Assessing Marine Plastic Pollution in India

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Abstract

Rampant use of plastics and inefficient waste management practices have led to the plastic waste being either piled up on dumpsites or finding their way into the open sea contributing to global problem of marine plastic pollution. The marine debris is a matter of grave concern both for marine biota and humans as marine animals habitat is turning into a plastic soup and humans face the risk of major health consequences after consuming plastic ingested sea food. There are also other economic losses like damaged ships, lost fish stocks, reduced tourism, depreciated coastal property values, etc. In India, plastic litter are documented to have caused serious damage to biodiversity in places like Cochin, Lakshadweep,Sutrapada,Vembanad Lake, Chilika Lake, Mandapam, Kilakkarai, Erwadi and Periyapattinam. There are also multiple cases of ingestion and entanglement from plastic debris leading to mortality of marine mammals and birds in the country. This study provides a descriptive picture of marine plastic pollution in India and the consequent future if no or limited action is taken. We have conducted stakeholder discussions and simulation analysis with data from secondary sources to arrive at the findings.

Key words: Beach debris, Entanglement, India, Ingestion, Marine plastic pollution, Nano plastic

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1. Introduction

The seriousness of plastic pollution was well evident when United Nations declared the main theme of the World Environment Day (5th of June) of 2018 to be 'Beat Plastic Pollution'. Plastics are omnipresent in our daily life, in almost everything we produce and consume. While human existence has become inseparable from plastic in modern times, lack of sustainable disposal mechanism for plastic waste has resulted in pilling up of plastic debris in many parts of the world including oceans.

Marine plastic debris is on the rise both in developed and developing countries (Jambeck et al., 2018; Kaladharan et al, 2017; Kirkley and McConnell, 1997). Approximately 5.25 trillion plastic pieces (tremendous amount of micro-plastics) are estimated to be floating in the world oceans weighing over 250,000 tons (Eriksen et al., 2014). Marine debris originate mostly from land sources (80%) like municipal and industrial waste dumped into sea and from littering by tourists in coastal areas and some come from the marine environment itself like disposed waste by ships, boats and the lost or discarded fishing gears (Lee, 2015; Katsanevakis, 2011). Boucher et al (2017) reports that over 300 million tons of plastics are produced every year globally and around 8 million tons of it are dumped into the oceans as plastic waste. Jambeck et al (2015) showed that 275 million metric tons (MMT) of plastic waste were generated in 192 coastal countries in 2010, of which around 4.8 to 12.7 MMTs entered the ocean.

Oceans provide a bunch of provisioning, supporting, regulating and cultural ecosystem services which are provisionally valued at USD$ 29.5 trillion per year, more than the USA's gross national product in year 2015.[1] Some of these services face threats from plastic pollution, especially the habitat services. For example, damage to coral reef from plastic pollution can result in loss of fishery as corals provide habitat to fish juveniles and help in growth of fish stock. Trucost, a research arm of Standard & Poor's, a financial-information provider, has estimated that marine litter costs $13billion a year, mainly through its adverse effect on fisheries, tourism and biodiversity.[2]

India is described as the 12th largest contributor of marine plastic pollution in the world (Jambeck et al., 2015) with coastal population and coastal urbanization increasing fast and

[1] https://ocean-climate.org/?page_id=3895&lang=en, accessed on 8th April 2020
[2] https://www.economist.com/news/international/21737498-so-far-it-seems-less-bad-other-kinds-pollution-about-which-less-fuss-made, accessed on 8th April 2020.

plastic waste treatment plants being almost nil in the country (Kripa et al., 2016). This paper makes a modest attempt to estimate plastic debris originating from land, the part going to sea and projecting some future scenarios under different assumptions. First, the study describes some general information on marine plastic pollution from global literature and then presents estimates, possible impacts and framework for economic estimates of damage from marine plastic waste in Indian context.

2. Types of Plastic Waste

Plastic waste comes in all sizes, from large visible items to small invisible particles, and are broadly categorized into the following. (a) **Macro-plastics:** Plastics, which are greater than 200 mm and can be spotted easily, e.g. plastic bags, plastic sheets, fishing nets, etc. (b) **Meso-plastics:** Plastics between 5 mm and 200 mm are known as meso-plastics. Often meso-plastics are not regarded as a separate category and are clubbed with macro-plastics. They often originate from land sources and are usually in the form of discarded plastic bottles, packaging materials, household items, toys etc. (c) **Micro-plastics:** Plastics which are smaller than 5 mm are known as micro-plastics. These are smaller and are hard to detect. They are further categorized into large micro-plastics (1 to 5 mm) and small micro-plastics or Nano-plastics (less than 1 mm). Micro-plastics are currently existing in two different forms: (i) primary micro-plastics which are made to carry out certain functions (e.g. toothpaste, skin cleansers and cosmetics) and micro-plastic pellets (MPPs) used for the manufacturing of plastic material and (ii) secondary micro-plastics, which are generated when macro-plastics in the marine environment are physically (through 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). Micro-plastics are abundant in marine environment and highest concentration of micro-plastics is found along coastlines and mid-ocean gyres (Cole et al, 2011).

