Toxics Link
for a toxics-free world

Quantitative analysis of microplastics along River Ganga

A report by Toxics Link

About Toxics Link

Toxics Link is an Indian environmental research and advocacy organization set up in 1996, engaged in disseminating information to help strengthen the campaign against toxic pollution, provide cleaner alternatives and bring together groups and people affected by this problem. Toxics Link's mission statement is "Working together for environmental justice and freedom from toxics". We have taken it upon ourselves to collect and share both information about the sources and the dangers of poisons in our environment and bodies, and information about clean and sustainable alternatives for India and the rest of the world." Toxics Link has unique expertise in the areas of hazardous, medical and municipal wastes, international waste trade, and the emerging issues of pesticides, Persistent Organic Pollutants (POPs), hazardous, heavy metal contamination etc. from the environment and public health point of view. We have successfully implemented various best practices and have brought in policy changes in the aforementioned areas apart from creating awareness among several stakeholders.

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Contents

1. Introduction

Plastics, which are synthetic polymers of low mass, are cheap and engineered to be highly durable and strong. This material is corrosion-resistant and has high thermal and electrical insulation qualities that make it a good water and oxygen barrier. These properties of plastics have led to its widespread applications. Its low cost spurred its use in making single-use or disposable products. Though plastic waste had caught the attention of environmentalists decades ago, microplastics has emerged as a key pollutant recently, and currently, there are few studies on microplastics in India. Previous reports on microplastics by Toxics Link were an attempt at bridging the knowledge gap in the understanding of microplastics and drawing up the linkages between plastics and microplastics. There is a serious inadequacy of information on microplastics, and its linkages to environmental, marine, and human health. The linkages between plastics and marine pollution are rarely established in discourses in India, mostly limiting it to management and human behavioural issues. There is a critical need to bridge the knowledge gap in our understanding of plastic pollution for a comprehensive understanding about microplastics, its sources, pathways and larger impacts on the environment and human health.

After many debates on the definition of Microplastics , a recent study (Frias et al., 2019) thus defined microplastics: "Microplastics are any synthetic solid particles or polymeric matrix, with regular or irregular shape and with size ranging from 1 μm to 5 mm, of either primary or secondary manufacturing origin, which are insoluble in water". For specific functions (e.g., resin pallets use as an industrial raw material, abrasive particles and powders for injection moulding) plastic is purposefully manufactured as primary MPs. However, secondary MPs are the result of fragmentation of larger plastic objects (e.g., paint flakes, rope and textile fibres, weathering and fragmentation of larger litter items, part of tyre and electronic waste) (GESAMP, 2019). If subject to

Figure 1

Top 20 polluting rivers as predicted by the global river plastic inputs model (Labreton et al., 2017).

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Table 1 | Top 20 polluting rivers as predicted by the global river plastic inputs model.

Catchment	Country	Lower mass input estimate ($t\,yr^{-1}$)	Midpoint mass input estimate ($t\,yr^{-1}$)	Upper mass input estimate ($t\,yr^{-1}$)	Total catchment surface area (km^2)[21]	Yearly average discharge ($m^3\,s^{-1}$)[21]
Yangtze	China	3.10×10^5	3.33×10^5	4.80×10^5	1.91×10^6	1.58×10^4
Ganges	India, Bangladesh	1.05×10^5	1.15×10^5	1.72×10^5	1.57×10^6	2.08×10^4
Xi	China	6.46×10^4	7.39×10^4	1.14×10^5	3.89×10^5	5.53×10^3
Huangpu	China	3.35×10^4	4.08×10^4	6.73×10^4	2.62×10^4	4.04×10^2
Cross	Nigeria, Cameroon	3.38×10^4	4.03×10^4	6.5×10^4	2.38×10^3	2.40×10^2
Brantas	Indonesia	3.23×10^4	3.89×10^4	6.37×10^4	1.11×10^4	8.18×10^2
Amazon	Brazil, Peru, Columbia, Ecuador	3.22×10^4	3.89×10^4	6.38×10^4	5.91×10^6	1.40×10^5
Pasig	Philippines	3.21×10^4	3.88×10^4	6.37×10^4	4.07×10^3	2.07×10^2
Irrawaddy	Myanmar	2.97×10^4	3.53×10^4	5.69×10^4	3.77×10^5	5.49×10^3
Solo	Indonesia	2.65×10^4	3.25×10^4	5.41×10^4	1.58×10^4	7.46×10^2
Mekong	Thailand, Cambodia, Laos, China, Myanmar, Vietnam	1.88×10^4	2.28×10^4	3.76×10^4	7.74×10^5	6.01×10^3
Imo	Nigeria	1.75×10^4	2.15×10^4	3.61×10^4	7.92×10^3	2.79×10^2
Dong	China	1.57×10^4	1.91×10^4	3.17×10^4	3.33×10^4	8.54×10^2
Serayu	Indonesia	1.33×10^4	1.71×10^4	2.99×10^4	3.71×10^3	3.70×10^2
Magdalena	Colombia	1.29×10^4	1.67×10^4	2.95×10^4	2.61×10^5	5.93×10^3
Tamsui	Taiwan	1.16×10^4	1.47×10^4	2.54×10^4	2.68×10^3	1.08×10^2
Zhujiang	China	1.09×10^4	1.36×10^4	2.31×10^4	4.01×10^3	1.33×10^2
Hanjiang	China	1.03×10^4	1.29×10^4	2.19×10^4	2.95×10^4	7.35×10^2
Progo	Indonesia	9.80×10^4	1.28×10^4	2.29×10^4	2.24×10^3	2.79×10^2
Kwa Ibo	Nigeria	9.29×10^4	1.19×10^4	2.08×10^4	3.63×10^3	1.92×10^2

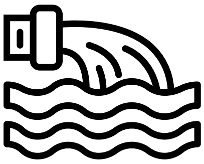
Input rate estimates (in $t\,yr^{-1}$) are representative of mismanaged plastic waste (MPW) production and catchment runoff. A lower, midpoint and upper estimate is calculated based on three regression analyses accounting for uncertainties in our field observations data set.

UV radiation, physical and mechanical abrasion or biofouling, plastic tend to break into smaller fragments which further increase the relative number of smaller particles to the number of larger litterite. (GESAMP 2015).

Labreton et al., 2017, estimated that between 1.15 and 2.41 million tonnes of plastic waste currently enters the ocean every year from rivers. Globally 74% of marine pollution is contributed by the top 20 polluting rivers, mostly Asian rivers. The Ganga is the 2nd most polluted river in the Asian continent (population ~1.380 billion). According to the study, the Ganga is the second largest contributing catchment with an annual discharge of 0.12 (range 0.10–0.17) million tonnes of plastic (Fig.1). It has also observed that the river's midpoint input estimates peak in August (wet season) with 44,500 tonnes while the river discharges <150 tonnes per month between December and March (dry season). The high concentration of pollution during the wet season is likely from the Indian and East Asian summer monsoon (June-September) in the north, when the freshwater flux is at peak.

India currently has alarmingly high levels of surface water pollution (Central Pollution Control Board, 2013). Though several studies are available on beach plastic litter to assess the distribution and abundance of MPs, the river data is still not known. There is hardly any research on MP distribution in the Indian coastal environment based on the spatial and seasonal scale. Most of the available studies conclude that beach recreation, tourism, fishing activity and religious waste as the major sources for beach plastic litter. (H.B. Jayasiri et al., 2013; Karthik et al., 2018; Dowarah et al., 2019; Sathish et al., 2019). Macro and meso plastics are identified as the major concern in all the above studies, but particle size less than 300um are more dangerous and affect the foodweb (uptake of MPs by marine organisms).

Untreated municipal discharges and industrial waste generated approximately 75% of pollution in the Ganga River, resulting in extreme pollution load



An important point source for MPs pollution is the discharge from wastewater treatment plants (WWTPs) (Boucher et al., 2019). Urban areas with choked sewers and non-functioning pumping stations release raw sewage into rivers. Untreated municipal and industrial discharges make approximately 75% of the pollution load of the Ganga (Das 2011; Dwivedi et al., 2018). Most plastic litter originates from land-based sources and inland areas (urban runoffs) and enters the marine environment through rivers. (Hurley and Nizzetto, 2018; Rochman, 2018). Since the early eighties, the Government has launched several plans and spent several millions of rupees for improving the water quality in the Ganga, but these efforts resulted in little success. The Ganga Action Plan (GAP) in 1985, IIT Consortium (2011) for water diversion and effective treatment, National Ganga River Basin Authority in 2009 with multi-sectorial plans, the ambitious National Mission for Clean Ganga in 2011 [implementation arm of National Ganga River Basin Authority (NGRBA)] and Namami Ganga Mission in 2014 have been only marginally effective in controlling the plight of the river (Kumar et al., 2019). None of these plans examined microplastic pollution in the mighty river.

As there is enough evidence of the ill-effects of microplastic pollution of foodweb through diverse routes (Galloway and Lewis, 2016; Li et al., 2016; Rochman et al., 2016; Seltenrich, 2015; Sigler, 2014; Heidbreder et al., 2019), it is important to examine it in detail. The present study has investigated the abundance, distribution, and composition of MPs in the Ganga water at different sampling locations (Haridwar, Kanpur and Varanasi). As a trans-boundary river of South Asia, the Ganga is not only the longest; it is the most sacred to Hindus. At the same time, it suffers from extreme pollution levels (Chaudhary et al., 2019) caused by the 400 million people who live close to the river (June 2003 Newsletter; ***Salemme,).*** This study draws attention to MP pollution of the Ganga and prompts action on the framing of guidelines and managerial action.

The Ganges and Plastic pollution

The 2525 km long Ganges, locally known as the Ganga, flows from the Himalayas to the Bay of Bengal and is one of the world's greatest, longest and highly polluted river. It flows through 100 cities with populations of over 100,000 and via 97 cities and 48 towns with populations between 50,000 to 100,000. Despite its cultural and religious importance, the river has rapidly degraded in the 20th century due to human activities. A large proportion of sewage water with high organic load drains in the Ganges from its basin area, besides industrial effluents from countless tanneries, chemical plants, textile mills, distilleries, slaughterhouses, and hospitals contribute to the pollution of the Ganges. Originating in the Western Himalayas, and fed by tributaries from Tibet, Nepal, Bangladesh, and India, the sacred river collects an estimated 1.2 billion pounds of discarded soft and hard plastic each year in its journey[1]. The staggering pollution puts the Ganga among the ten rivers in Asia and Africa that together transport 93 per cent of river-based plastics to the Earth's oceans[2]. The river represents an extreme paradox — though worshipped by 1 billion Hindus and relied upon as a water source by roughly 400 million people, it is contaminated with industrial effluents, untreated sewage and household trash. Because of its religious significance, the Ganga also attracts a lot of tourists and pilgrims, who leave behind a trail of garbage, mainly constituting single-use plastics. But overall, there is a considerable lack of plastic pollution data on the Ganga.

