Review Paper:

A perspective study on occurance, impacts and sources of microplastics in the marine environment of south China Sea and Gulf of Thailand

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Abstract
The continuous discharge and the presence of the plastic wastes are global environmental issues requiring immediate mitigation and prevention measures to avoid and safeguard the marine biota and human health. Distribution, fate and effects of microplastics on the environment have gained more attention in recent years. The present study aims to synthesize the available data of microplastics to identify the load and trend of abundance in marine environment of South China Sea and the Gulf of Thailand based on mounting evidences on the microplastics reports. The major input of the microplastics to the South China Sea was contributed by Pearl River and the Mekong Rivers of Vietnam and Cambodia.

Among the available literature, the Gulf of Thailand found medium plastic abundance level when compared to the other surrounding areas. The outcome of these findings will be an aid in providing the management strategies and decision making in decreasing the entry of microplastics into the South China Sea and Gulf of Thailand which are considered as the most sensitive hotspots in contributing the discharge of plastics into the marine environment.

Keywords: Microplastics, South China Sea, Gulf of Thailand, Mekong River, Pearl River, Biota.

Introduction
Increasing population and associated anthropogenic activities have led to the emission of increased pollutants, dominated by synthetic organic compounds to the marine environment[22,66,71]. The population of the Asia and Pacific river basins is predicted to be 2.1 billion people, with a projected increase to 2.964 billion by 2050. Two million tonnes of sewage, agricultural and industrial pollutants were released into the world's rivers as a result of increased anthropogenic activity[19]. Every year the world is producing 300 million tonnes of plastics which is nearly equal to the weight of the entire human population (https://www.unep.org/interactives/beat-plastic-pollution/).

Since the early 1950's, more than 8.3 billion tonnes of plastics has been produced in which only 9% of all plastic waste has been recycled and 12% has been incinerated[70]. The rest 79% of that plastics has been ended up as wastes into the environment. These plastics wastes persist in the environment for centuries[68]. Plastics from inland and coastal operations are dumped into the sea in large quantities, posing a severe environmental threat[59]. The river network may make it easier to transfer large amounts of plastic into the sea[14].

The first study has been on plastic debris at Sargasso Sea[13] and after that numerous studies have been reported on marine plastic pollution[1]. An estimate shows that there are more than five thousand billion plastic particles floating on the world's seas[35].

Continuous discharge and presence of plastic trash are global environmental hazard that necessitates rapid mitigation and prevention efforts to protect marine biota and human health[1,13]. Because of their longevity and resistance to disintegration, plastics will take decades to degrade completely. Due to photo degradation, it can break into tiny fragments known as microplastics[18,35].

Types and sources of microplastics
Due to lack of agreed nomenclature and considering the practical difficulties in sampling and measurement of different sizes, it is called 'microplastics' using the generic term as small pieces of plastics. In general, the plastics are classified in two major types i.e. 'Primary' and 'Secondary' microplastics.

Microplastics are derived from two distinct sources i.e. 'primary microplastics' and 'secondary microplastics'. Originally produced to be that of size are called primary microplastics whereas the breakdown and fragmented materials from larger macro plastics are called secondary microplastics. In 2008, during the international workshop on the 'occurrence, effects and fate of microplastics in marine debris' organized by National Oceanic and Atmospheric

Administration (NOAA), USA, it was agreed that the microplastics upper size is 5mm. Microplastics reported in various size ranges with diameter of <10 mm to <1 mm[10,18,29]. As per Thomson, the size of plastics less than 5mm considered as microplastics[65].

Microplastics are used in cosmetics products, facial cleansers, peelers, granules in shower gels, scrubbers, moulding plastic powders, microbeads, nano size particles used in manufacturing process, vector for drugs, baby products, hair colouring shampoos, dyes, nail polishes, repellents and sunscreen lotions, garment materials like synthetic clothing etc.[5,17,18,28,52]

Due to physical, chemical and biological processes, larger plastics are fragmented into smaller particles called 'secondary' microplastics. Several environmental factors such as temperature, ultraviolet radiation are influencing the disintegration process into smaller fragments to the extent of nano particles[18,21,35]. Over time, these microplastics are accumulating at various levels of ecosystems and entering into aquatic ecosystem posing major environmental problems. These microplastics are entering into the marine environment via different pathways (Fig. 1).

East Asia is the world's most populous region with 2.66 billion people living in the coastline region alone, accounting for 75 percent of the region's population. Because of high population and related development activities, this region contributes significantly to the economy and expanding coastal activities such as tourism, shipping and fishing posing considerable challenges to the marine eco system.

China has produced the most plastic garbage of the nine countries surrounding the South China Sea. According to Jambeck et al[35], China generated approximately 3.53 million metric tonnes of marine plastic garbage in 2010 and is the world's largest donor of ocean waste[4,9]. When compared to the other studied rivers, the Chinese Yangtze River mouth reported the highest plastic concentrations of 4,137 particles per cubic metre during the world-wide sampling survey investigation. The Xi, Dong and Zhujian rivers in China's Pearl River Delta were also found to be discharging 0.106 million tonnes of unmanaged plastics into the South China Sea per year[57].

According to Greenpeace South-East Asia report, Thailand is the world 6th biggest contributor of ocean waste. Thailand generates 1.03 million tones of plastic per year with over 3% of that flowing its way into the ocean[4]. The river Mekong from Thailand is considered as one of top 10 rivers polluted by plastics globally[34,44]. Yearly upper mass input of plastics from Mekong river was estimated at 3.76 x10^4 (t yr^{-1})[57]. Many studies have indicated that microplastics exist in significant proportions in the marine ecosystem[18,35]. Microplastics' presence and fate have gotten increased attention in recent years as a severe environmental hazard affecting both aquatic and terrestrial ecosystems.