Eriksen et al (2014) reported that the weight of plastic pollution globally comprises of 75.4% macro-plastics, 11.4% meso-plastics, and 10.6% large micro-plastics and 2.6% small micro-plastics. Additionally, they report that a minimum of 233,400 tons of larger plastic items are afloat in the world’s oceans against 35,540 tons of micro-plastics. This reveals the dreadful scenario of the plastic pollution in our oceans around the world. In context of South Asia, the study reports the estimated marine plastic waste to be of 12780 tons which include over 10000 tons of macro-plastics, 1240 tons of meso-plastics and 1540 tons of micro-plastics (including Nano plastics).

3. Sources of Marine Plastic Pollution

3.1 Land based sources

The main land based sources of marine plastic waste are municipal waste landfills located at coast, riverine transport of waste to coast, untreated municipal discharges, storm water discharges, and waste from plastic and other industries (Katsanevakis, 2011). Another land based source is littering of plastic products such as plastic bottles, shopping bags and packaging materials by tourists. The debris is then carried away by the sea current into the deep marine environment. Whereas marine plastic waste coming from the coastal areas (less than 50km of the coast) was estimated to be between 4.8 to 12 million tons (Jambech et al. 2015), between 1.15 and 2.41 million tons of plastic waste was estimated to enter the sea via rivers (Lebreton et al. 2017). The top 20 polluting rivers, most located in Asia, account for 67 percent of these wastes, of which nearly 75 percent occur during monsoon. Globally, river Ganges is reported to be the 2nd most polluting river after river Yangze of China, with estimated annual plastic waste contribution to ocean ranging from 0.10 to 0.17 million tons per year (Leberton et al. 2017). The plastic waste from Ganges peaks in the month of August with 44,500 ton per month and reduces to less than 150 ton per month between December and March, which signify the role of monsoon season.

There are substantial evidences of plastic generation being strongly and positively linked with Standard of Living or GDP of a state and to urban population. In the United States, standard of living, as measured by GDP per capita, increased by 76 percent in between 1965 and 1990, whereas plastic production grew much more rapidly by 407 percent (Kirkley and McConnell, 1997). In terms of per capita plastic production, it increased from 0.01 lb per person per day in 1960 to 0.43 lb in 1993, an increase of more than 4000 percent (Kirkley and McConnell, 1997). In India, it is also observed that coasts of heavily urbanized states such as Karnataka and Gujarat and tourism based states such as Goa are more polluted with plastic debris than less urbanized state such as Odisha (Kaladharan et al., 2017).

While anthropogenic pollution is mostly local near the point source, marine debris at a place depends on movement of sea currents. Distant locations, even uninhabited areas are seen to have piling of marine debris (Erikson et al., 2014; Kripa et al, 2016). The shore and coastal regions of Andaman and Nicobar and Lakshadweep Islands in India have higher levels of pollution and substantial amount of marine plastic debris than the mainland coastal states, which imply that marine litter is coming from neighboring nations like Sir Lanka, Maldives, Singapore, Malaysia, Indonesia and other East Asian Countries (Kaladharan et al, 2017; Dharani et al., 2003). The share of plastics in marine debris was 40 percent for Lakshadweep and 47 percent for Andaman and Nicobar islands, whereas the national average stood at 14 percent (Kaladharan et al, 2017).

3.2 Maritime sources

Maritime sources consist of plastic waste disposed by ships, ferries and boats at sea. Ship crew and passengers generally consume packaged food and dispose the waste into the ocean. Other than food packaging materials, marine plastic waste also consists of items such as water bottles, shampoo and conditioner containers, plastic plates and cups etc. (Katsanevakis, 2011). Though, International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL 73/78) prevent dumping any kind of plastic waste into the sea, discarding plastic waste into the sea seem to be still continuing (Gregory, 1999). Veerasingham et al (2016) studied the spatial and seasonal variability in the distribution, composition, weathering pattern and possible sources of micro-plastic pellets (MPPs) in the coast of Goa state in India and found the MPPs to be arriving at the coast only during the SW monsoon and the probable sources are Ocean-based sources (e.g., unintentional and/or accidental spills from vessels during their transport through national and international shipping routes) and/or are from neighboring countries.

Another maritime based source is plastic waste generated by fishing and aquaculture. Fishing nets are frequently discarded by fishermen or lost at sea which has far reaching consequence. Debris in the form discarded or lost fishing gear often continue to trap fishes and other marine animals; a phenomenon known as ghost fishing (Laist, 1997). Along with fishing nets, littering by fishermen and fishing boats and ships also contribute to maritime source of marine debris. Another potential source of marine debris is plastic waste generated form aquaculture installations.

Small pleasure crafts and small boats also dump plastic into the sea water. Though individually they are not significant contributors, collectively they contribute a significant portion of marine litter. Finally, offshore petroleum platforms such as oil and gas extraction plants also contribute to marine debris (Katsanevakis, 2011). These installations frequently discard plastic and other waste into the sea. Thus, shipping industry together with fishing industry, marine tourism and offshore petroleum industry are major sources of marine litter at sea. However, it must be noted that though maritime sources contribute to marine debris in significant proportion; more than 80% marine debris comes from land (Lee, 2015; Andrady, 2011).