The Ganges River contributes 315 tons of plastic waste per day, the equivalent of 79 elephants!

Source: https://www.arcgis.com/

In a 2019 study done by ICAR-Central Inland Fisheries Research Institute, Kolkata, (Dhruba Jyoti Sarkar, Soma Das Sarkar, Basanta Kumar Das, Ranjan Kumar Manna, Bijay Kumar Behera, Srikanta Samanta) sediments of the lower stretches of the Ganga at seven locations, namely Buxar, Patna, Bhagalpur, Nabadwip, Barrackpore, Godakhali and Fraserganj, were analysed for the distribution of meso and microplastics. All the sediments were found to contain mesoplastics (>5 mm) and microplastics (<5 mm) particles with varying degrees of the mass fraction (11.48 to 63.79 ng/g sediments), numerical abundance (99.27–409.86 items/kg) and morphotypes. Analysis of the mesoplastics with FT-IR revealed polyethylene terepthalate (39%) as the major contributing plastic debris in the sediments followed by polyethylene (30%). The statistical analysis of water and sediment samples revealed a strong correlation between the abundance of microplastics and pollution traits, BOD and available phosphates.

1 https://www.nationalgeographic.com/environment/2019/02/partner-content-alliance-renew-oceans/
2 https://www.scientificamerican.com/article/stemming-the-plastic-tide-10-rivers-contribute-most-of-the-plastic-in-the-oceans/

Figure 2 Garbage on the bank of Ganga in Kolkata

Despite campaigns for cleanliness, the country has not been able to control the massive proliferation of plastics along the Ganga

Image Source: https://www.nationalgeographic.org/activity/plastic-Ganges-river/

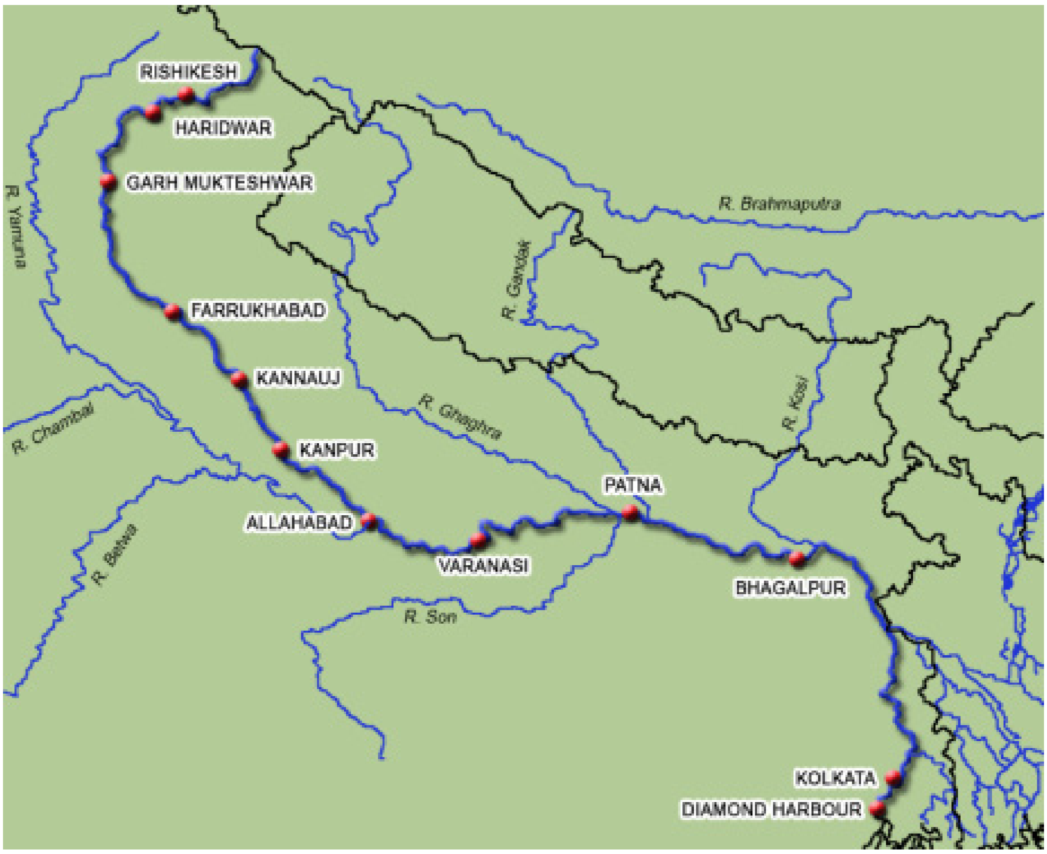
Need and importance of microplastics study of the Ganges

- The Ganga covers about 2,525 kilometres from its origin to its mouth and supports 625 million people in its basin. An estimated 11,625 tons of solid waste is generated in cities situated along the Ganga and its largest tributary, the Yamuna.
- Lebreton et al., (2017) ranked River Ganga as the second most polluted among the top 20 polluted rivers in the world based on the global model using geospatial data of population density. However, there is no real-time data available to validate their study. The proposed study, therefore, is extremely important.
- Method standardization is needed to obtain comparable data from different environmental compartments and sites. This includes sampling strategies (at spatial and temporal scales), sample treatment (taking into consideration high levels of organic matter and suspended solids) and reliable analytical methods.
- Implementing mitigation strategies requires an understanding and quantification of marine plastic sources, taking spatial and temporal variability into account.

2. Materials and methodology

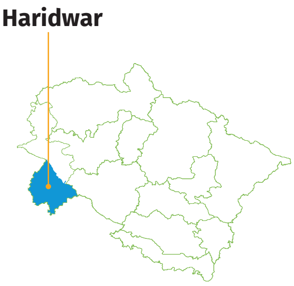
Study areas

Varanasi, also known as Kashi and Banaras, is situated on the banks of river Ganges in Uttar Pradesh, India, 320 kilometres (200 miles) south-east of the state capital, Lucknow, and 121 kilometres (75 miles) east of Allahabad at an elevation of 80.71 metres (264.8 feet). It is a famous Hindu pilgrimage site and a global tourist attraction. Varanasi is also an important industrial centre famous for its muslin, silk, perfumes, ivory works, and sculpture. The city has 88 ghats for sacred religious ceremonies and holy bathing, which are performed every day in large numbers. The ghats also represent the spiritual city under the threat of acute pollution of the holy river. River Ganga, along whose banks the city rose, is at a risk of endangering levels of pollution not only from sewage, or as a result of a large number of cremations every day but also as a result of the huge microplastic pollution, which is generally unnoticed or lesser-known due to the lack of studies and public awareness (Sayantani Basak et al., 2015).



The details of the study area and sampling locations are given in Table 1 and Figure 2.

Kanpur city is a metropolis in the state of Uttar Pradesh, India, and is known for its leather and textile industries. It is the 12th most populous city and the 11th most populous urban agglomeration in India. It is also the second-largest city and the largest urban agglomeration in Uttar Pradesh. As per the provisional results of 2011 census, Kanpur city has a population of 2,767,031. Situated on the west bank of river Ganga, Kanpur is a major trade and commercial centre in North India with the first wool mill of India, commonly known as the Lal Imli. Anthropogenic activities and reduced freshwater in the river flow have deteriorated the river water quality along Kanpur. The tanning industry is the major source of pollution of the Ganga in Kanpur city. It has contaminated water and aquatic flora and increased the nutrient load in the river water resulting in eutrophication (algal blooms) (Sandeep Arya and Richa Gupta., 2013). In addition to smoke, dust, polluting gases, water pollution through the discharge of industrial effluents (R.P. Singh.,2001), plastic waste disposal and microplastics pollution, are becoming a serious threat to the aquatic ecosystem as well as humans.



Haridwar, covering an area of about 2360 km^2, is in the south-western part of Uttarakhand state of India. Haridwar is situated at a height of 314 metres from the sea level, between Shivalik Hills in the North and Northeast and the Ganges in the South (Census of India, 2011). It is regarded as a holy place by Hindus and hosts important religious events. It also serves as a gateway to several prominent places of Hindu pilgrimage. As per the 2011 India census, Haridwar district has a population of 1,890,422. The city also has a thriving industrial area, which was established in 1964 and currently employs over 8000 people (*https://en.wikipedia.org/wiki/Haridwar*). A study has revealed high pollution load at industrial estates, which may be due to the discharge of untreated effluents from metal processing industries (Tushar Arora et, al., 2017). Haridwar has many plastic manufacturing units, which may result in the disposal of huge amounts of plastic waste into the environment.

Table 1

Description of the study area along with the starting and ending point (Lat/long) in the river Ganga

Location/ date	Sample ID	Starting point (Lat/Long)	Ending point (Lat/long)	Description
Varanasi(V) (06/02/20)	V1	25.3047508 / 83.0090871	25.3051443 / 83.0141028	Assi ghat to Kedar ghat full of organic matter (flowers, plants)
	V2	25.3048361 / 83.0093248	25.303200 / 83.008512	Kedareswar ghat to Pandey ghat
	V3	25.304252 / 83.009876	25.317780 / 83.023262	Sheetala ghat to Gaay ghat (Bigger size plastics were observed floating on the surface)
	V4	25.3113035 / 83.0158738	25.312471 / 83.017324	Sankatha ghat to Dashashwamedh ghat (Full of organic waste)
	V5	25.2817008 / 83.0101234	25.2838190 / 83.0093925	Near Assi river (discharge outlet was there for the release of inland waste)

Location/ date	Sample ID	Starting point (Lat/Long)	Ending point (Lat/long)	Description
Kanpur(K) (10/02/20)	K1	26.368803 / 80.496345	26.365860 / 80.499084	Started from Dohri ghat, Jamuna mandir (2 sewage stations)
	K2	26.378462 / 80.490557	26.380484 / 80.487751	Upward side of Dohri ghat (many discharge outlets were there for the release of inland waste
	K3	26.5018717 / 80.3205611	26.5021147 / 80.3206962	Atal Ghat (Full of tourists)
	K4	26.4928100 / 80.3352489	26.4928391 / 80.3344731	Sisamau ghat
	K5	26.4842922 / 80.3592724	26.4851214 / 80.3548555	Sarsaiya ghat
Haridwar(H) (13/02/20)	H1	29.9535167 / 78.1699730	29.9423204 / 78.1556879	Lalitpura, Hari ki Paudi (observed as a holy place for Bathing (Ganga snan)
	H2	29.9422986 / 78.1557633	29.9423204 / 78.1556879	Dam kothi at Ganga kenal (Discarded plastic gangajal bottles were floating on the surface water)
	H3	29.9373988 / 78.1480110	29.936478 / 78.146552	Lovkush ghat
	H4	29.9304665 / 78.1368128	29.927972 /78.132627	Kankhal, Prem Nagar ghat (Garbage littering observed during the sampling)
	H5	29.9266799 / 78.1303091	29.926168/ 78.129333	Singhdwar Abdut Mandal ghat