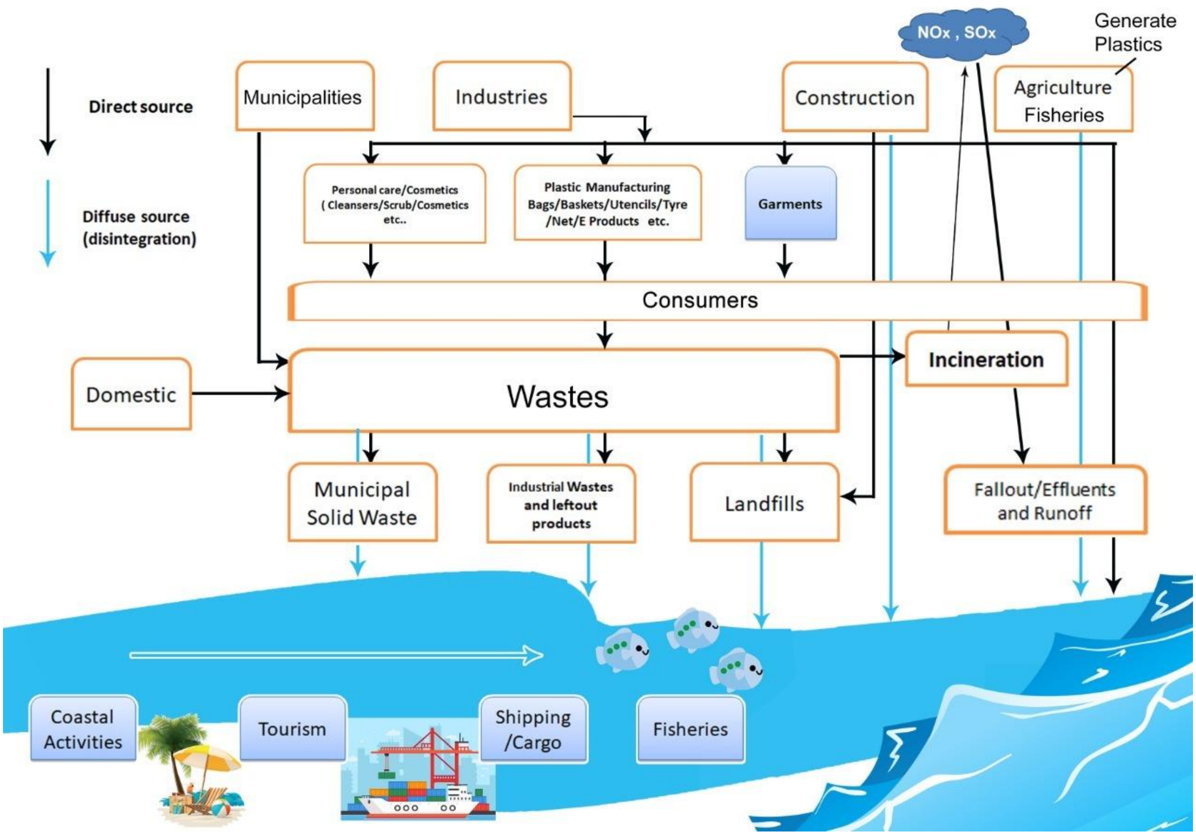

Fig. 1: Sources of Microplastics and transfer routes to sea

According to Schmidt et al[56] globally 2.75 million metric tons of plastics are entering into the oceans per year. This study also reveals that the discharges of 88-95% of plastic wastes originated mainly from the 10 rivers from Asia and Africa countries.

Study area

South China Sea (Fig. 2) is located between the Pacific Ocean on the East and the Indian Ocean on the West. It covers an area of 3.447 million square kilometers and a maximum depth of 5,245 meters at Manila Trench[40]. The Sea is surrounded by nine countries i.e. Brunei, China, Cambodia, Malaysia, Indonesia, Singapore, Thailand, Viet Nam and the Philippines and Small Islands. About 50% of the total area of the South China Sea is occupied by the north eastern sub-basin.

Cities are mainly located on Pearl River delta and Yangtze River delta. Dense population and large numbers of manufacturing industries are located on Pearl River delta. The seasonal circulation pattern in the South China Sea is largely affected by winds from the monsoon and the Northern South China Sea circulation linked water exchanges between the South China Sea and the East China Sea, as the South China Sea is located in the monsoon regime. The central South China Sea circulation is governed by monsoon winds and interactions between the circulation systems in the Northern South China Sea and the South China Sea Circulation, according to research findings[69]. During the northeast monsoon, Mekong River water enters into the lower Gulf of Thailand due to the circulation of water[31,79].

South China Sea receives more than billion cubic meters of combined freshwater discharges from Pearl River from Guandong Province, Red River and Mekong river in Vietnam Coast and Chao Phraya River in Gulf of Thailand. The major discharge from the river Chao Phraya is about 13.22 x 10^3 Km^3 whereas in the coast of Vietnam from River Mekong[31], it is about 326x10^3 km^3. Discharges from these rivers including land-based contaminants influence the distribution of marine habitats and resources in the South China Sea and the Gulf of Thailand.