4. Impacts of Marine Plastic Pollution

Plastic Pollution can impact in a number of ways and effects are far reaching. Along with serious impact on marine biodiversity, human society also suffers tremendously. The impacts of marine debris are discussed below at length.

4.1 Impact on Biodiversity

4.1.1 Entanglement

Marine animals often get entangled in marine plastic debris and often get killed by drowning, suffocation, or strangulation. Entangled animals often injure themselves trying to free themselves and may suffer restricted efficiency of movement due to injuries leaving them disabled to catch food or avoid predators (Katsanevakis 2011). Additionally, infections due to injuries can be fatal (Laist 1997). Entangled animals also die due to fatigue which they incur during their struggle to free themselves.

Several marine species have been victims of entanglement. According to Katsanevakis (2011), at least 20 species of pinnipeds (seals and sea lions) are reported to be affected by entanglement making them most vulnerable. Similarly, entanglement has been reported for at least 14 species of cetaceans (whales) and several species of marine turtles with juveniles being the most affected. Entanglement is common among seabirds, fishes and crustaceans such as crabs and lobsters (Robards et al. 1997; Laist 1997). In case of fishes and crustaceans, entanglement is often caused by discarded or lost fishing nets resulting in ghost fishing (Coe and Rogers 2012; Kirkley and McConnell 1997). Needless to say, entanglement is death sentence for the entangled animal.

4.1.2 Ingestion

Ingestion of plastic debris is a common phenomenon in marine animals such as fishes, mammals, turtles and seabirds (Laist 1997). Ingestion in animals can occur either due to mistaking plastic as food or prey or consuming accidentally during feeding or normal behaviour. Ingestion can cause serious harm by blocking digestive track of the animal or causing internal injuries which may lead to death. Ingestion can also cause reduced growth in animals, disruption of enzyme and hormone, delayed ovulation and reproductive failure among others.

Plastics debris also have tendency to absorb harmful chemicals like DDT and PCBs (Dharani et al. 2003; Sindermann 2005). Through ingestion, absorbed harmful chemicals such as PCBs and DDT enter into the system of the animal causing a number of health effects. Animals contaminated with PCBs and DDT have shown reduced reproductive successes, disruption in development and growth, disruption in endocrine system, pathological changes in cells and tissues, suppression of immune system and genetic anomalies (Sindermann 2005). Further, absorbed PCBs and DDT can end up in humans through consumption of sea foods causing health hazard.

Gall and Thompson (2015) presents an updated list of marine species getting entangled or having ingestion or both of plastics compared to the list presented by Laist (1997) and it shows a sharp rise in percentage of sea turtles, sea birds, marine mammals and fish getting affected between 1997 and 2015 (Table 1). Nearly 73% of the mesopelagic fishes in Northwest Atlantic were found to contain plastic in their gut (Weiczorek et al. 2018). Ingested plastics were found to be microplastics, mainly polyethylene fibers, and few species had ingestion rate of 100 percent. At least 17% of species affected by entanglement and ingestion are listed as threatened or near threatened in IUCN Red List (Gall and Thompson 2015). Ingestion of plastic may not cause mortality, but ingestion of large plastics does it definitely, especially in whales and sea turtles who either mistake large plastics for food or accidently ingest them (Laist 1997). An adult female *Longman's beaked whale* was choked to death due to the ingestion of four thick plastic bags near Sutrapada, Gujarat coast (Kaladharan et al. 2014).

Table 1: Impact of marine plastic debris on Biota

Species Group	Number of known species	Number of species with entanglement record		Number of animal with ingestion record		Number of animal with entanglement or ingestion records or both	
		Laist (1997)	Gall & Thompson (2015)	Laist (1997)	Gall & Thompson (2015)	Laist (1997)	Gall & Thompson (2015)
Sea Turtles	7	6 (86%)	7 (100%)	6 (86%)	6 (86%)	6 (86%)	7 (100%)
Seabirds	312	51 (16%)	79 (25%)	111 (36%)	122 (39%)	138 (44%)	174 (56%)
Marine mammals	115	32 (28%)	52 (23%)	26 (23%)	30 (26%)	49 (43%)	62 (54%)

Fish	16752	34 (0.2%)	66 (0.39%)	33 (0.2%)	50 (0.30%)	60 (0.36%)	114 (0.68%)

Source: Gall & Thompson (2015)

4.1.3 Damage to Coral Reefs and Sea Grass Beds

Plastic debris such as discarded or lost fishing gears are threats to coral reefs. Debris snags on the coral structures and the situation is further complicated by wave action which cause breakage of coral heads (Katsanevakis 2011). Similarly, sea grass beds are also at risk as plastic debris pile up on them. In India, coral reefs of Lakshadweep, Mandapam, Kilakkarai, Erwadi and Periyapattinam have piled up plastic debris (Kripa et al. 2016).

4.1.4 Assisting invasion of alien species

Floating plastic debris often accompanies marine species which can be transported from one place to another due to waves and current (Gall and Thompson 2015) and can invade the area at the cost of native species. This unnatural invasion of alien species can bring about catastrophic result for the native marine species as alien species can use up resources including food or prey on them bringing about ecological chang e to the previously stable environment.