Figure 3
The maps of the sampled locations: A-Varanasi, B - Kanpur (B), and C- Haridwar. The arrows point to the sites sampled and their corresponding number for reference.

i) Collection of Samples

At each site, a set of 5 surface water samples were collected in the month of February 2020. The samples were taken from multiple locations along Ganga river (see Table 1, Fig 3), with a focus on sampling areas which were heavily polluted with any wastewater treatment plant along the river. The samples were collected using a plankton net (50 cm i.d. and 1.8m length) of 300µm mesh size attached to a small receiver which was deployed from the side of the boat and towed for around 10-20 minutes (based on the water system). After trawling the net, sample was brought over to the boat and the water retained in the receiver was collected in separately cleaned and sterilised glass bottles. It was then taken to water laboratory for analysis. A flow meter was attached to the net to allow estimation of total water volume sampled and the expression of results in m^3. The volume passed through was formerly filtered by pouring into a 5mm,1mm steel mesh and 300µm nylon net which were staked from top to bottom, attached with a steel receiver at the end. In order to prevent the loss of particles, the sample bottle and the lid was rinsed with distilled water. The water collected in the steel receiver was then filtered using a vacuum filtration unit containing a filter paper of 47mm diameter and 5µm pore size. Finally, the filter papers were transferred into the labelled petri-plates and dried in an oven at 40ºC until it fully dried. The analytical procedure is given in the Fig 4.

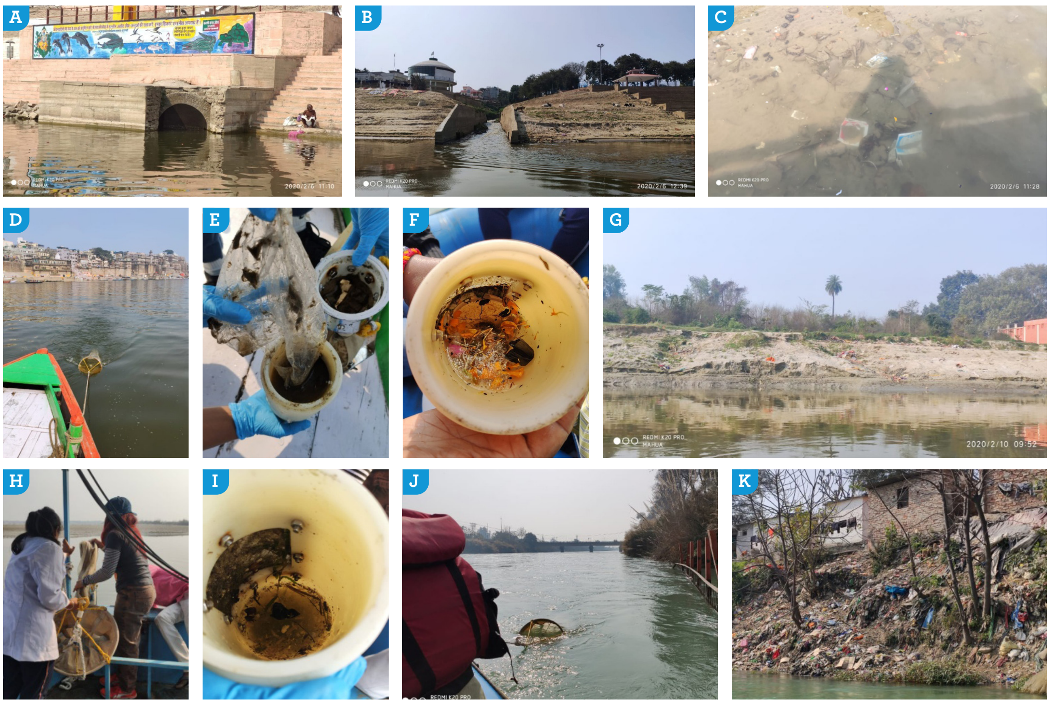


Figure 4

Pictures showing different sampling locations along the Ganga. Varanasi (A, B, C, D, E and F), Kanpur (G, H and I) and Haridwar (J and K).

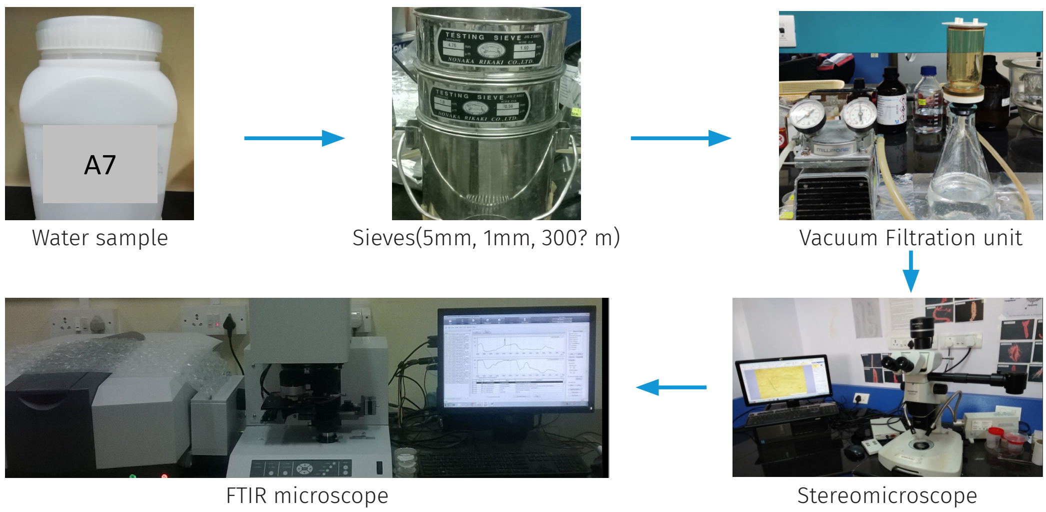


Figure 5

Flow chart showing the analytical procedure for the extraction of microplastics from the surface water

ii) Identification of microplastics

The extracted plastic particles from all samples were categorized according to their colour and shape. The colours identified were white, transparent, blue, green, black, yellow, orange, red, pink, purple, grey, and brown. Based on the MSFD Technical Subgroup on Marine Litter (2013) report, the shapes were classified as: fragment, film, pellet, foam, bead, and fibre.

iii) µ-FTIR analysis

The composition of microplastics in each filter paper was identified using Micro-Fourier transform infrared spectroscopy (µ-FTIR) with advanced imaging and microscopy (AIM). The specification of FTIR were as follows: Made of Shimadzu; IR tracer and AIM view software; spectrum resolution 16cm^{-1}; number of scans =100 per sample; mirror used for background correction and advanced AIM correction. Blank filters were examined to check the airborne contamination. The images of microplastics in FTIR are given in Fig 5.

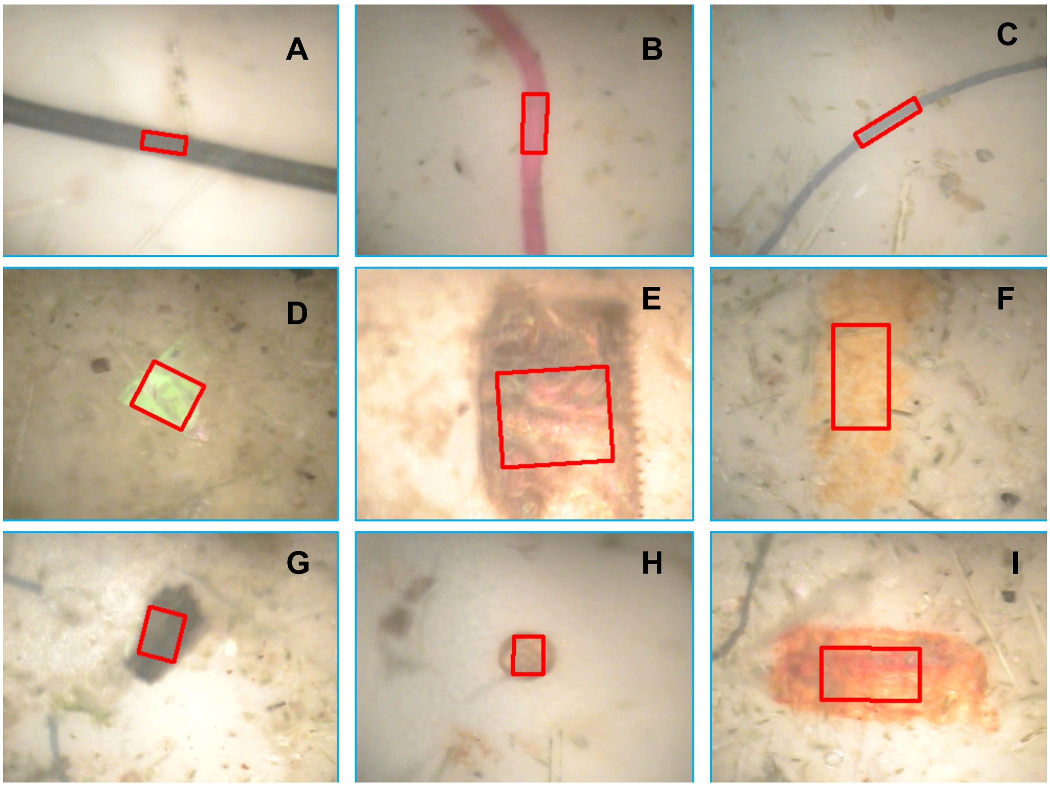


Figure 6
Selected MPs pictures Fiber (A, B and C), Film (D, E, F and I), Fragment (G) and Bead (H) in µ-FTIR

Deliverables from this study

- The study establishes baseline data on abundance, seasonal variation and source of macro to microplastics for future aquatic pollution and water quality monitoring.
- Standardization of new methodology on microplastics research.
- As a useful guide for the coastal and offshore stakeholders, managers and policymakers, State and Central Pollution Control Boards.
- Establishing advanced microplastics study in India

Constraints during surface water sampling and instrument setup

- While collecting a surface water sample, high water flow and turbulence makes it difficult to tow the net, which provides a demanding environment, especially when handling a large-sized net.
- Organic matter (plant leaves, flower and other natural waste) can get stuck into the net, which can hamper the movement of the flowmeter.
- Taking measurements in medium and large-sized natural streams and keeping the device stable at the required points in the water column is challenging.
- Towing time of the net should be selected based on the water system (river, estuary, ocean) because there will be a high chance of eructation of the net due to phytoplankton blooms and other natural phenomena.
- In shallow water, especially when the water depth is less than 3 metre, towing the net is not possible as sediment load can prevent the flow of the net horizontally.