Fig. 2: Study Area Map showing South China Sea and Gulf of Thailand
Source: https://pasarelapr.com/detail/south-china-sea-location-on-world-map-4.html

South China Sea is the world's busiest international water way due to country's industrial and economic growth, rich sources of oil and natural gas in this region. South China Sea pollution is often reported because of its increasing population and associated activities. Major rivers that flow into the South China Sea include the Zhujiang known as Pearl river, Min Jiang , Longjiang known as Jiulong, Red river also known as Hong Ha, Mekong river at Vietnam coast, Rajang, Pahang rivers from Malaysia, Agno, Pampanga and Pasig Rivers from Philippines. Mekong River is the world's largest international river which flows from China through Myanmar, Thailand, Laos, Cambodia and Vietnam and enters into South China Sea.

The Gulf of Thailand is surrounded by the countries Cambodia, Malaysia, Vietnam and Thailand which cover roughly about 320,000 km² semi-located in the western part of the South China Sea (Pacific Ocean). Gulf of Thailand is influenced by seawater intrusion from the South China Sea[76]. The major rivers Chao Phraya and Nakhon Chai Si enter into the Gulf of Thailand. Gulf of Thailand mean circulation is forced by the South China Sea during the Northeast monsoon[31,79]. There are main harbours located along the Gulf of Thailand which are also economically important for fishing activities. Mekong River is the world largest international river which flows from China through Myanmar, Thailand, Laos Cambodia and continues to Vietnam into six tributaries in Tien River and three tributaries in Hau River and enters into South China Sea and Gulf of Thailand.

Based on the mounting evidences on the microplastics reports and considering the continuous pressure on marine environment in this region, the present study aims to synthesize the available data of microplastics to identify the load and trend of abundance in marine environment of South China Sea and the Gulf of Thailand. Furthermore, this study will be able to identify the sources and effects of microplastics in the marine environment. The outcome of the study will give the concise information of microplastics and will aid in providing the management strategies and decision making in decreasing the entry of microplastics into the South China Sea and Gulf of Thailand which are considered as the most sensitive hotspots in contributing the discharge of plastics into the marine environment.

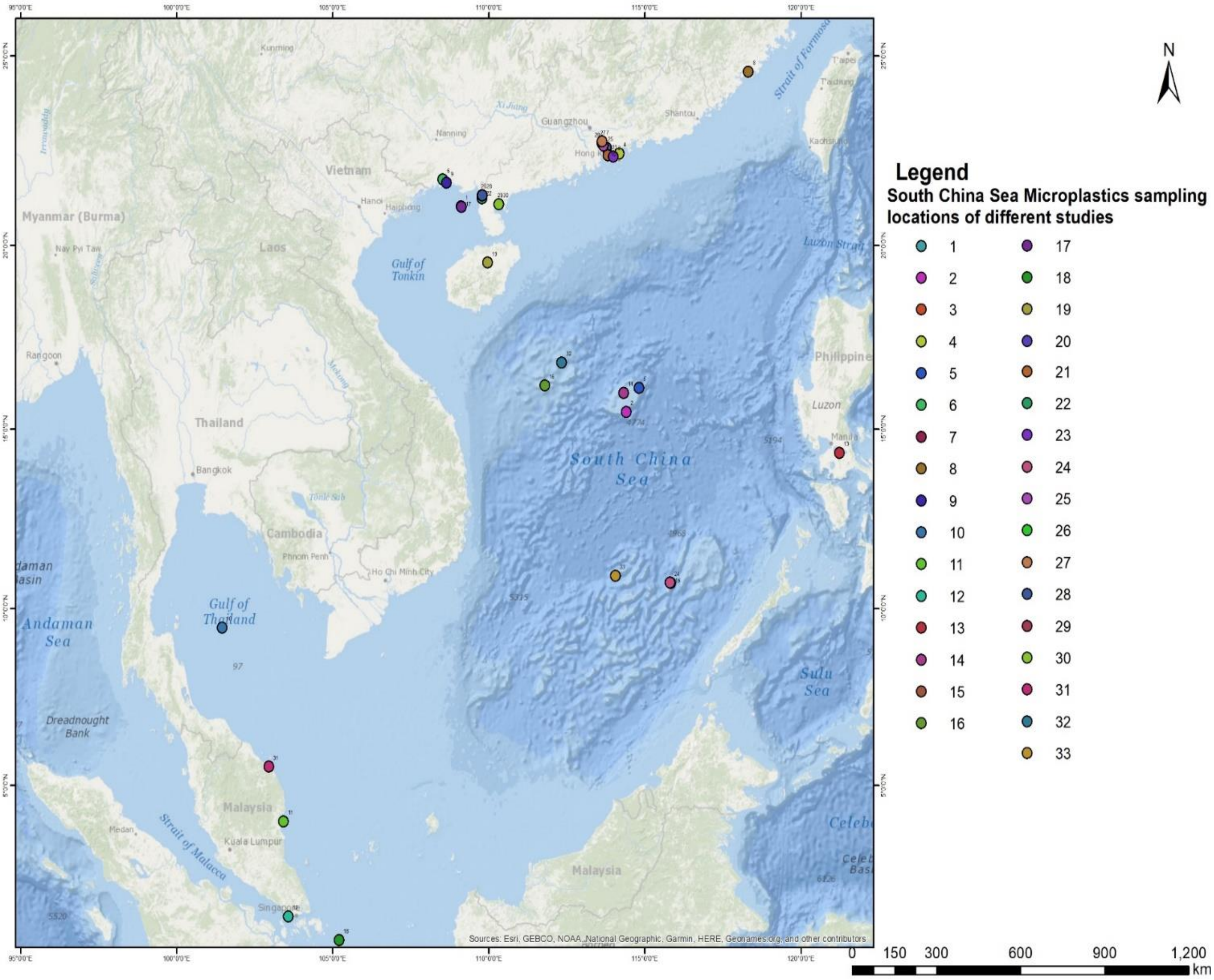

Fig. 3: Overview of the sampling locations of different studies (locations shown in table 1)