4.2 Impact on Human Health

Microplastic pellets (MPPs), due to their very small size, are ingested by a variety of marine biota including fish and get accumulated within the organisms. When human consume fish or other marine species ingested with plastic, it leads to ingestion in humans. Microplastics, in the form of polyethylene, can be absorbed by gastro-intestinal lymph and circulatory system of exposed human (Lee 2015). Toxicity can also arise from leaching constituent contaminants such as monomers and plastic additives, capable of causing carcinogenesis and endocrine disruption (Wright et al. 2013). Additionally, harmful chemicals such as PCBs and DDT absorbed by plastic waste, especially the MPPs, can end up in humans through ingested fishes and cause major health hazard in the form of physiological and morphological change (Sindermann 2005; Holmes et al. 2014; Jayasiri et al. 2015). Lee (2015) estimated the cost to human health and safety due to marine debris to be between £0.51 and £1.33 million in United Kingdom.

4.3 Damage to Ships

Discarded fishing nets and other large plastic waste can cause considerable damage to the ships as the plastic debris entangle with propellers and other parts of the ship (Coe and Rogers 2012). Debris can also cause clogging of the water inflow of the engine cooling system, while collision with massive debris may cause serious damage to the ship resulting in massive repair costs and opportunity costs of lost sea time. Lee (2015) estimated damage to shipping industry from marine plastic waste to be between £1.30 and £3.90 million in United Kingdom.

Additionally, rescue missions to save and retrieve ships to harbours cost huge amount of money (Newman et al. 2015). Mouat et al (2010) report that estimated cost for the U.K. Royal National Lifeboat Institution for 286 missions to rescue vessels with entangled propellers was between €830,000 and €2,189,000. The study further reported that the estimated cost of removing marine litter was €2.4 million per year to UK Ports and Harbors.

4.4 Impact on Fishermen and Fisheries

Fishermen are at much loss due to plastic debris in water. Debris of different types and sizes gets caught in fishing nets and removing them is a time consuming task which costs fishermen their fishing time. In a study conducted in Vembanad Lake, average shrimp catch ranges from 0.525 kg to 1.36 kg while average waste of litter ranges between 1.87- 13.8 kg per day per net (Kripa et al. 2016). Moreover, ghost fishing may cause reduction in fish stocks causing reduced supply to both fishermen, particularly subsistence fishermen and consumers (Katsanevakis 2011).

Marine debris often entangle with the propeller and engine of the fishing boats causing damage to the boats. This causes substantial losses to commercial fishermen who have to incur both repair cost and opportunity cost of lost fishing time (Katsanevakis 2011; Kirkley and MacConnell 1997). As reported by Wallace (1990), the occurrence of entanglement is frequent, over 45% of commercial fishing ships and boats had their propellers caught, over 30% had their gear fouled and over 35% engine's cooling system clogged by plastic debris in eastern United States. In United Kingdom, estimated damage from marine litter to fishing and aquaculture was between £26.79 - £35.55 million (Lee 2015) and average cost to fishing vessels between €17,000 and € 19,000 per year (Newman et al. 2015; Mouat et al. 2010).

4.5 Impact on Tourism

Plastic debris along coastal beaches reduces the aesthetic value of the beaches ultimately affecting recreational experience of the visitors often resulting in sharp decline in number of visitors at the beeches (Kirkley and MacConnell 1997; Smith et al. 1997). This results in substantial loss to coastal tourism industry. Loss to coastal tourism in U.K was reported to be between £5.49 and £16.46 million (Lee 2015). Similarly, McIlgorm (2011) estimated damage from marine debris to marine tourism in Asia-Pacific region to be $0.622 million.

Coastal municipalities often face direct economic cost of clearing the litter to sustain, revive or avoid loss to the tourism industry. In U.K., the cost of removing beach debris in all coastal municipalities was estimated to be between €18-19 million with an average cost of € 146,000 per municipality (Newman et al. 2015; Mouat et al. 2010). On similar lines, Lee (2015) estimated shoreline cleaning cost along beaches in U.K. to be around £16 million. Plastic debris not only affects coastal tourism, but also marine tourism. Marine tourism in the form of recreational boating, diving and fishing is also impacted by plastic pollution in two ways. Plastic debris threatens the propulsion and steering system of recreational boats and reduces natural beauty of the environment (Kirkley and MacConnell 1997). As a result, pleasure crafts and recreational fishing boats can suffer huge economic losses.

Though the cost of cleaning marine debris is high, the economic gain from such cleaning can be much higher. Leggett et al (2014) reported that reduction of marine debris in beaches of Orange County, California by 50 percent could generate economic benefits worth $67 million to residents in a three-month period. Similar findings were reported from Chesapeake Bay where 20 percent improvement in water quality was expected to increase economic benefits by about $40 million per year (Kirkley and MacConnell 1997).