3. Results and discussion

Abundance and distribution of microplastics in surface water of Ganga River

The river water samples collected for the study were polluted with plastic waste - mainly single-use and secondary plastic products. Accumulation of plastic litter was found in and around the river banks and its negative impact was observed in the river as floating litter. The river gets all the urban wastes, and sewage is discharged directly into the river.

Varanasi

The number of microplastics detected in surface water of river Ganga in Varanasi was (2.42±0.405 MPs/m^3). V1 resulted in high number of microplastics in surface water (2.82 MPs/m$^{3)}$ followed by V2 (2.60 MPs/m^3), V4 (2.56 MPs/m^3), V3 (2.33 MPs/m^3) and V5 (1.76 MPs/m^3). Assi Ghat (V1) showed the maximum abundance of microplastics as it is the most popular ghat in Varanasi and is one of the very few ghats that is linked with the city through a wide street. Additionally, one sewage outlet was observed draining the wastewater and sewage directly into the Ganga which may affect the microplastics concentration and abundance in and around the sampling site. The second most polluted ghat was Kedareshwer ghat (V2) followed by Dasaswamedha (V4) and Sheetala ghat (V3). The lowest concentration was observed (V5) near Assi river, which may be due to the influence of heavy flow in this river resulting in heterogeneous distribution of microplastics , leading to their increased dispersion throughout the surface water allowing them to travel long distances.

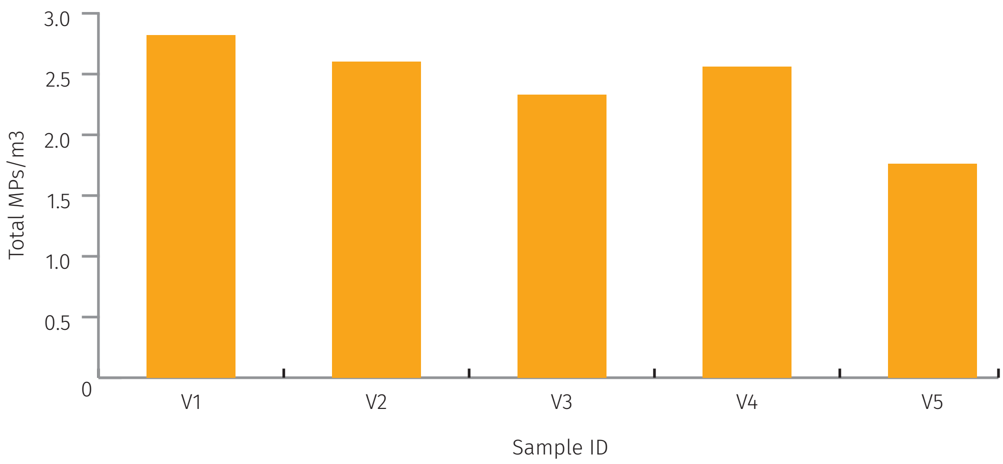


Figure 7
Distribution of MPs at each location in Varanasi

Table 2. Relative distribution of microplastics/m3 at different sampling locations along the Ganga

Location	Sample ID	Distance trawled (m)	Duration of trawling (minute)	Cylindrical Area covered (m^2)	Total volume passed through the net (m3)	Total volume Filtered (ml)	Total no. of MPs found in filtered water (number)	Total MPs/m^3
Haridwar (H)	H1	1089.8	19	1711.3785	126.567	2700	232.9	1.84
	H2	249.13	10	391.5266	75.371	700	66	0.88
	H3	749.43	15	1176.9976	112.346	1200	76.8	0.68
	H4	879.31	16	1380.9092	115.190	2000	204	1.77
	H5	641.39	14	1007.3748	109.502	1000	143	1.31
Kanpur (K)	K1	454.56	13	714.0517	59.728	1000	93	1.56
	K2	798.17	17	1253.5194	83.904	1800	223.2	2.66
	K3	469.32	14	737.2249	63.995	1000	116	1.81
	K4	399.39	11	627.4348	55.462	1300	148.2	2.67
	K5	593.73	15	932.5486	72.527	1500	153	2.11
Varanasi (V)	V1	668.59	16	1050.0788	83.904	1500	237	2.82
	V2	364.39	11	572.4848	52.618	1200	136.8	2.60
	V3	201.29	10	316.4178	41.241	850	96	2.33
	V4	397.92	13	625.1269	56.884	1300	145.6	2.56
	V5	676.89	17	1063.1098	86.748	1000	153	1.76

Kanpur

The number of microplastics detected in the surface water samples of river Ganga in Kanpur was 2.16±0.500 MPs/m^3**.** Slightly low concentration of microplastics was found in this region as compared to Varanasi. K4 and K2 manifested approximately same no. of MPs/m^3 (2.67) followed by K5 (2.11), K3 (1.81) and K1 (1.56). Discharge of sewage water into the Ganga from Sisamau nullah (K4) has completely stopped (Dec 2019), which earlier used to discharge 140 MLD of sewage wastewater daily into the Ganga river (*www.indiatimes.com*), but still the highest number of microplastics were found in the sample collected from this point. K2 (upstream of Dohri ghat) has more than 20 sewage water treatment plants resulting in the release of wastewater from the city directly into the Ganga, which was witnessed during sampling. Apart from the industrial waste generated from these plants affecting the microplastics pollution in the Ganga near Dohri Ghat, famous temples and tourist locations like the Hanuman temple is also situated on Dohri Ghat and may be leading to plastic pollution at the location. When the sample was collected from this site, it was cleaned and waste disposal sites/waste bins were systematically arranged. But it is difficult or not feasible to remove the microplastics (<1mm) which have already escaped in the river waters. Also, during the sampling, we observed many floating particles were easily caught in the plankton net showing significant contamination. The third most polluted location is (Sarsaiya ghat) K5, which is an ancient ghat and popular among pilgrims. This ghat was recently revamped under the Namami Gange programme (*www.aninews.in*), attracting locals as well as tourists from all over the country. Atal ghat (K3) and Dohri ghat (K1) were least polluted as they were cleaned in Dec. 2019 under the Namami Gange programme before the arrival of the Prime Minister.

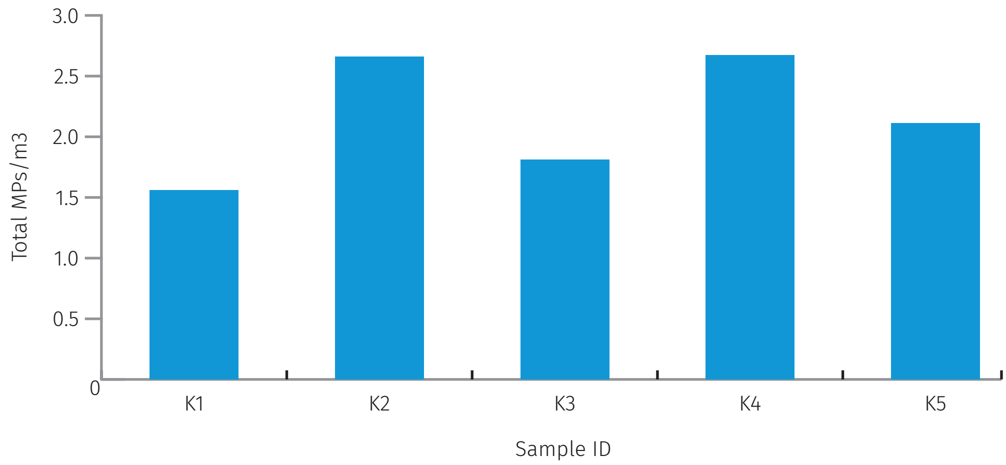


Figure 8
Prevalence of microplastics in the water samples from the Ganga in Kanpur

Haridwar

Haridwar resulted in the lowest number of MPs/m³ (1.30±0.518) as compared to Varanasi and Kanpur. Within Haridwar locations, Har ki Pauri (H1) showed the maximum prevalence of microplastics (1.84 MPs/m³), but it was much lesser than those noted for Kanpur and Varanasi. The second most polluted location in Haridwar was Kankhal (H4) (1.77 MPs/m³), which is famous for its ancient history and temples. Apart from being home to several temples and ashrams, Kankhal is also home to numerous havelis and estates that attract tourists from all over the world and generates huge amount of waste, especially plastic waste, which ultimately drains into the river through urban runoffs, rainfall, mismanagement of solid waste disposal etc. Singhdwar (H5) (1.31 MPs/m3) was the third most polluted location. It harbours many hotels, markets and residential places, which might lead to discharge of domestic and hotel wastes directly or indirectly into the river. Lovkush ghat (H3) and Dam kothi (H2) showed the lowest abundance of microplastics (Table2). The flow of the Ganga is higher in Haridwar than Varanasi and Kanpur. There is a high chance that microplastics are flushed faster in Haridwar and, therefore, not trapped in the plankton net during the sampling. Although the Ganga in Haridwar was found to be cleaner as compared to in the other two locations, factors like hydrodynamic conditions, turbulences, domestic and industrial waste discharges, and even the microplastics characteristics themselves can influence microplastics distribution pattern (De Troyer, 2015; Mani et al., 2015; Lestari et al., 2020).

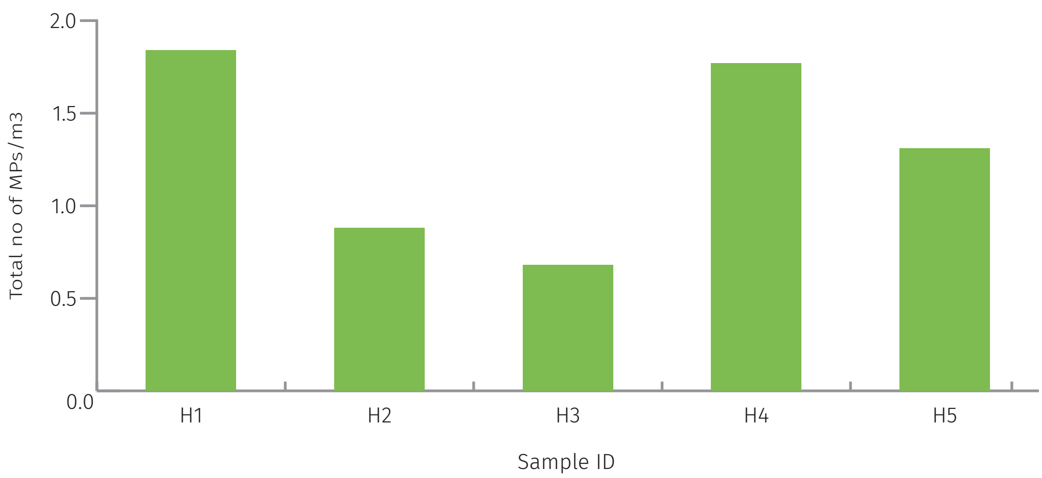


Figure 9
Distribution of MPs at each location in Haridwar

Characterisation and Identification of Microplastics

Shape, size and colour

The shapes of the observed particles were sorted into fibres, fragments, films and beads (Fig 9). Fragments were the predominant shape in all locations, followed by film and fibre. Slight difference was observed in Kanpur as fibres were more abundant than films (Fig.8). This may be due to the flourishing textile industry in Kanpur city. Textiles are major source of these fibres and contribute majorly to the MPs pollution in River Ganga. Interestingly, microbeads were observed in Varanasi (2.2±2.049) and Kanpur (0.6 ±1.342). Varanasi is a well-known place for bathing, and the personal care products used during such activities (facewash, scrub, detergents and other cosmetics) can get directly released into Ganga waters and cause a great potential risk to small freshwater organism. Very less prevalence of beads was observed in Kanpur as compared to Varanasi. Surprisingly, no beads were found in Haridwar though, like Varanasi, it is also a popular bathing and cleaning spot.

