, the physical harm such as internal abrasions and blockages will take place. Moreover, toxicity could also arise from leaching constituent contaminants such as monomers and plastic additives, capable of causing carcinogenesis and endocrine disruption (Wright et al., 2013a). Understanding the surface alteration of MPPs in the marine environment could be used to comprehend the interaction between pollutants and plastic debris. Although the adsorption of persistent organic pollutants by MPPs in the marine environment has been studied (Mato et al., 2001; Ogata et al., 2009; Antunes et al., 2013; Holmes et al., 2014; Jayasiri et al., 2015), only a few laboratory studies examined the alteration of plastic surfaces (Kyrikou et al., 2011) and surface properties of beached MPPs (Fotopoulou and Karapanagioti, 2012; Acosta-Coley and Olivero-Verbel, 2015; Veerasingam et al., 2016).

Driving forces – winds and currents – transport the floating microplastics and also influence weathering (especially fragmentation), abundance and distribution of microplastics (Kukulka et al., 2012; Reisser et al., 2013; Isobe et al., 2014; Eriksen et al., 2014; Kim et al., 2015). However, direct movement of plastics due to wind drift is neglected in many oceanographic models of plastic movement studies in marine environment (Martinez et al., 2009; Kako et al., 2011; Reisser et al., 2013; Isobe et al., 2009, 2014; Maes and Blanke, 2015). Kubota (1994) simulated a simple model for Hawaiian Islands, combining geostrophic, Ekman and Stokes currents as follows: floating debris is first brought by Ekman currents on the northern flank of trade winds, then advected eastward by geostrophic currents, and finally deposited on the north of the Islands. The value of wind drift coefficient varies from 1% (Ebbesmeyer et al., 2011) to 6% (Maximenko et al., 2015). The recent modelling of plastic debris transport in the marine environment deals with open ocean gyre region having larger oceanic scales (Lebreton et al., 2012; Reisser et al., 2013) or within seas (Kako et al., 2011) at coarse resolution. Modelling plastic transport in the ocean is challenging since plastics range in size, shape, buoyancy and density (Critchell and Lambrechts, 2016).

Though a few studies have been attempted on the occurrence of MPPs along the beaches and coasts of India (Nigam, 1982; Ogata et al., 2009; Jayasiri et al., 2015; Veerasingam et al., 2015, 2016), a gap still exists in understanding the following questions regionally: (i) what are the probable sources for MPPs depositing along the Goa coast? (ii) What are the controlling factors on their transport towards the coast? and (iii) what are the ecological risks of MPPs. In this study we made an attempt: (i) to identify spatial and seasonal variation in the abundance of MPPs on various sandy beaches along the Goa coast, (ii) to characterise the surface degradation features of MPPs, (iii) to identify polymer types and age of the MPPs, and (iv) to study the influence of hydrodynamics on the distribution, degradation and possible sources of MPPs.

2. Materials and methods

2.1. Study area

Goa State located on the central west coast of India is one of the most famous tourist spots in Asia attracting nearly 4 million tourists every year because of its beautiful beaches, cultural heritage sites and associated recreational activities. It is surrounded by the state of Maharashtra to the north, Karnataka to the east and the Arabian Sea to the west. Goa has a coastline of approximately 105 km. The economy of Goa mainly depends on tourism and population is 1.45 million according to the 2011Census data. The coastline of Goa is characterised by bays, headlands, creeks, promontories, sea cliffs, estuaries and world famous beaches. Goa has a unique hydrodynamic condition due to biannually reversing southwest (SW) monsoon winds from June to September and northeast (NE) monsoon winds from November to February, and the wind-induced surface ocean currents. The rivers Tiracol, Chapora, Mandovi, Zurai, Sal, Talpona, and Galgibaga criss-crosses the Goa state and bring various types of effluents from the urban and industrial areas located in the eastern side. Mormugao Port, one of the major ports on the west coast of India, located in the mouth of Zurai estuary. Marine litter especially plastics on the beautiful beaches along the Goa coast destroy the beauty, and negatively affect tourism and economic benefits. The coastal population as well as the state government is very particular about activities which are related to plastic pollution in the coastal zone. This project is taken-up as a part of the Government of India's Mission Program "Swachh Bharat", meaning "Clean India".

2.2. Sampling of MPPs

MPPs were collected from six famous tropical beaches (Keri, Vagator and Calangute of north Goa, and Colva, Mobor and Galgibag of south Goa) along the Goa coast (Fig. 1) during the northeast (January 2015) and southwest (June 2015) monsoon seasons. Around 100 MPPs were collected from the high-tide line of the sandy surface of each beach using pre-cleaned stainless-steel tweezers. The MPPs were wrapped in aluminium foils, put into paper envelopes and transported to the laboratory. We followed the general protocol that has been described by several authors (Thompson et al., 2004; Ogata et al., 2009), with modifications to fit topographical conditions and meteorological characteristics of the study area. To assess the amount of MPPs entered into the Arabian Sea from the rivers of Goa, neuston samples were collected from Mandovi, Zuari, Chapora and Sal rivers using a cylindro-conical WP2 net with 50 cm mouth diameter, 1.5 m long and 100 μm mesh.