5. Marine Plastic Pollution in India

The solid waste management is inefficient and recycling of plastic waste has not been the standard practice in India (Annepu 2012). Jambeck et al (2015) report that 87% of the plastic waste is mismanaged in India per year, of which, 0.09 - 0.24 million metric tons goes into the ocean ranking India the 12th in the world in plastic marine debris generation. However, marine plastic pollution is an under-researched area in India with little information on how, from where and what type of plastic waste is entering the sea and what consequences it has on marine life. This study followed a mixed approach, from stake holder interviews to simulation analysis using Indian specific parameters collected from other studies, to build up the status of marine plastic pollution in India.

The study team took input from coastal stakeholders from Kerala, Odisha, Maharastra, and Goa to understand the gravity of the problem from beach debris and coastal pollution and the type of economic consequences they are facing. The plastic issue looked less serious in Odisha, probably due to low plastic use which is linked to low standard of living and most importantly due to the use of bio packaging materials like palm leave baskets, earthen pots, etc. in the famous Jagannath temple where millions of pilgrims visit regularly. Plastic marine debris seemed to be serious in Kerala, Maharastra and Goa and the respective state governments reported to have started taking preventive steps.

Per capita waste generated by urban India increased from 0.44 kg in 2001 to 0.5 kg in 2011 and the total solid waste generation in urban India is estimated to be 68.8 million tons per year or 188,500 tons per day (Annepu 2012). Of the total solid waste generated in India, 3% is estimated to be plastic waste (Jambeck et al. 2015; Kripa et al. 2016), though it is much higher for urban areas.

Detailed waste generation data for some areas of Northern Goa is being maintained since 2016 and plastic waste constitutes 4.7 to 5.8% of solid waste being generated (Table 2). May to August witness lower plastic waste generation and then there is monotonic increase in all subsequent months with January and February witnessing the maximum (Figure 1). Goa being tourism based, plastic waste generation seemed to be linked to tourist arrival, as December, January and February are the peak tourist months.

Table 2: Plastic Waste as percentage of Municipal Solid Waste (MSW) generated in North Goa, India

Year	Months	Monthly Average Municipal Waste generated (Tons per Day)	Average Plastics Waste (hard, soft plastic and polythene bags)(Tons per day)	Plastic Waste as % of total waste
2016	August	71.31	3.836	5.38
2016	September	62.95	3.003	4.77
2016	October	85.97	4.884	5.68
2016	November	96.78	5.449	5.63
2016	December	102.97	5.175	5.03
2017	January	123.91	6.484	5.23
2017	February	106.54	6.208	5.83
2017	March	97.91	5.039	5.15
2017	April	96.04	5.234	5.45
2017	May	109.5	5.613	5.13
2017	June	102.57	5.071	4.94

2017	July	117.73	5.843	4.96
2017	August	107.55	5.541	5.15
2017	September	119.59	6.583	5.50
2017	October	136.46	7.434	5.45
2017	November	144.7	8.056	5.57
2017	December	153.87	8.273	5.38
2018	January	170.92	9.886	5.78

Source: Hindustan Waste Treatment Pvt. Ltd., Department of Science, Technology and Environment, Government of Goa

Figure 1: Month wise plastic waste generated in North Goa

Kaladharan et al (2017) showed higher level of marine plastic debris in heavily urbanized states such as Karnataka and Gujarat where mean beach litter was reported to be 178.44 and 90.56 gram per square meter respectively against least urbanized state like Odisha where beach litter was 0.31 gram per square meter. Beach litter in Goa was reported highest with a mean value of 205.75 gram per square meter. Sridhar et al (2007) had found plastic debris in four sandy beaches of Karnataka, southwest coast of India to range between 6.9 and 37.9 gram per square meter. Evidence of plastic debris has also been documented on the beaches of coastal megacities. Jayasiri (2013) reported average abundance of marine litter in four beaches of Mumbai to be 7.49 gram per square meter. The study also found that occurrence of debris in Mumbai was more in the beaches which were visited more -- Juhu and Dadar beaches being more polluted than Versova and Aksa.

Using information and parameters from Annepu (2012), contribution of coastal cities to marine plastic pollution are calculated for two of the Indian census years, 2001 and 2011. It is observed that coastal and near coastal cities contributes 169 to 450 tons of plastic waste per day to sea

(Table 3). Most cities have registered more than 50 percent increase in Municipal Solid Waste (MSW) Generation in 2011 compared to 2001 with the exception of Navi Mumbai where MSW decreased by almost 80% from the previous decade. Kolkata produces the highest amount of marine plastic waste (between 45.10 and 120.27 tons per day) followed by Greater Mumbai (between 43.55 and 116.13 tons per day) and then Chennai (between 23.95 and 63.87 tons per day).