The average abundance of different shapes of MPs were distinctively observed in all the sampling locations, though Varanasi seems to be the major contributor of MPs among all the three locations followed by Kanpur and Haridwar (Table 3).

Domestic wastewater (a point source) drains directly into public water, without passing through WWTPs, when there is no sewer system. When a sewer system is developed, domestic wastewater drains into public water after most of the debris is removed at a WWTP (Dris et al., 2015).

Table 3. Relative average concentration of microplastics

Location	Fragment	Fibre	Film	Bead
Haridwar	72±36.572	13.2±3.421	17.2±12.677	0
Kanpur	71±5.00	23±8.456	15±2.2236	0.6±1.342
Varanasi	91.2±25.024	14.8±2.049	18.4±7.635	2.2±2.049

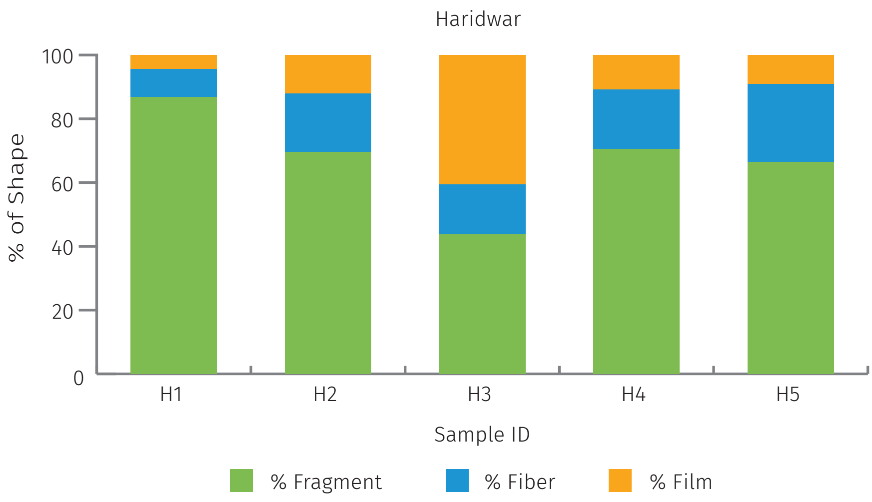
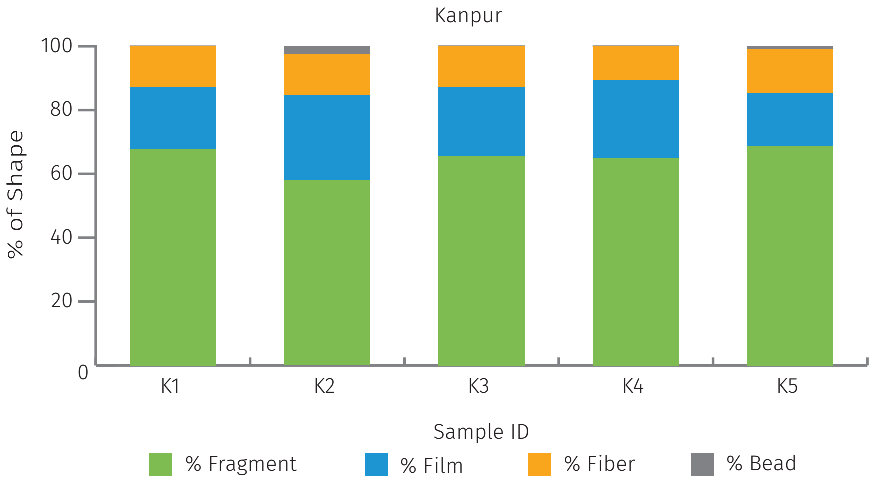
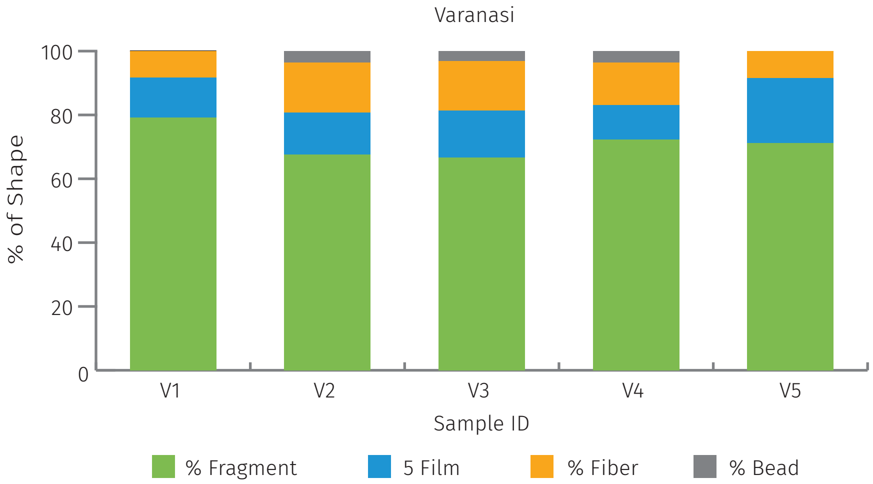


Figure 10
Percentage of different shapes of MPs in all 3 locations





Size is one of the important factors that can affect distribution of the microplastics in surface waters. The most frequent size range observed in all the samples was <300μm as compared to the size frequency of 1-5mm. This further highlights the process of photo-degradation, mechanical, physical, biodegradation and weathering phenomenon as very small sized particles with more surface area tend to reside in the surface water, thus increasing their abundance in the river.

Therefore, the longer plastic waste is exposed to the degradation mechanisms, the more abundant and smaller the size of the microplastics is (Lassen et al., 2015; Firdaus et al., 2019; Lestari et al., 2020).

Black and brown colour particles were found in more numbers followed by coloured particles in all three locations (Fig.10). Dominance of black coloured particles (mainly fragments) may be attributed to particles produced as a result of abrasion of tires on road surfaces (Wik and Dave, 2009; A.D. Gray et al., 2018) as most of the black fragments were mainly composed of styrene-Isoprene rubber, PI and polyacetal. This is in contrast with other studies reported worldwide showing the predominance of coloured microplastics. Coloured microplastic particles mainly come from packaging, clothing materials, and many other applications (Xu et al., 2018) and may potentially contribute more to the organism ingestion due to resemblance of its prey items (Wright et al., 2013). In addition, various colours of plastic materials are made by colorant addition, such as pigments, dyes, and special effect ones (Muller, 2011). The colorant agent can get released or leached out from plastic material into the environment through degradation processes (Gewert et al., 2015; Lestari et al., 2020).

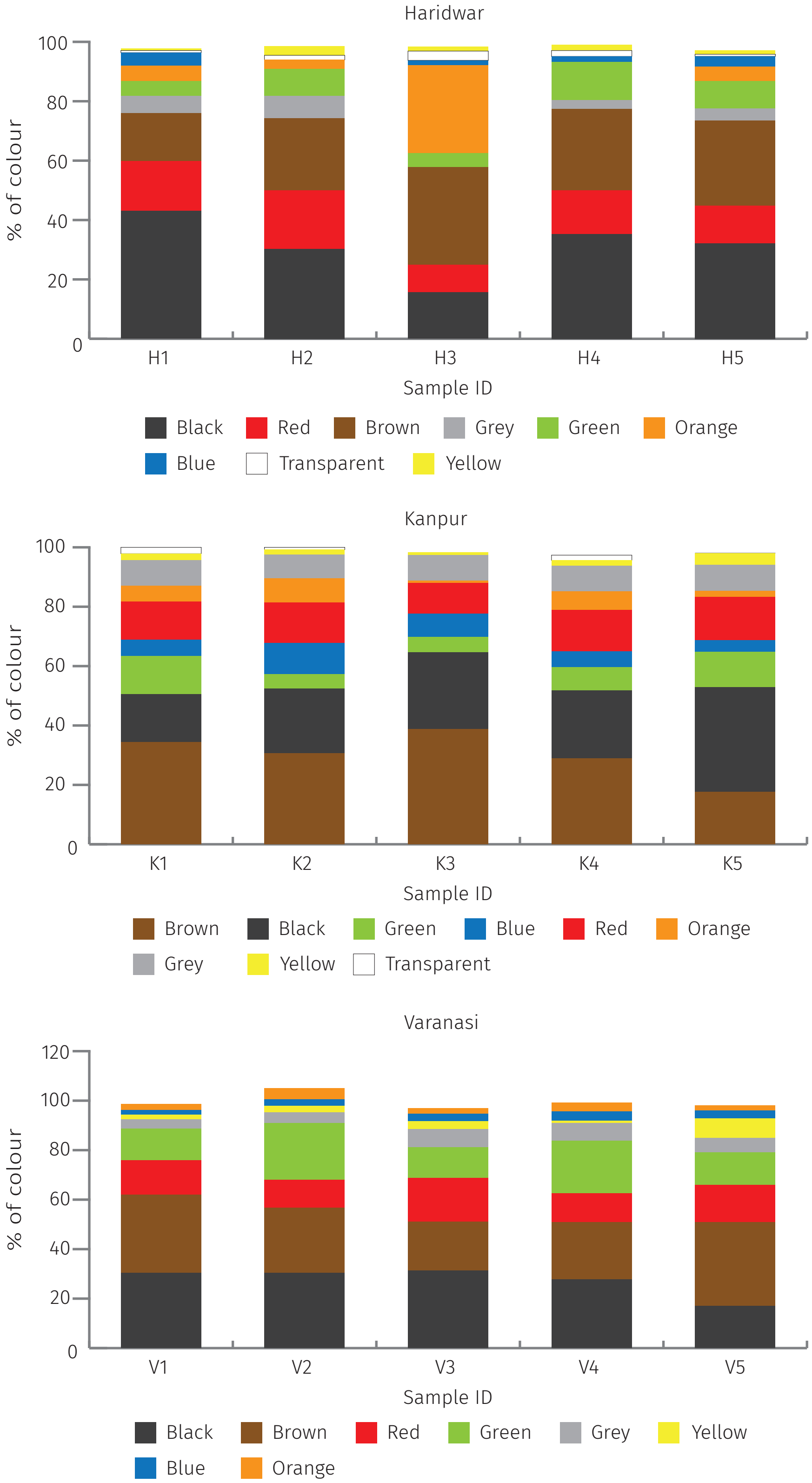


Figure 11

Percentage of different colors of MPs in all 3 locations

Composition

Based on the µ-FTIR analysis, 40 different types of polymers were detected in microplastics found in Ganga waters at Haridwar, Kanpur and Varanasi. EVOH, Polyacetylene, PIP, PVC and PVAL were predominant at all three locations. However, each station had their varying abundance(Fig 11). The potential sources of these polymers are discussed hereunder:

EVOH or ethylene vinyl alcohol is known for the best barrier resistance to gases such as oxygen, nitrogen, and carbon dioxide. This makes it particularly suited for packaging food, drugs, cosmetics, and other perishable products. When compared to other common films, EVOH is considered to have superior barrier properties. **Polyacetylene,** which is a conductive polymer, has no commercial application but is used as a doping agent in manufacturing electronics and thin films (Ron Dagani 1981). It is found very commonly. Some studies suggest that it is a plant-based polymer, and therefore its amalgamation with organic particles in the river may also be a reason of its high concentration. **PP or Polypropylene is** very commonly used in packaging, plastic sheets, fibre and fabrics, tape, rope etc. Phenol, isopropylated phosphate or **PIP** is mainly used in footwear and baby bottle nipples. **Polyamide (PA)**, commonly known as nylon, is used as a natural fibre and metal wires in clothing and industry. **PVC** or polyvinyl chloride is used in pipes, wires and cables, medical devices and automotive industry.

PVP or polyvinyl pyrrolidone is majorly used in cosmetics and pharmaceutical industry. Presence of a wide variety of plastic resins clearly indicates that microplastics in Ganga waters may not be coming only from industrial waste but also from the anthropogenic activities (degradation of larger plastic debris into small fragments).

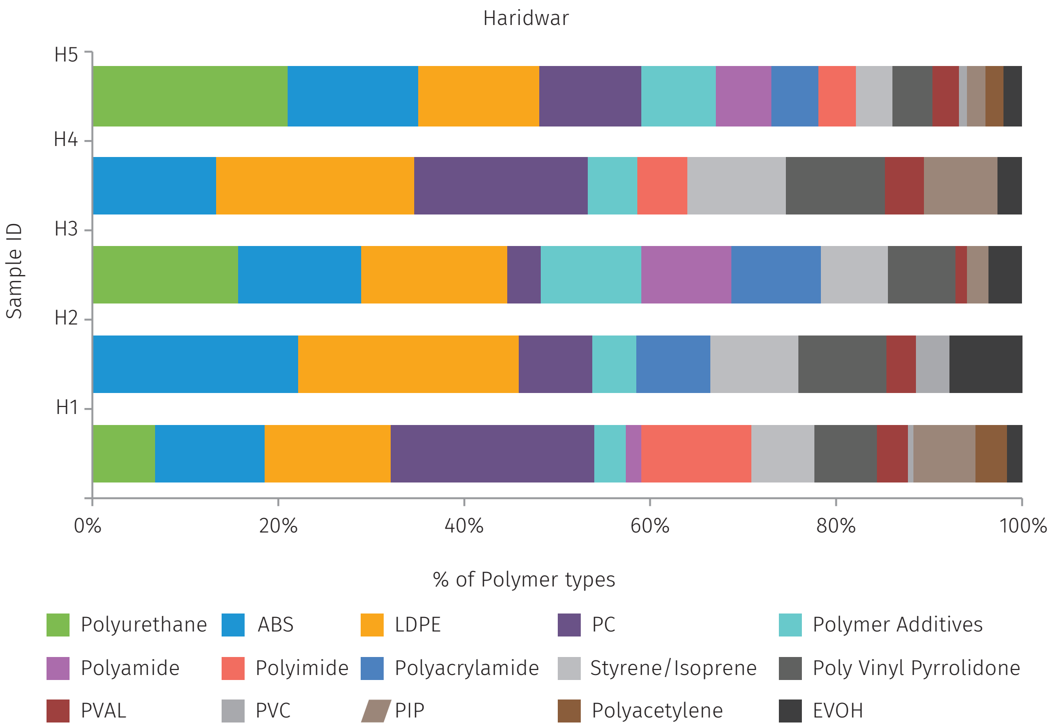
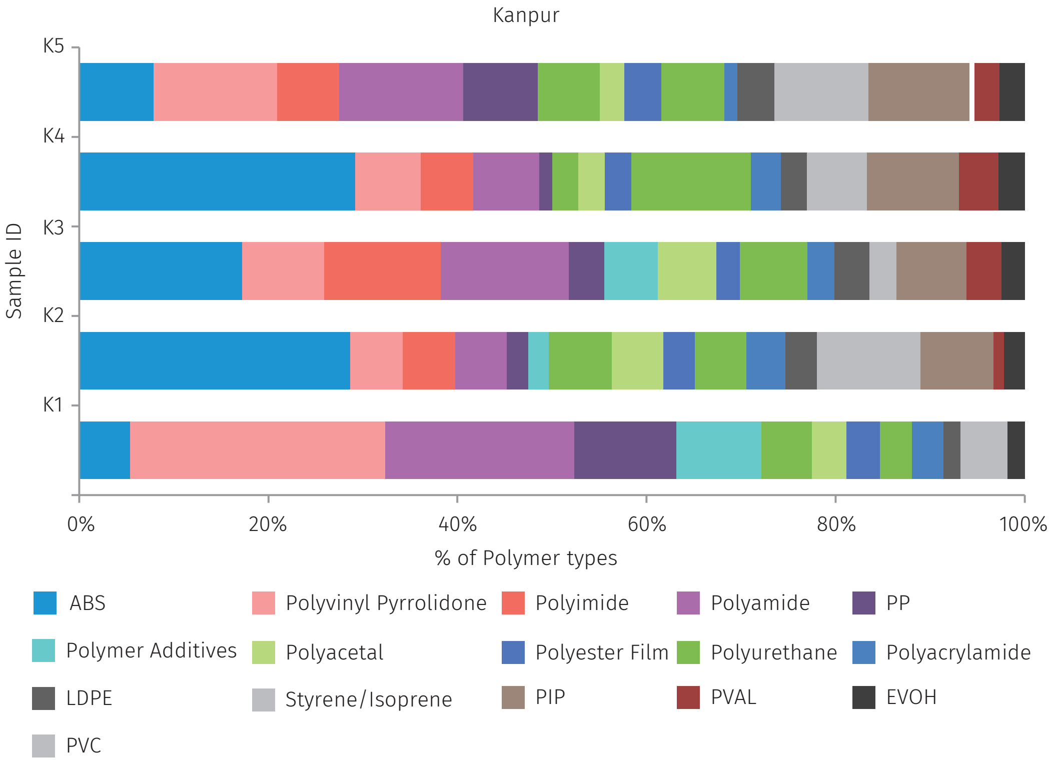
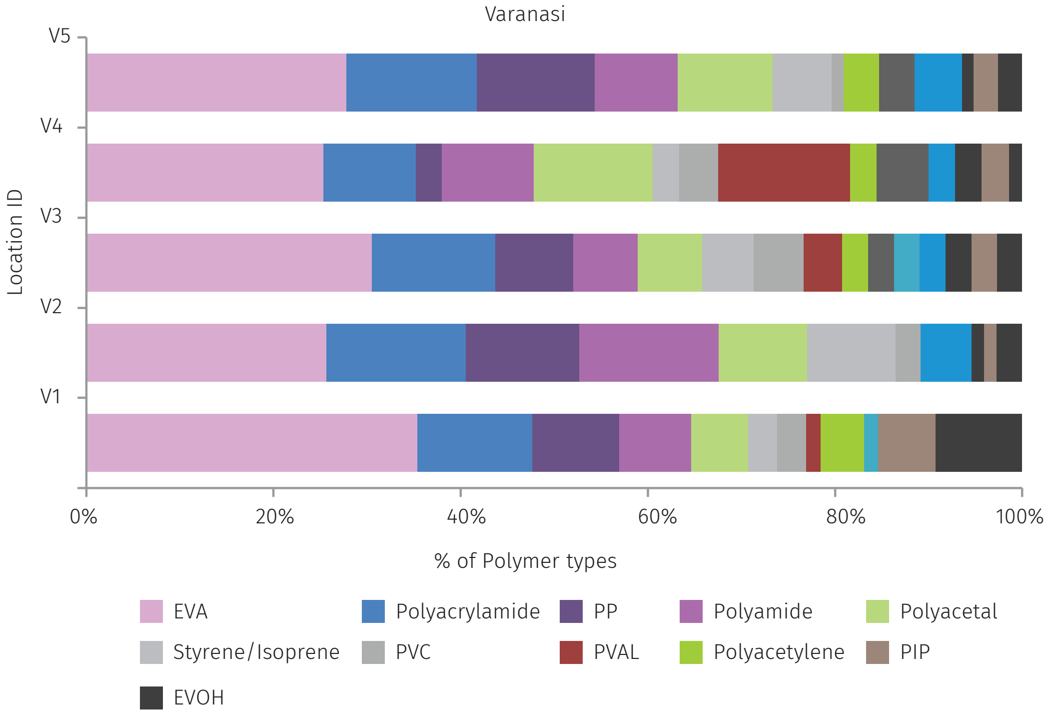


Figure 12
Percentage of polymeric composition of MPs in all 3 locations





Plastic litter largely originates from land-based sources and is relocated, for example by urban runoffs, riverine movement culminating in the marine environment (Hurley and Nizzetto, 2018; Rochman, 2018; S.M. Mintenig et al., 2018.). Globally, between 0 and 1.3 MP m^{-3} (median 2.75 MP m^{-3}) was reported in river surface waters (Koelmans et al., 2019; Mintenig et al., 2020). The concentration of microplastics in this study is comparable to other riverine systems (Table. 4) as we have used the same sampling methods with 300µm plankton net and µ- FTIR technique for the identification of polymers up to 20µm in size. Furthermore, many studies have reported very few polymers, but the present study identifies more than 40 polymers (Figure.11). Interestingly, several types of rubbers (butadiene, polyisoprene, natural rubber), hitherto not reported for riverine surface waters, were also found abundantly. Several studies reported that they have analysed only 10-25% of filter paper, whereas here we have analysed all filter papers in the µ-FTIR and found rare polymers which might be the reason of high diversity in the polymeric composition of microplastics.