Table 1
Microplastic abundance in South China Sea and Gulf of Thailand

S.N.	Location	Sample Type	Types of Microplastics	Abundance
1.	Zhuhai and Weizhou Island, China[82]	River Discharge	Polypropylene Polyethylene	59.7% 31.9%
2.	South China Sea, China[12]	Marine Water	21 types of Microplastics ranging from	0.045-2569 pieces/m^3
3.	Hong Kong Coast, Hong Kong[27]	Coastal water	polystyrene	92% 0.315-5mm
4.	Lam Tsuen River mouth Tolo Harbor Hongkong, Hongkong[16]	River Discharge	NA	7.428 pieces/m^3 1,615,506 pieces/km^2
5.	South China Sea, China[73]	Marine Water	Maritime coating synthetic fibers	33% 29.6%
6.	Maowei Sea Estuary, China[42]	Mangrove sediment	Polyethylene Polypropylene Polystyrene	520 to 940pieces/kg^{-1}
7.	Pearl River, Hong Kong[26]	Water	NA	0.57 – 0.71 pieces/lr
		Sediment	NA	685 Pieces/Kg^{-1}
		Esturay Sediment	NA	258 pieces/kg^{-1}
			Polypropylene Ethylene propylene Fibrous polyethylene	
8.	Xiamen Coast, China[61]	Surface water	NA	103-2017 times/m^3
		Sediment	NA	76-333 pieces/kg^{-1}
			Polyethylene Polypropylene	
9.	Qinzhou Bay, China[43]	Water	NA	15-12852 pieces/kg^{-1}
		Mangrove Sediment	NA	306-6168 itmes/kg^{-1}
10.	Gulf of Thailand, Thailand[6]	Fish	fibers	79.52%
	Pearl River Estuary, Hong Kong[78]	Water	Polyamide Cellophane	8902 pieces/m^3
11.	Malaysian Marine water Kuala Nerus and Kuantan Port, Malaysia[37]	Water	NA	>1.02 g cm^{-3}
12.	Gulf of Thailand Johor Straights, Malaysia[48]	Sediment	NA	1900 pieces/kg-dry
			NA	300 pieces/Kg
13.	Talim Bay, Malaysia	Beach sediment	NA	Fibers 0.26 pieces/g
14.	South China Sea, China[85]	Northern Continental Slope	NA	1.96 pieces /individual
			NA	1.53 pieces/g
		Fish	NA	1.77 pieces/individual
			NA	4.82 pieces/g
15.	Nansha Island, China[51]	Water	NA	1733 pieces/m^3
		Fish	NA	3 pieces/individual
16.		Coral reef	NA	20-330μm

17.	Xisha Island and Nansha Island[23] Weishoo Island Sanya Hui Tou[81]	Sea water and Fish	NA	40-610 times/g
18.	Pangandaran Bay, Indonesia[33]	Water	Fragments and Fibers fibers	49.74% 22.8%, ranging from 0.12 to 5mm
19.	Hainan Island[62]	Water Sediment Corals Fish	Predominant Fibers	14.9 pieces/lr 343 pieces/Kg^{-1} 4.97 pieces/cm^{-2} 0.67-3.12 pieces/cm^{-1}
20.	Pearl River Estuary[45]	Fish	polyethylene terephthalate	0.17-1.33pieces/Individual
21.	Lingding Bay of the Pearl River Estuary[39]	Water	Polyyethylene Polypropylene and Polypropylene/ethylene propylene rubber	0.355-5.0mm
22.	Beibu Gulf[80]	Seaward boundary Landward boundary	Fiber, fragment, foam and line	80-1020 pieces/kg 520-6040 pieces/kg
23.	Hong Kong Beach[53]	Beach	Pellet, Foam, Bead, Fragments	
24.	Nansha Island[62]	Coral Reefs	Polypropylene and polyethylene	0.0556 ± 0.0355 pieces/m^3
25.	Pearl River Estuary[87]	Sediments	Polybrominated diphenyl ethers, decabromodiphenyl ethane, 1,2-bis (2,4,6-tribromophenoxy)ethane and hexabromocyclododecane	100-7900 ims/Kg^{-1}
26.	Beibu Gulf[43,77]	Sediment Sea Snail Ellobium chinese	Polypropylene fibers and polyethylene fibers	61% of the total concentration of surface sediment 7±2 pieces/kg to 53±6 pieces/kg
27.	Pearl River[36]	Water	Triclosan, triclocarban, methylparaben and N,N-diethyl-3-methylbenzamide	0.94 pieces/m^3
28.	Beibu Gulf[38]	Fish	Polyester and nylon	0.027-1.0 pieces/Individual
29.	Zhanjiang Mangrove wetland[32]	Fish	Polyethylene, polyethylene terephthalate, polypropylene and cellophane	0.6-8.0 pieces/individual
30.	South Eastern Coastal Zone[84]	Mangrove Sediments	Foams Fibers	74.6% 14%
31.	Terengganu coast of Malaysia[49]	Water	Polyamide	3.3 pieces/lr
32.	Yongxing Island[85,86]	Seabird Shorebird	Polypropylene-polyethylene	56 pieces in 4 Bird species
33.	Zhubi Reef Island[32]	Water	Polypropylene, polyamide	1400-8100 pieces/m^3

Large amount of data has been obtained from the available literature using e-library portal SMART service@KKU from Khon Kaen University and EndNote. The data have been compiled and explored to understand the fate and effects of microplastics in the aquatic ecosystem of South China Sea and Gulf of Thailand. Combinations of keywords like microplastics, effects, source, effects relevant of South China Sea and Gulf of Thailand were used into search engine. Supporting searches such as EBSCO, Google scholar, PlumX metrix were also considered in 2020. Articles were considered for this review based on the relevance of topic i.e. microplastics in South China Sea and Gulf of Thailand. This review may not be a complete review The overview of the sampling locations is presented in fig. 3.