Table 3: Marine Plastic Waste Generated by Coastal and Near-Coastal Cities

States	City	MSW Generated (TPD)		% Change in MSW	Plastic Waste Going to Sea(TPD) in 2011*	
		2001	2011		Lower Limit	Upper Limit
Andaman & Nicobar	Port Blair	76	114	50.00	0.45	1.19
Andhra Pradesh	Guntur	199	299	50.25	1.17	3.12
	Rajahmundry	151	227	50.33	0.89	2.37
	Nellore	200	301	50.50	1.18	3.14
	Kakinada	140	211	50.71	0.83	2.20
	Vizianagaram	72	108	50.00	0.42	1.13
	Machilipatnam	89	134	50.56	0.52	1.40
	Srikakulam	59	89	50.85	0.35	0.93
Dadra & Nagar Haveli	Silvassa	7	11	57.14	0.04	0.11
Daman & Diu	Daman	15	23	53.33	0.09	0.24
Goa	Panaji	54	81	50.00	0.32	0.85
Gujarat	Ahmadabad	1,674	2,518	50.42	9.86	26.29
	Surat	1,153	1,734	50.39	6.79	18.10
	Vadodhara	403	606	50.37	2.37	6.33
	Bhavnagar	169	254	50.30	0.99	2.65
	Junagadh	99	149	50.51	0.58	1.56
	Navsari	82	123	50.00	0.48	1.28
	Porbandar	50	75	50.00	0.29	0.78
	Bharuch	64	96	50.00	0.38	1.00
	Veraval	55	83	50.91	0.32	0.87
Karnataka	Mangalore	270	405	50.00	1.59	4.23
	Udupi	64	96	50.00	0.38	1.00
Kerala	Kochi	909	1,366	50.28	5.35	14.26
	Kozhikode	285	429	50.53	1.68	4.48
	Thrissur	153	230	50.33	0.90	2.40
	Kollam	192	289	50.52	1.13	3.02
	Alappuzha	142	214	50.70	0.84	2.23
Lakshadweep	Kavarati	3	5	66.67	0.02	0.05

Maharashtra	Greater Mumbai	7,395	11,124	50.43	43.55	116.13
	Thane	492	740	50.41	2.90	7.73
	Kalyan Dombivli	427	642	50.35	2.51	6.70
	Bhiwandi	311	467	50.16	1.83	4.88
	Navi Mumbai	289	58	-79.93	0.23	0.61
Odisha	Cuttack	174	262	50.57	1.03	2.74
	Puri	91	136	49.45	0.53	1.42
	Balasore	54	82	51.85	0.32	0.86
Pondicherry	Pondicherry	299	449	50.17	1.76	4.69
Tamil Nadu	Chennai	4,067	6,118	50.43	23.95	63.87
	Tirunelveli	208	313	50.48	1.23	3.27
	Thoothukudi	122	183	50.00	0.72	1.91
	Nagercoil	104	156	50.00	0.61	1.63
	Kancheepuram	95	142	49.47	0.56	1.48
	Cuddalore	79	119	50.63	0.47	1.24
West Bengal	Kolkata	7,659	11,520	50.41	45.10	120.27
	Maheshtala	119	179	50.42	0.70	1.87
	Haldia	60	91	51.67	0.36	0.95
	Bisarhat	40	59	47.50	0.23	0.62
	Total	28,914	43,110		169	450

Data Source: Annepu (2012)

**The calculations for Plastic Waste Going to Sea are based on Jambeck et al (2015). MSW is multiplied by percentage of plastic waste in MSW (3% in Indian context) to arrive at the volume of plastic waste being generated and this is then multiplied by the proportion of mismanaged plastic waste (87% for India) to generate the volume of Mismanaged Plastic Waste. 15% of Mismanaged Plastic Waste gives Lower Limit (Column 6) of Plastic Waste going to the sea whereas 40% gives the Upper Limit (Column 7). Both these limits are taken from Jambeck (2015).*

*Lower Limit = MSW*0.03*0.87*0.15*

*Upper Limit= MSW*0.03*0.87*0.40*

Plastic marine debris in India also comes from neighboring countries. According to Dharani et al (2003), substantial amount of marine plastic debris found along the shore and coastal regions of Andaman and Nicobar Islands are not of local origin. Similar evidences were found for Lakshadweep Islands by Kaladharan et al. (2017).

6. Marine plastic waste in India in future

On the assumption that plastic waste constitute 3% of total solid waste generation, the estimated plastic waste generated by urban India will be 4828.8 tons per year by 2041 (see table 4).

Alternatively, if India follows China which has higher plastic consumption and hence, higher plastic waste percentage (11%) in urban solid waste, the estimate of plastic waste generation will increase to 17705.6 tons per year which is 266% more than the previous estimate.

Table 4: Approximate Plastic Waste Generation Scenario in India (2011 - 2041)

Year	Per Capita Urban Waste Generation	Total Solid Waste (TSW) generation (= column 2 x projected urban population) ('000 Tons/year)	Total Plastic Waste Generation ('000 Tons per Year)	
			3% of TSW	11% of TSW (at par with China from 2021)
2011	0.498	47.30	1.419	-
2021	0.569	71.15	2.1345	7.8265
2031	0.649	107.01	3.2103	11.7711
2041	0.741	160.96	4.8288	17.7056

Source: Authors' calculation. Column 2 taken from Annepu (2012)

Next, we simulate few future scenarios of plastic waste generation in India using different rates of plastic generation depending on standard of living and economic prosperity. First, we assume plastic production to increase by 20% in each decade (i.e. from 3% in 2011, it becomes 3.6% by 2021, 4.3% by 2031, etc.) and then by 30% (i.e. from 3% in 2011, it becomes 3.9% in 2021, 5.07% in 2031, etc.) over the present level of 3% of total solid waste generated in the country, considering that there will be rise in standard of living in future. Next, we assume the percentage of mismanaged plastic to improve over the years. The percentage of mismanaged plastic waste in India has been taken to be 87% in the literature and we assume it to improve by 5% in a decade (i.e. from 87% in 2011, it becomes 82.65% in 2021, 78.52% in 2031, 74.59% in 2041, etc.). Similarly, an optimistic scenario with 10% improvement in solid waste management per decade is also included.[3] We present these results in Table 6. Without any improvement in Solid Waste Management, plastic debris going to the ocean comes to around 1884 - 5024 tons per day by 2051 with a 20% decadal increase in plastic waste generation.