In our study, each location where particles detected were in the range between 1-5mm showed less dense and common polymers viz PE, PP and HDPE, and these have less concentration in smaller sized microplastics. From the studies (Haave et al., 2019; Lorenz et al., 2019; Mani et al., 2019; S.M. Mintenig et al 2020) it is confirmed that smaller size particles <1mm have diverse polymers, but > 1 mm are almost exclusively made from PE or PP. Some particles (black, opaque with rubberlike consistency) are probably from vehicle tires, from both natural wear-down processes during driving and shredding of used tires for recycling purposes (Heloisa Westphalen and Amira Abdelrasoul, 2018). Quantitative and qualitative information on the occurrence of water-soluble polymers (e.g., PVP, Polyacrylamide) is very limited, covering only a few polymer types and chain lengths (Petrović ***et al.,*** 2000; Huppertsberg et al., 2020). This may be attributed to a general lack of awareness in the scientific community (Arp et al**,** 2020; Huppertsberg et al., 2020) and some severe analytical challenges.

A 2017 study by Pieter Jan Kole at The Open University of the Netherlands, published in the ***International Journal of Environmental Research and Public Health***, estimated that tires account for as much as 10% of overall microplastic waste in the world's oceans. A 2017 report by the International Union for Conservation of Nature put that number at 28%. Synthetic rubber, made from a variant of plastic, makes up around 60% of the rubber used in tires. Apart from tires, fragments found in the study are mainly attributed to the breakdown of larger plastics (plastic bags, plastic bottles, plastic cups etc.) due to physical factors like fragmentation and weathering. Films were the second most abundant shape found in all the locations. This may be because films suspend in waters rather than deposit in sediments. Fibres found during the study, could be originating from WWTPs and may constitute fibres from textiles and washing machine effluents from household, laundry, other domestic and industrial runoffs, which directly discharge their waste into this holy river. In addition, mismanaged plastic can be more rapidly fragmented on land and enter rivers as microplastics. Moreover, litter along the river banks is one of the major reasons for this pollution.

Key Findings

- The Ganges is polluted with plastic waste, mainly single-use and secondary plastic.
- The microplastic abundance in the surface water of river Ganga in Varanasi was 2.42±0.405 MPs/m^3.
- The number of microplastics detected in surface water of river Ganga in Kanpur was 2.16±0.500 MPs/m^3**.**
- Haridwar has the lowest MPs/m^3 (1.30±0.518) as compared to other two locations Varanasi and Kanpur.
- Fragments were the predominant shape in all locations, followed by film and fibre. Slight difference was observed in Kanpur where fibres were more abundant than films.
- The most frequent size range observed in all the samples was <300µm.
- Black and brown coloured particles were found to be more in number followed by coloured particles in all the three locations. Dominance of black coloured particles suggest its origin from abrasion of tires.
- Several types of rubbers (butadiene, polyisoprene, natural rubber) were abundantly found in the river water samples
- 40 different types of polymers were found during analysis. EVOH, Polyacetylene, PIP, PVC and PVAL were predominantly found in all the three locations.

Table 4

Comparison between this study and other studies for suspended microplastics (particles/m3) in surface water

Sr. No	Region	River	MPs' Abundance (particles/m³)	References
1	Indonesia	Surabaya	21.16	Prieskarinda Lestari et al.,2020
2	Europe	European River	5.57	Christian Scherer et al.,2020
3	Europe	Mediterranean	18.8±28.1	Mel Constant et al.,2020
5	Europe	Seine	3 to 36 (may) 4-108 (April)	Dris et al., 2015
6	Europe	Danube	0. 316.8± 4.664	A. Lechner et al. 2014
7	Europe	Po	1-12.2	Vianello et al., 2015
8	Europe	Rhine	1.85-4.92	Van der Wal et al., 2015
9	North America	Patapsco	0.399-8.72	Yonkos et al., 2014
10		Magothy	0.240-1.73	
11		Rhode	0.124-0.880	
12		Corsica	0.0369-0.617	
13	South America	Elqui	0.129	Rech et al.2015
14		Maipo	0.64	
15		Biobio	0.05	
16		Maule	0.74	
17	Asia	Ganga	1.30-2.42	Present study

4. Conclusion

The Ganges has a deep spiritual connection with people in India. It is part of the Hindu mythology, religion and rituals and has supported one of the oldest civilizations. It originates in the Himalayas and running through the northern plain, supporting several towns and cities along its course, it finally ends in the Bay of Bengal, Indian Ocean. The Ganga's deep significance notwithstanding, the alarming levels of pollutants, both industrial and sewage, discharged into it every day by over 1100 industrial units and several towns situated on its banks have made it one of the most polluted rivers in the world. A recent report by the Central Pollution Control Board declared that the Ganga water is unfit for bathing, let alone for drinking from it directly.

The current study has thrown up alarming results as microplastics were found in all the samples. However, the concentration of microplastics was significantly different in different sampling sites. Locations with higher population density and greater industrialisation (textile, tannery, etc.,) etc., had a higher microplastics concentration in the river. The study findings indicated higher microplastic levels in the samples collected from Kanpur and Varanasi in comparison to Haridwar. Among the three cities, Varanasi showed the maximum load of microplastics in the Ganga waters as compared to the other two cities. This may be due to cumulative downstream pollution as well as industry and human activities. Assi Ghat (V1) in Varanasi had the maximum abundance of microplastics, which may be due to the drainage of sewage and industrial effluents directly into the Ganga..

According to a recent study, more than 663 species are affected adversely due to marine debris. 11% of them are said to be related to microplastic ingestion alone.

In the case of Kanpur, K_2 (upstream of Dohri ghat) showed the highest abundance among the five sampling sites, which is most likely due to the sewage and/or industrial effluents coming from the city of Kanpur. Though the lowest concentration of microplastics was found in Haridwar, within Haridwar, Har ki Pauri showed the maximum presence of microplastics. This could be corelated with human activities as it is one of the most popular ghats, where thousands of pilgrims come for a traditional bath daily. Results of this study indicate higher microplastic pollution in the Ganges as we go downstream from Haridwar to Varanasi. It indicates that municipal and industrial discharges are responsible for microplastic pollution in the river water. The situation becomes more prominent in Kanpur and Varanasi which may be due to discharge from tanneries and other industries like textiles, etc..

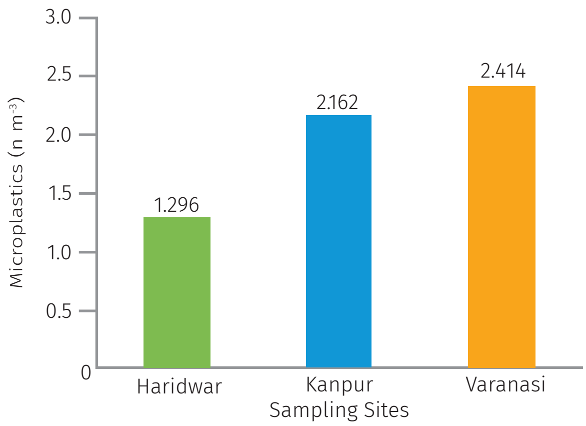


Figure 13
Average microplastic concentration in the three study cities

If we compare microplastic concentration in the Ganges waters with the similar studies on other rivers across the globe, like the Rhine in Europe, the Patapsco, Magothy, Rhode in North America, the Elqui, Maipo, Biobio, and Maule in South America (see Table 1), in the Ganga microplastics pollution is much higher. This is in spite of a higher per capita consumption of plastic in the European states, north, and south America as compared to India.

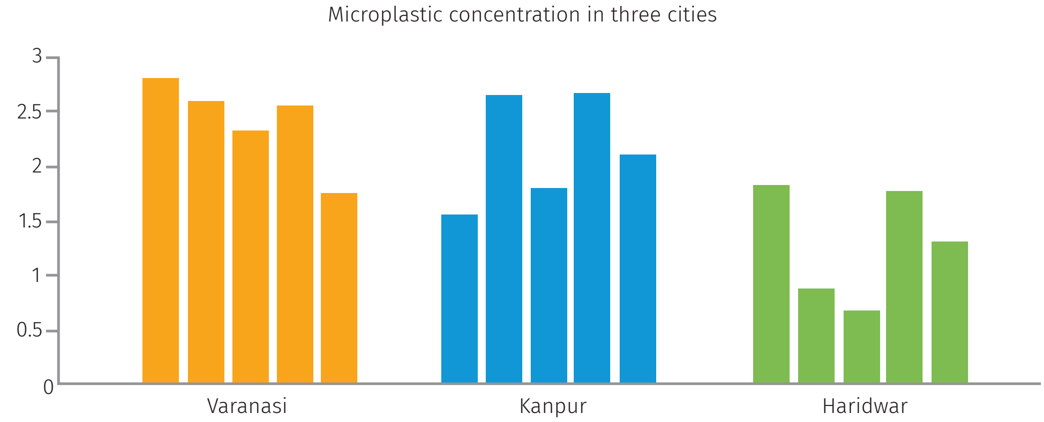


Figure 14
Microplastic concentration in three cities

The concern of microplastic pollution in the Ganga is critical as the water from the river is used for drinking and irrigation purposes quite extensively. An increased abundance of microplastics in a river increases the potential harm that it can cause to organisms and humans. After ingestion, microplastics cause toxicity through several pathways and mechanisms. The polymeric compounds and additives such as copper ions used in the production of plastics are toxic. More importantly, microplastics absorb various toxins in waters (including harmful chemicals) that are first absorbed onto microplastics, and subsequently may desorb inside a host organism. The study also shows that the river is acting as a carrier of plastics and microplastics and transporting significantly large quantities into the ocean.

This study exhibits the spatial distribution of microplastics in the Ganga along densely populated areas. Its emphasis is on the emerging pollutant in the inland river system, underlining its role as a transporter of plastic fragments finally into the ocean.

Recommendations

Water is absolutely essential for the basic sustenance of human beings. No wonder most of the civilisations have come up on the banks of rivers or in the river valleys. India is no exception. In India, every city has come up on the bank of a major river. As mentioned in the earlier chapters, river pollution, especially of the Ganga, has been a major concern for many years now. Decline in its quality of water is affecting the health, agriculture and overall life of a significant number of the Indian masses. The findings from this study on microplastic pollution add a new dimension to this entire issue. Microplastic pollution in the Ganga can have very serious implications for the environment as well as human health. The current study has looked at the Ganga at three locations, and the findings do suggest that there is an urgent need to look extensively at this global pollutant not just in the Ganga but also other river bodies in the country.