Sources and presence of microplastics in South China Sea and Gulf of Thailand

Plastic wastes are entering into marine environment through direct disposal into rivers, streams, seas and diffused source through wind and water and losses during transport[8,11,57,65,75]. Mismanaged plastic wastes are distributed across the oceans globally especially in the seas surrounded by highly populated coastlines[7]. Study shows that majority of the world's ocean plastic pollution arises from Asian Countries[1]. China contributes the maximum plastic wastes of 28% (231,157 tonnes/year) followed by 10% from Indonesia (77,822 tonnes/year), 6% from Vietnam (41,717 tonnes/year) and Philippines (45,535 tonnes/year) and 3.2% (27,263 tonnes/year) from Thailand[1,72]. This shows that plastic debris poses a high risk in polluting the aquatic ecosystem. Approximately 80% of ocean microplastics are contributed by land based sources and 18% from aquaculture or fishing industries[25,35,52].

It is estimated that the major source of plastic wastes to the world marine waters is from Yangtze River, Yellow river, Hai rivers in China followed by the Indus River which flows through India and Pakistan and the rivers from Africa[34]. An estimate shows that more than 270 million people live in the coastal zone of the South China Sea[40]. Land-based activities in river basins and coastal areas, increasing tourism, coastal aquaculture, cargo shipping are the main source of contaminants and pollutants in coastal waters. Approximately 70% of contaminants entering the South China Sea are derived from coastal rivers which include agricultural and urban run-off, industrial discharges and discharges from ports and harbours.

The first study on the distribution of marine debris in the Northern part of South China was reported by Zhou et al[83,84]. The floating marine debris (FMD) seafloor marine debris (SMD) and beached marine debris (BMD) include small and medium based debris, woods, fibers etc.

The study also reveals that about 90% of the debris sources are land-based attributed to anthropogenic activities in the region. The first study on the abundance, compositions and sizes of microplastics in the South China Sea was reported by Cai et al[12]. The study revealed that large quantities of microplastics were found in the South China Sea ranging from 0.045 to 2569 ± 1770 particles/m^3. There were 21 types of plastic polymers dominated by smaller-size fractions of microplastics which contributed 92% of the total load. The beaches located in at Zhuhai, Macau, Qinzhou, Beihai and Weizhou Island and Hong Kong were potentially influenced by river discharges. The highest quantity of small size plastic debris was found at Zhuhai and Weizhou Island which consisted of polypropylene (59.7%) and polyethylene (31.9%)[83].

In Hong Kong Coast lines were detected with microplastic debris size in the range of 0.315-5mm[12]. Majority belongs to microplatics (mean abundance 5595 pieces/m^2) which accounts for 92% of polystyrene, 5% as fragments and 3% of pellets. An abnormal type of microplstic fragment (pellet, foam, bead, fragment) has been reported in the beaches of Hong Kong[82].

A study from Lam Tsuen River entering into Tolo harbor of Hong Kong found the microplastic abundance of 7.428 pieces/m^3 (1,615,506 pieces/km^2) during the rainy season. The findings are nearly double the amount than the coastal surface area of Hong Kong[27] acting as one of the major transports of microplastics to the South China Sea. The elevated level of microplastics evidenced that Hong Kong is a hotspot of marine plastic pollution. Earlier findings reveal that abundance of microplastics is significantly higher during the rainy season than the dry season due to the highest discharge attributes to the highest level of discharges from Pearl River from the west side of Hong Kong[53].

Another study found eight types of floating microplastics in South China Sea mainly consisting of maritime coating (33%) and synthetic fibers (29.6%)[16]. The study reveals that the diversity of microplastics has been increased with offshore distance. This may be attributed to mean circulation in South China Sea. It was estimated that Pearl River and its tributaries are transporting 15,963 tonnes of microplastics to Pearl River Estuary. The abundance of microplastics in the river water was found in the range of 0.57 to 0.71 pieces/litter whereas in sediments 685 Pieces/ kg^{-1} and 258 ± 133 pieces /kg^{-1} in estuary sediments are formed. The plastics polymers were dominated by polypropylene, ethylene propylene and fibrous polyethylene[15].

Another study of microplastics abundance at Inner Lingding Bay of the Pearl River Estuary was conducted by Lam et al[39]. The concentration of microplastics ranges from 0.355-5.0 mm in surface water which constitutes 95.4% of the total abundance by number.

The average microplastic concentration was almost 3.5 times higher than that of central Peal River Estuary which indicates the positive correlation between plastic concentration and proximity to the river mouth.

The abundance of microplastic in mangrove sediments from of the Pearl River Estuary, South China ranged from 100 to 7900 pieces/kg^{-1} dry weight with an average of 851 ± 177 pieces/kg^{-1} dry weight. The abundance was relatively higher when compared to the other regions of the world. The most common polymers detected are polybrominated diphenyl ethers, decabromodiphenyl ethane, 1,2-bis (2,4,6-tribromophenoxy) ethane and hexabromocyclododecane[26]. Another study by Jia et al[36] found that the abundances of microplastics in the Pearl River System, South China surface water was 0.94 ± 1.87 pieces/m^3. This study also reveals that this might be major source for biocides contaminant in the region.