[3] This is as per the statements made by plastic manufacturers and recyclers in public forum (Conference on "Sustainable Plastics: Issues, Challenges and Remediation", 18th May 2018, Delhi)

Under the same condition of no improvement in Solid Waste Management, the figures jump to 2595 - 6920 tons per day under a 30% decadal increase.

With a 5% decadal improvement in solid waste management and 20% increase in plastic waste proportion, the amount of plastic debris going to the ocean come around 1534-4092 tons per day by 2051. Alternatively, with 30 % increase in plastic waste proportion, the amount of plastic marine debris is estimated between 2114 and 5636 tons per day by 2051. Similarly, a 10% improvement in solid waste management per decade and a 30% increase in plastic waste proportion will lead to 1703-4540 tons of marine plastics per day by 2051. Compared to the present estimate of plastic debris going to ocean (399-1063 tons per day), even the highly optimistic figure of 1236-3296 tons per day in 2051 is very high, nearly 3 times the 2011 figures. India needs to increase its decadal plastic waste management capacity approximately by 62 percent per decade to reduce the mismanaged plastic to 1-2 percent of plastic waste generated[4] by 2051 and by a much higher rate to achieve such goal in near future.

Table 6: Scenario of Marine Plastic Waste Generation

Year	Coastal Population (in millions)	Plastic Waste Going to Sea (Tons Per Day)					
		No Improvement in SWM		5% Decadal Improvement in SWM		10% Decadal Improvement in SWM	
		20 % Increase in Share of Plastic Waste	30 % Increase in Share of Plastic Waste	20% Increase in Share of Plastic Waste	30% Increase in Share of Plastic Waste	20% Increase in Share of Plastic Waste	30% Increase in Share of Plastic Waste
2011	203.60	399§ - 1063	399 - 1063	399-1063	399-1063	399-1063	399-1063
2021	228.70	611¥ - 1630	662 - 1766	581-1549	629-1678	550-1467	596-1590
2031	250.16	915 - 2441	1074 - 2865	826-2203	969-2585	741-1977	870-2320
2041	265.43	1331 - 3548	1692 - 4511	1141-3042	1450-3868	970-2587	1233-3289
2051	274.30	1884 - 5024	2595- 6920	1534-4092	2114-5636	1236-3296	1703-4540

Source: Authors' calculation based on Jambeck et al (2015) and Annepu (2012):

Notes: TPD refers to Tons Per Day; Population growth projections for India are taken from UN's DESA / Population Division

§ $398 = 0.498*203.6*10^6*0.87*0.03*0.15$;

¥ $611 = 0.569*228.7*10^6*0.87*0.036*0.15$

[4] The plastic waste management as per USA standard.

7. Documented Impacts of Marine Plastic Debris in India

As mentioned before, impacts of marine plastic litter is under researched in India with few studies so far. Plastic debris is reported to be a major environmental issue in Chilika Lake in Odisha (Sahu et al. 2013). The plastic debris has been interfering with the ecological functioning of the aquatic environment of the lake by affecting all including benthic, plankton and nektons organisms. The effects are further noticed in resident and migratory birds which usually depend on benthic organisms for food. Plastic debris have caused considerable harm to Olive Ridley sea turtles who use Chilika Lake as mass nesting site as they often ingest plastic debris. Occurrence of ghost fishing in Chilika due to discarded fishing nets has resulted in decrease in fish stock.

In Cochin backwaters and adjoining canals, shrimps and pearl spot, major fisheries resources of the region, are affected due to plastic litter (Kripa et al. 2016). In a survey, mean litter density on corals of Lakshadweep was estimated to be 7.71 gram per square meter (Kripa et al. 2016) which is at par with the plastic debris found along beaches of Mumbai (Jayasiri et al. 2013). Similar situation have been reported in ecologically sensitive sea grass beds at Mandapam, Kilakkarai, Erwadi and Periyapattinam (Kripa et al. 2016). In Vembanada Lake, ingestion of microplastic particles in benthic fauna and zooplankton has been reported to have led to contamination in food web, including human health, as locals consume clams, prawns and fishes which live on benthic faunas and zooplanktons (Sruthy and Ramasamy 2017). In the same area, average shrimp catch ranges from 0.525 kg to 1.36 kg while average waste of litter ranges between 1.87- 13.8 kg per day per net (Kripa et al, 2016).