The findings clearly indicate that the river pollution is linked to human activity, and plastic waste management needs to improve substantially to control land-based pollution sources. Untreated sewage from many cities along the river's course, industrial waste and religious offerings wrapped in non-degradable plastics add large amounts of pollutants to the river as it flows through densely populated areas. During the festival season, the immersion of idols adds large amount of plastic and chemicals, further adding to the plastic pollution of the water. The unchecked effluent discharges and sewage dumping is resulting in serious pollution which needs to be addressed immediately.

Though Plastic Waste Management Rules have been in force in the country for some years, their implementation on the ground is very poor. Improving this along with minimizing the single-use plastics could be part of the solution.

Some of the key recommendations

- ***Need for further research on microplastics in the Ganga as well as other rivers in the country*** - A detailed study to analyse the microplastic pollution in the Ganga and other rivers will be quite useful to understand the problems related to the river waters in India. There is also a need to look at the microplastic sources, especially the primary ones.

- ***Microplastics and human health:*** Microplastics and its impact on marine bodies and the environment is documented through various research studies. But there is hardly any work for assessing its impact on human health. Considering its property to absorb toxic pollutants, microplastics can have serious impact on human health. Studies need to be taken up to understand this in depth.

- ***Strengthening of plastic waste management in the country and improved implementation of the Plastic Rules-*** Land-based pollution sources need to be reduced and for that plastic management needs to improve substantially.

- ***Improved effluent and industrial discharge systems, especially around the water bodies in the country -*** Industrial discharge, many a time untreated, is creating havoc with our river water and the oceans. This needs serious and immediate attention. Regular monitoring and penalization on violation needs to be brought in to improve the ground situation.

- ***EPR to improve Plastic waste -*** Plastic Waste Rules brought in the concept of Extended Producer Responsibility in plastic waste management but little is being done on the ground. EPR will need to be implemented in true spirit, if this massive waste stream and its spread is to be arrested.

- ***Notifying the areas around the water bodies as no-plastic litter zone and stringent penalties on violation-*** Rivers are the lifelines of any country and need to be protected. Declaring the areas around the rivers and seas as no-litter zone and no-plastic zone should be taken up as a priority.

- ***Restrictions on single-use plastic products, wherever possible and where alternatives are available***- Long-term solutions need to be thought of for reduction in plastic pollution. Most studies have indicated that single-use plastic is one key pollutant. Strict measures to replace them or phase them out, wherever feasible, will need to be enforced.

- ***Mass campaign to bring behavioural change needs to be taken up with desired emphasis***- Public awareness will hold the key to improving plastic waste management and the subsequent reduction in microplastic pollution. Various stakeholders, including the industry, government, civil society organisations, need to join hands to bring about the change.

There is a need to look at the threat of plastic to river life more realistically, more comprehensively, and above all, with an eye on the future. A scenario build-up for the future will help the decision-makers arrive at an appropriate strategy to address the problem.

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Annexures

Effects of microbeads

The use of a personal care product with microbeads results in the release of around 5000 to 95,000 microbeads, due to which billions of microbeads have been released in the oceans over the last few years. This leads to massive contamination of our seas, which is indirectly linked with diseases and poor health conditions among humans. Because microbeads are too small in size, normal water filtration systems cannot trap them. They escape water treatment and filtration processes and find their way in rivers, drains and other water bodies. When microbeads enter the water system, they become toxic carriers with eco-toxicological consequences. They absorb toxic chemicals, including petrol, PAHs, engine oil, pesticides, PCBs, industrial sewage etc. When marine animals ingest these particles, they often choke to death. When humans ingest these microbeads through fish/ seafood they too exhibit adverse effects on their nervous and endocrine systems.

Synthetic microfibers

Synthetic microfibers (MFs) are made up of non-biodegradable polymers including nylon, polyester (PE), rayon, polyethylene terephthalate (PET), polypropylene (PP), acrylic or spandex having a diameter less than 5 mm. China, India, Europe, the USA, Taiwan are the leading synthetic apparel producing countries, where China and India are contributing 70% and 7.64% of global synthetic fabric production, respectively. Asia continent counting China, India, Taiwan, Indonesia, South Korea, Thailand and Japan, which are the major synthetic fibre producing countries, together produce around 95% of the global consumption of synthetic fibres. Synthetic microfibers are considered a major source of marine microplastic pollution and are mainly released from synthetic clothes during domestic washing. In a single wash of 6 kgs synthetic garment through domestic laundering around 700,000 microfibers are released. A single jacket can liberate up to 250,000 fibres in a single washing machine wash. The numbers of MFs are ever increasing in the environment due to the mounting contribution of domestic washing, textile industries, abrasion of tyres, personal care products, illegal landfilling and dumping, fragmentation of large plastics and other anthropogenic factors. Fragmentation of large plastics, like fishing nets release about 640,000 ton of fibre. These synthetic fibres washed off from laundering and other sources get into the water system through sewage and eventually enter our oceans. After ending up in rivers and oceans, these fibre pollutants absorb all toxic chemicals, heavy metals, oil that are already present in the water and become lethal. Microfibres are known to bind with several pollutants, such as heavy metals, polycyclic aromatic hydrocarbon (PAH), Polybromide diphenylethers (PBDEs), polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT) and endocrine-disrupting compounds (EDCs). In aquatic environments, these fibres regularly release carcinogenic toxins. The released chemicals from these synthetic tiny fibres may transfer to upper trophic levels via the food chain harming the entire ecosystem. Fibres present in the ocean gather toxins and are consumed by marine organisms, thus contaminating the food chain and risking animal as well as human life.

S.No	Aquatic species	Source & Exposure	Hazardous effects
1	Fish	Microfibres uptake from clothes, fishing net, rope etc.	Endocrine disruption, Toxicity in liver, damage in intestine and reproductive problems
2	Phytoplanktons	Feed on plastic fragments, microfibers	Reduction in chlorophyll absorption
3	Zooplanktons	Entanglement of synthetic fibres, plastic beads	Decrease in feeding, growth and development, and reproduction
4	Mussels	Engulfment of synthetic fibres from bags, rope, microplastics	Gut blockage
5	Laboratory ingestion of polystyrene beads	Neurotoxicity, genotoxicity and DNA damage	Marine mollusc
6	Copepods	Ingestion of plastic beads	Decrease in survival and fecundity
7	Microalgae	Feed on plastic fragments and beads	Reduced feeding rate
8	Lugworm	Uptake of plastic beads, fragments	Reduction in feeding capability
9	Zebra Fish	Intake of microfibers and plastic beads	Blockage in gut, Liver damage
10	Rotifer	Uptake of fishing net, plastic beads	Decrease in growth rate and reproduction
11	Echinoderm	Ingestion of microplastics	Reduced larval growth and development
12	Monogonont Rotifer	Intake of microplastic particles	Decrease in growth rate, fecundity, lifespan, reproduction time
13	European sea bass	Intake of fishing net and rope fragments, synthetic fibers from garment, microplastics	Larvae death due to blockage of the intestinal lumen
14	Cetacean Species	Intake of marine debris, bags, ropes, bottles etc.	Chronic and acute injuries resulting in pathology and mortality
15	Corals	Ingestion of coastal plastic debris	Stock in the gut
16	Crustaceans	Uptake of microplastics	Lowering of branchial function
17	Polychaete worm	Ingestion of microplastics from fragmented plastics, cosmetics and industries	Reduced feeding activity, reserved energy
18	Oyester	Uptake of synthetic microfibers	Decreased oocyte number and sperm velocity
19	Sea urchin	Intake of microplastics	Developmental toxicity and cytogenetic irregularity
20	Seals	Entanglement of plastic debris, fishing gear	Decrease in feeding capacity, swimming habit
21	Penguins	Ingestion of fishing net fragments, marine debris	Puncture in the gut, death
22	Polar bear	Marine litters	Alternation in feeding habit
23	Chlorella and Scenedesmus	Ingestion of microplastics, fishing trawls, plastic beads	Reduced photosynthetic ability

S.No	Aquatic species	Source & Exposure	Hazardous effects
24	Nematode	Ingestion of microplastics, fishing gears	Intestinal damage
25	Sea bird	Intake of microplastic debris from sea shores, fishing lines	Alternation in the feeding behaviour, reproductive problem and mortality
26	Sea turtle	Ingestion of fragments of fishing trawls, packaging bands, drinking straws, etc.	Blockage of digestive tract, undernourishment, death
27	Lobster	Ingestion of plastic particles, rubbers	Decreased larval survival and metamorphosis
28	Sperm whale	Uptake of polyethylene bag and bottles	Gastro-intestine tract rupture, and malnutrition
29	Baleen Whales	Engulfment of all type of marine debris	Impairment to the digestive processes and obstruction of the intestinal tract
30	**Human**	**Ingestion and inhalation of synthetic microfibers, microplastics**	**Respiratory problems, breast cancer, damage to liver, kidneys, and intestine etc.**

Table: Chemicals commonly released and adhered to microplastics.

Chemical types	Characteristics	Toxicity	References
PCBs	Thermo stability, high chemical durability, high liposolubility.	Carcinogenic: causes brain, skin, and visceral diseases; and affect the reproductive, nerve, and immune system; accumulated in adipose tissue easily.	Wang et al.(2018), Antunes et al.(2013), Frias et al.(2010).
DDTs	Chemical stability, resistance to acids, and insolubility in water.	Hormonal secretion of the organism disrupted; affects liver, reproductive (disrupt the egg shells) and nervous systems functions; have carcinogenic properties.	Bernardes et al.(2015), Antunes et al. (2013) Rios et al.(2010), Endo et al.(2005)
PBDEs	Low solubility in water and Lipophilicity.	Have toxic effects on the organisms and humans; thyroid hormone disruptors.	Heindel et al. (2015), Choi et al. (2009), Darnerud (2008)
PAHs	Low solubility in water, chemical solubility.	Causes cancer in humans by contact; strong carcinogenic effects.	Perera (2017), De Sá et al. (2018)
BPA	Bisphenol—A is a moderately water-soluble compound (300 mg/L at room temperature).	Threatens the health of a foetus and children; causes cancer; lead to endocrine disorders.	Vermeirssen et al.(2018), Endo et al. (2005), Teuten et al. (2007), Oehlmann et al.(2009)
NP	Stabilizes, solubilizes, emulsifier, moderately soluble in water,	Can mimic oestrogen; affects the sexual development of the organism; and interfere with the endocrine functions of the organisms.	Jabeen et al.(2015), Hirai et al. (2011), Nayak et al., (2010), Sonnenschein and Soto(1998)

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