The abundance of microplastics in surface water of Xiamen Coastal area at South China Sea was found in the range of 103-2017 pieces/m^3 and in sediments, it ranged from 76 to 333 pieces/kg^{-1} in which the polymers of polyethylene (PE) and polypropylene (PP) were found dominant[87]. The increased concentration of microplastics attributed to the increased industrial growth and urbanization in the southeast China.

In Qinzhou Bay at Guangxi Province, the microplastic abundance ranged between 15-12852 particles/ kg^{-1}. Polystyrene, polyethylene and polypropylene are the dominant microplastics with the size between 0.16 to 5.0mm. The abundance of microplastics in Mangrove sediments in this area ranged between 306 to 6168 Pieces/ kg^{-1}.

Impact of microplastics in mangrove ecosystems is receiving increasing attention due to their unique ecosystem features. The distribution of microplastics in mangrove ecosystem is still limited in South China Sea. A study conducted by Li et al at Maowei Sea Estuary Mangrove sediments found the concentration of microplastics ranging from 520 ± 8 pieces/kg^{-1} to 940 ± 17 pieces/kg^{-1}. The greater contribution of microplastics is from polyethylene (PE), polypropylene (PP), polystyrene (PS), with the size of <1 mm. The rhizosphere of mangroves found the highest concentration due to microbial activities. The pore volume of rhizosphere also plays the major reason for highest accumulation of microplastics of <1mm.

Distribution of microplastics in mangrove sediments in Beibu Gulf, South China was studied and a general increasing trend from the seaward boundary ranging from 80 ± 16 pieces/kg to 1020 ± 89 pieces/kg and to the land ward boundary ranging from 520 ± 32 to 6040 ± 114 pieces/kg was found[41]. Distribution patterns of microplastics along the East Coast of Hainan Island, South China Sea was investigated by Tang et al[61,62].

Average concentrations of 14.9 particles/L^{-1} in seawater, 343 particles/kg^{-1} in sediment, 4.97 particles/cm^{-2} in corals and 0.67-3.12 particles/cm^{-1} in Tridacnidae, Trochidae and fish intestines were identified. This study reveals that the enrichment of microplastics in corals and other reef-dwellers in this region alters the coral community.

Zhou et al[83,84] found five different shapes of microplastics in the mangrove sediments of South-Eastern Coastal zones of China. Among the microplatics, the dominant types are foams (74.6%) and fibers (14.0%) The FTIR study reveals the composition of polystyrene (75.2%), polypropylene (11.7%), rayon (4.6%), polyester (3.4%), polyethylene (2.8%) and acrylic (2.4%). The abundance was ranging from 8.3 to 5738.3 pieces/kg^{-1} (dry sediment) among the sampling sites.

The distribution of microplastics ranged from 1400 to 8100 pieces/m^3 of surface water of Zhubi Reef in the South China Sea. The abundance of microplastics was much higher than the previous reports in other regions. The predominant type of polymers are: polypropylene (25%) and polyamide (18%). The study reveals that the enrichment of microplastics was derived from the intensive fisheries and emissions from adjoining coastal cities[62].

The average concentration of microplastics in Nansha Island of South China Sea was found 1733 pieces/m^3 for surface water samples with the size of <5mm. In surface water samples, about 76.5% of particles were detected as micro beads. Presence of high concentration of fibers resulted in increased fishing activities from the Nansha Island[84]. The study explains that fishery activities and human domestic sewage might be the dominant sources of microplastic pollution in the Nansha Island, South China Sea. The sediments of Beibu Gulf were detected the abundance of microplastics with a strong correlation of polypropylene fibers and polyethylene fibers32 attributed to the intense fishery activities in the region.

A study by Wang et al[72-74] found that the abundance of microplastics was 150.4 ± 86.2 pieces/kg dry weight. Significant increased abundance of microplastics was observed in Gulf of Thailand at 6-12cm layer sediments attributed to the increased use of plastics in the region. This study reveals that microplastics were detected almost in all the surface samples from Gulf of Thailand and not in the deeper layers. A study by Handyman et al[30] at Java Sea in Indonesia proposed that the presence of microplastic particles possibly originated from the South China Sea and the pacific oceans. According to the study by Jambeck et al[35] the Indonesia produced 3.2 million metric tonnes of mismanaged plastics every year of which 1.29 million tons end as marine debris.

The first report on the microplastics in Malaysian marine water was reported by Khalik et al[37] in Kuala Nero and Kuantan Port. The results showed a density of >1.02 g cm^{-3} particles from six types of polymers such as polyester, polystyrene, polyamide, polyvinyl chloride, poly propylene and polyethylene. Matsuguma et al[48] measured the microplastics in Gulf of Thailand at 1900 pieces/kg-dry sediment. The highest abundance was observed at 2-4 cm layer than the deeper core sediments of Johor straights Malaysia. The findings reveal that in sediment cores, the abundance of microplastics increased toward the surface which indicates the increasing microplastic abundance over the time.

In the Terengganu coast of Malaysia, a total of 983 microplastic particles with an average abundance of 3.3 particles/L^{-1} were detected in surface seawater[37]. Vietnam is one among the top 5 nations discharging 0.28 to 0.73 million tones of mismanaged plastics in a year[48]. It is found that the studies on microplastics in Vietnam marine water are limited. Similarly, the study of microplastics in Singapore and Philippines marine water was also found limited.