Plastics have affected mangrove as well. Plastics entering the mangrove creeks of Mumbai, caused by the dumping of trash by human settlements and/or tidal flow, get entangled among the network of root structures of mangroves (Vennila et al. 2014; Kantharajan et al. 2017). For instance, 55-71% of the non-biodegradable wastes inside the Mahim creek mangroves are plastics and they obstruct tidal flow into and from the mangrove swamp (Singare 2012). The accumulation of plastics, which hindered regular water flow, was considered one of the main causes of the Mumbai floods in 2005. The blocking of tidal flow can adversely affect the feeding sites of many animals (Sandilyan & Kathiresan 2012; Joshi & Kale 2013).

8. Economic Impact of Plastic Pollution in India

Globally, there are very few studies measuring the economic impact of marine litter on the marine industry sectors and coastal tourism (Lee 2015), though there are some detailed studies on biological impacts of marine plastic pollution. Literature on assessment of impact of marine plastics on human health is almost nonexistent.

Meta-data analysis estimates the damage from marine debris to be in between £38 million and £56.4 million per annum in United Kingdom (Lee 2015). The estimated damage to marine industries due to marine debris for the 21 countries in the Asia Pacific rim was US$1.26 billion per annum in 2008 which is equivalent to 0.3% of the gross domestic product of the region (McIlgorm et al. 2011).

In India, the literature on plastic pollution in the marine environment, including economic assessment of impacts, is minimal (Kumar and Shivkumar 2016). Further, there are problems of data availability and reliability. An analytical framework for assessment of economic impact is presented below which can be useful for future assessment exercises.

8.1 Assessment Framework

The framework on assessment of economic impact of plastics pollution on marine environment has been adapted from different literature. We follow a sectoral approach in which the possible impacts on the sector and the economic indicators reflecting the loss are described. Next, we describe the valuation method to use to measure the monetary loss to the sector due to the plastic pollution. Table 7 shows the details.

Table 7: Possible impact of marine plastic on different sectors, the indicators of loss and valuation method to use

Sectors Damaged	Possible Effects	Economic and Welfare Losses	Valuation method(s) to use
Damage to Fisheries	Damage to Habitat Mortality Disease and Abnormalities Impaired Reproduction Decrease in Site-Specific Abundance and Distribution Harvest Closers/Restrictions on Specific Water bodies	Increase in cost of catch, increase in prices, human health effects	Market price or production function method to measure change in Consumer or producer surplus

Damage to Birds, Mammals and Sea Turtles	Mortality Disease and Abnormalities Impaired reproduction	Loss in biodiversity, Recreational value, Impact on food chain, Impacts on human health	Replacement cost, Contingent valuation, Travel cost, Expenditure on health
Damage to Public Health	Microplastics and Pathogens in Water, Unsafe Seafood	Health impacts, Loss to fishery due to lack of demand	Health production function, Contingent valuation, Income loss
Damage to Beach	Debris on Beach, Clean up of Debris	Loss of tourism, Cost to management,	Travel cost, Income loss, Employment loss, Cost of cleaning
Damage to Ships and Vessels		Repair cost, Productivity loss, Loss in recreational boating	Income loss, Cost of repair, Travel cost
Damage to Property		Loss in property price due to debris, foul smell, physical damage from pollution	Hedonic price model

9. Conclusion and Way Forward

With rise in standard of living and population growth, marine plastic pollution will increase in India in future causing harm to marine biodiversity, and bringing economic and non-economic losses. There exist data gaps in context of plastic debris and more particularly, for marine plastic debris in India which limits the attempts for assessment of losses to enable informed policy making. Interdisciplinary studies based on primary surveys can bring out some of impacts of such pollution. At the same time, the government at all levels (local, state and center) should consider marine plastic pollution as an emergency and be actively involved in information, awareness and policy to prevent and reduce marine plastic waste.

As mentioned previously, a significant amount of marine plastic debris comes from the river networks and thus, an integrated management of river and ocean debris is needed. Along with control of the waste dumped into rivers, dumping sites near rivers should also be discouraged and managed. In the age of smart cities, there exists an urgent need to make Solid Waste Management smart and integration of waste management into smart city infrastructure which does not seem to be happening when one reviews the smart city infrastructure development plans and projects. Recycling and use of dustbins should be encouraged along with promotion of use of biodegradable and reusable products such as paper bags and reusable bags. Also, products which contain micro and nano plastics such as in personal care and cosmetic products should be discouraged or use of plastic substitutes be encouraged. Further, public awareness programs should be put in place to bring about behavioral change and change in attitude towards plastic use. The "*Tera Mera Beach*" campaign and the involvement and empowerment of civil society in beach cleaning activities in Goa, through awareness generation, are good examples to be replicated in other parts of the country. The awareness programs should be focused on educating masses on harmful impacts of plastics, both on land and sea.

The Government of India had passed plastic recycling and management rules as early as in 1998 and amendments are being brought out regularly for effective management, however implementation has been loose and plastics are being used overwhelmingly in the country. The new development paradigms like "Make in India" and the type of industrial infrastructure being provided by government are clear indicators that plastic production is going to increase in the country. Urgent steps such as 'making laws banning plastic littering more stringent', 'providing for plastic waste management infrastructure', 'making waste segregation at source mandatory', etc. are needed to manage plastic waste.

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