Impact of Microplastics on Biota in South China Sea

Presence of microplastics is the evidence of understanding the risks posed by microplastics in the marine ecosystem. Small plastic particles have been observed in several species of crustaceans, bivalves, fishes and birds. According to Sweet et al[59], plastic litter in marine environment is affecting more than 800 coastal and marine species.

The average abundance microplastics from the deep-sea (200-478 m) fishes from the northern continental slope of the South China Sea was found 1.96 pieces/individual and 1.53 pieces/g. The intestines of fish samples contain 1.77 pieces/individual and 4.82 pieces/g[64]. The majority of microplastics ingested by fish were <1 mm in size. The above findings are reflecting the high levels of microplastic contamination in this region potentially affecting the living organisms.

The abundance of microplastics in the fish species from Zhanjiang mangrove wetland, South China was found in 30 out of 32 fish species at an average concentration of 2.83 ± 1.84 pieces/ individual^{-1} and ranged from 0.6 to 8.0 pieces/ individual^{-1} in each species The majority of polymers were identified as polyethylene, polyethylene terephthalate, polypropylene and cellophane[62].

In the Terengganu Coast of Malaysia, average of one plastic particle was detected in 130 individuals from 6 groups of zooplnkton such as fish larvae, cyclopoid, shrimps, polychaete, calanoid and chaetognath where they ingested 0.14, 0.13, 0.01, 0.007, 0.005 and 0.003 particle/individual respectively[37].

Zooplankton are playing an important role in the marine food web to link the primary producer level to higher trophic level. The microplastics in Zooplanktons were detected in northern part of the continental slope of South China Sea sampled by 160 and 505µm mesh size plankton nets. The highest proportion (70%) of microplastics was found as fibers with the average length of 125µm and 167µm. The increasing trend at trophic level was observed and it may attribute to the bioaccumulation through the food chain. The average abundance of microplastics ingested by zooplankton was 4.1 pieces/m^3 and 131.5 pieces/m^3 for net I and II respectively[59].

Zhu et al[86] conducted a study on one seabird species and two shorebird species in Yongxing Island of South China Sea to detect the microplastics debris. 56 pieces of plastic debris were detected in 4 out of 9 birds ranging from 0.67 to 8.64 mm size. About 92.9% of microplastics are <5 mm (52 pieces). The predominant fractions were identified as polypropylene-polyethylene copolymer (83.9%).

In Nansha Island of South China, the average concentration of 3.1 pieces/ individual for fish samples with the size of <5mm was detected[84]. Microplastics occurrence in gastrointestinal tracts and gills of fish from Beibu Gulf, South China Sea was detected as of 0.027-1.000 pieces/individual^{-1}.These microplastics were found in fish stomach, intestines and gills with the count percentage of 57.7%, 34.6% and 7.7% respectively. The most common polymers were detected as polyester (44%) and nylon (38%)[58].

Microplastics found at digestive tracts of fishes from Pangandaran Bay in Indonesia were categorized as fragments 49.74% fibers 22.8%, ranging from 0.12 to 5mm in size[85]. Microplastic concentration in sea snails (*Ellobium chinense*) from mangrove forest in north of Beibu Gulf was studied by Li et al[41-43]. The study reveals that in the snails (*Ellobium chinense*) organs, rather than the shell, dominant fractions of microplastics were observed in the organs of the snail rather than the shell to the maximum level of 60% and a total of 7±2 pieces/kg-53±6 pieces/kg was measured in snails. The results reveal that these contaminations possibly originated from the abrasion of fishing gear and contributed to 61.6% of the total concentration in the surface sediment.

A study of 26 species of wild fish from the Pearl River Estuary showed the microplastics concentration ranging from 0.17 pieces/individual^{-1} (*Boleophthalmus pectinirostris* and *Acanthogobius flavimanus*) to 1.33 pieces/individual^{-1} (*Plectorhynchus cinctus*) among different species. The composition of most common polymer was polyethylene terephthalate accounting to 38.2%[33].

Plastic pollution is also having an adverse effect on coral reef ecosystems in the seas, posing a severe environmental hazard[49]. The effects and statistics on the coral reef are still limited, but they are gaining popularity. Microplastics in the coral reef of Xisha Island in the Northern South China Sea were found in the range of 1mm to 5mm in both seawater and fish, with a higher proportion of fibrous rayon and polyethylene terephthalate[7,43]. was Another study was conducted by Zhang et al[80,81] at the coral reefs of South China Sea. The concentration of microplastics has been found in four sampling sites at Weishou Island, Sanya Hui

Tou (LHT), Xisha and Nansha Islands with the range of 40 to 610 pieces/kg^{-1} of South China Sea. The study reveals that the greater proportion i.e. 75% of microplastics is in the range of <1mm at Nansha and Xisha Islands than the other sampled sites.

Wide spread microplstics were detected in the remote uninhabited coral reefs of Nansha Islands in South China Sea surface waters with an average concentration of 0.0556 ± 0.0355 pieces/m^3. The most common polymers are polypropylene and polyethylene in which > 70% of them were <3 mm in size which is due to waste released from nearby residential islands and high-intensity fishing activities around the island[23].

The study also reveals that when compared with captive mullet, the wild mullets have increased risk of microplastics ingestion[81]. Increased amount of microplastics in Oysters (*Saccostrea cucullate*) was found in the range of 1.4 to 7.0 pieces/ individual or from 1.5 to 7.2 pieces/ gram tissue wet weight in the Pearl River Estuary attributed to the increased amount of plastic inputs from the surrounding waters. Microplastics fibers dominated with 69.4% of the total plastic detected. This study suggested that Oysters can be used as bio monitors for the microplastic contamination[36].

The abundance of microplastics in the Oyster was higher in the South China Coastal areas than the Northern part of Coastal area. The average abundance was found at 0.62 pieces/g and 2.93 pieces/individual. Fibers dominated 60.67% with the polymers of cellophane, polyethylene and polyethylene terephthalate. The results revealed that the abundance was high when compared with other parts of the world[60]. Another study discovered significant levels of plastic fragments in the stomach of a green turtle, Chelonia mydas, in the South China Sea[14] which was ascribed to increased microplastic input from the environment.

Microplastics associated effects

Evidences shows that microplastics cause biological stress, oxidative stress, neurotoxicity and genotoxic effects[63]. Few studies have been conducted on the microplastics abundance in sea water organisms. Azad et al[6] reported the first evidences of existence of microplastics at Gulf of Thailand in the intestines of fish samples. It was reported that abundance of microplastics can also cause the physical impacts on the sediments such as reducing water permeability, heat conductivity and transport of minerals in the root system at mangrove ecosystem[51].

Existing evidences shows that microplastics is causing various toxic effects such as disruption in physical activity, feeding activity, reproductive system performance, metabolism, increased binding capacity of Persistent Organic Pollutants (PoP's) etc. at various trophic levels. Hence it is recommended to carryout risk assessment and associated legislative measures[54]. A study by Jia et al[36] in the Pearl River System, South China found the concentration of biocide in the microplastics ranging from 16.9–2890 ng/g considered as major source for biocides contaminant in the region.

Lo et al[47] studied the affinity of polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and 18 organochlorinated pesticides (OCPs) on the microplastics of the Hong Kong beach sediments. Elevated levels of this compound reveal the potential eco-toxicological risk in this region. Abundance of Microplastics was observed in sea snail *Ellobium chinense* in the mangrove on the Beibu Gulf[38]. This contamination leads to the subsequent movement through the food chain.

Based on the previous findings, the Pearl river is considered as a major source of microplastics in Hong Kong Region. An estimate shows that Pearl river is discharging about 13.6 thousand tonnes of plastic wastes into South China Sea[57]. The microplastics abundance in the surface water of Pearl river water was found in the range of 379-7924 particles/m^3 and in the sediments it ranges from 80 to 9597 particles/kg^{-1} in which 64.3% was found as polyethylene and 73.8% as polypropylene[2]. The mean abundance of microplastics in Pearl River in Guangzhou urban section was found as 19,860 pieces/m^3 and in Estuary section, was about 8902 pieces/m^3.

The micro plastic particles in this region were dominated by the size of less than 0.5 mm with most common types of polymers such as polyamide and cellophane[47]. With the above findings and considering the estimate of 39 billion particles or 66 tons, which converts to 2400-3800 tons of plastic debris of annual input, the abundance of microplastics from river pearl is considered as one of the major sources of microplastics into the South China Sea.

Conclusion

In recent years, increased attention has been paid to the distribution, fate and impact of microplastics on the environment. Although significant progress has been made at the global level, regional data is inadequate in understanding the distribution sources and fate of microplastics. The present study was based on previous findings from various sampling locations in the South China Sea from various countries. According to the data, the Pearl River and the Mekong Rivers of Vietnam and Cambodia are the major sources of microplastics in the South China Sea. This study suggests that more research on microplastics in this region should be conducted in order to determine the current state of dispersion, destination and consequences on the marine ecosystem. To control the transport of microplastics by rivers, site specific management strategies shall be adopted in term of reducing per capita usage of plastics, decreasing the output from sewerage discharges and waste water treatment plant discharges.

The waste water treatment facilities shall be upgraded with increased efficiency of micro plastic removal systems. More empirical research has to be focused to understand more insights of distribution pattern of microplastics. Increasing use of plastics and cost effective production are the major causes of increasing levels of mismanaged plastics in the environment. Considering this, developed and developing countries should take effective measures or guidelines to reduce the per capita consumption of plastics.

Smart cities should ensure the microplastic reduction and the removal technologies in the wastewater treatment plants. Research on cost effective biodegradation methods should be promoted. Waste water treatment plants should be designed to fully remove microplastics. In France, 83 to 95% removal was done by wastewater treatment plants[46]. The possible technological advancement should be adopted in the developing countries to minimize the microplastic load in the aquatic environment.

Countries should formulate guidelines, standards and monitoring procedures. The technical guidelines of China State Oceanic Administration for monitoring and evaluation of marine litter was the good move by China. Similarly, the monitoring of microplastics abundance and national standards for analysis and monitoring methods, environmental flow assessment, regional level initiatives, research promotion and risk assessment should be formulated. China has launched the research and development plan in 2016. However, still lack of awareness among the common people was observed and that should be addressed by the Government authorities. More research is needed on the transport, fate and the behavior microplastics from coastal zone to the marine environment.

According to Thailand Government road map for plastic waste management 2018-2030, three types of plastics will be banned from use by the end of 2019 i.e. microbeads, cap seals and oxo-degradable plastics. By 2022, 40 types of single-use plastics with a thickness of 36 microns will be outlawed. The aforementioned measures appear to be a positive sign of environmental preservation. Farmers, public health officials, environmental scientists, engineers, decision makers, municipal waste management officials, planners and developers are expected to focus source reduction, consumption and cost-effective plastic treatment technologies.

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