International Research Journal of Environmental Sciences ISSN 2319–1414
Vol. **13(3),** 1-10, July **(2024)** *Int. Res. J. Environmental Sci.*

Microplastics pollution in Narmada River water and sediments: characterization, source distribution and risk assessment

Kalpana Patidar[*], Dilip Kumar Mahato and Balram Ambade
Department of Chemistry, National Institute of Technology, Jamshedpur 831014, Jharkhand, India
kalpana8kashish@gmail.com

Available online at: www.isca.in, www.isca.me
Received 22nd January 2024, revised 5th April 2024, accepted 7th June 2024

Abstract

Plastic pollution has been caused by the unavoidable and regular use of plastic materials in daily life along with manufacturing and chemical processes, which is extremely dangerous for the environment. In the current study, we investigated abundance of MPs, their probable sources, risk assessment of microplastics in surface water and sediments of the Narmada River in India. A stereomicroscope was used to determine the MPs size, shape, color, and an Attenuated Total Reflection-Fourier Transform Infrared (ATR-FTIR) spectrometer was used to determine the polymer composition of the MPs. The average MP concentration observed was 6.3 ± 3.8 in the water and 119.4 ± 39.6 in the sediments during the study period. Highest abundance of MPs was observed in diameter of less than 1mm, fibers, and fragments were the most common shapes. MPs colour composition of black and white in water, whereas white and blue was spotted in the sediments. The chemical structure of MPs in water and sediment samples i.e., polyvinyl chloride (PVC), polyesters (PEs), polypropylene (PP), polyethylene (PE), polyamide (PA), and polystyrene (PS) were analysed. The estimated pollution load index (PLI) result shows a category I pollution load in water, hazard level II in sediments and categories III, IV, and V polymer hazard levels, which indicates threat to ecosystem. According to recent research findings, the largest contributor of MPs contamination is probably due to river influxes, terrestrial and other aquatic activities. This research aims to assist individuals in reconsidering the irregular behaviours of MPs in diverse surroundings and may be useful in comprehending their biological consequences in wide-spread environmental situations.

Keywords: Microplastics, Abundance, Sources, Risk assessment, Hazard level.

Introduction

Plastic residues are becoming a problem in aquatic environments due to their prevalent existence in large amounts, uncontrolled utilisation, and poor disposal, every factor which contribute to their pervasive presence[1]. Small solid particles comprised of plastics that are not biodegradable like PE, PVC, PEs, PA that are less than 5 mm in size are known as "microplastics (MPs)". However, they differ from one another in terms of size, shape, and their process and location of production. Primary MPs are purposefully generated for usage as beads or pellets in products like stones and basic sanitation, among other applications[2].

Large plastic trash items gradually degrade into smaller fragments under the influence of physical force, UV light, oxidative characteristics of the environment, and hydrolytic characteristics of water bodies[3]. The aquatic environment serves as one of the primary recipients for MPs and plays an essential role to their prevalence and transit[4,5].

The accumulation of plastic in the aquatic environment is caused by a number of factors like fishing for commercial purposes, residential and industrial discharge, the aquaculture industry, tourist attractions, and coast activities[6].

Each residence in India produces substantial quantities of plastic waste, which accounts for about 60% of the total municipal trash produced[7]. Glaciers, rain, and urban and industrial effluents are some of the sources of these MPs that enter the river ecology[8]. Additionally, MPs are capable of introducing additional hazardous compounds to the species, altering their level of bioavailability[4].

As microplastics effectively adhere to the biomass of aquatic macrophytes, bio adhesion has been identified to be the main process in these associations[9]. Many studies have discovered that MPs have the potential to serve as carriers for heavy metals and organic compounds including PCPs and polycyclic aromatic hydrocarbons (PAHs)[10-12]. In the modern era, the use of plastic has spread throughout the world and now poses severe risks to both human health and the environment[6]. Microplastics have been responsible for cytotoxicity and genetical harmful effects in both plant and human population[13,14]. Changes in gut populations of bacteria, alterations to lipid and metabolic processes[15]. These results showed that freshwater ecosystems are not exempt to MPs and are equally affected by human activity as those in the oceans. Therefore, rigorous rules and regulations, sustainable tourism, appropriate plastic use reduction, and attention to the aquatic environment are all necessary for avoiding the anthropogenic threat.

The current study validates the presence of MP pollution in the Narmada River water and sediments, India, by providing baseline site- and specific data for the qualitative and quantitative features of the microplastics. The present investigation will be helpful in doing additional research and establishing mitigation strategies, as well as helping to produce guidelines for regulating MP pollution.

Methodology

Sampling site description: The Narmada River is the longest river running through Madhya Pradesh and the third holiest and fifth-largest west-flowing river in all of India[16]. The basin is located on the northern edge of the Deccan plateau and is bordered on the east by the Vindhya and Satpura ranges. The river basin covers a surface area of 98,796 km^2. The river has a 1000 to 1850 mm per year average flow rate. Visitors from every corner of the nation come to this station because of its spiritual significance for worship at the Shri Omkar Mandhata temple[17]. The investigation location is situated between latitudes of 22.151°N and 22.230°N and longitudes of 76.346°E and 76.240°E of Omkareshwar and 22.106°N and 22.110°N and 75.346°E to 75.260 of Maheshwar along the Narmada River, respectively. Figure-1 depicted the studied area map (created using QGIS-Desktop 3.26 software). Maheshwar is a little town in the Madhya Pradesh state in central India's Khargone district. It is 91 kilometres from Indore, the state's commercial capital. The city is located on the Narmada River north bank.

Sample collection: At every point of sampling, surface water was collected in glass reagent bottles, with the help of stainless-steel bucket. Total 20 samples of both water and sediment were gathered from each point during the April-May months. Samples 1–5 were taken from the Omkareshwar, and samples 6–10 were collected from the Maheshwar along the Narmada River. Table-1 show the details of the sample collection site, sampling code and abundance of MPs. With a 1L steel mug we collected the water sample from the upper layer of the river water, which lieup to1 to10 cm deeper. The mug was carefully cleaned and rinsed by distilled water before sample collection. The sample of surface water is shifted to a 1 L glass flask after being filtered through a stainless-steel mesh sieve and being cleaned with distilled water before being utilized.

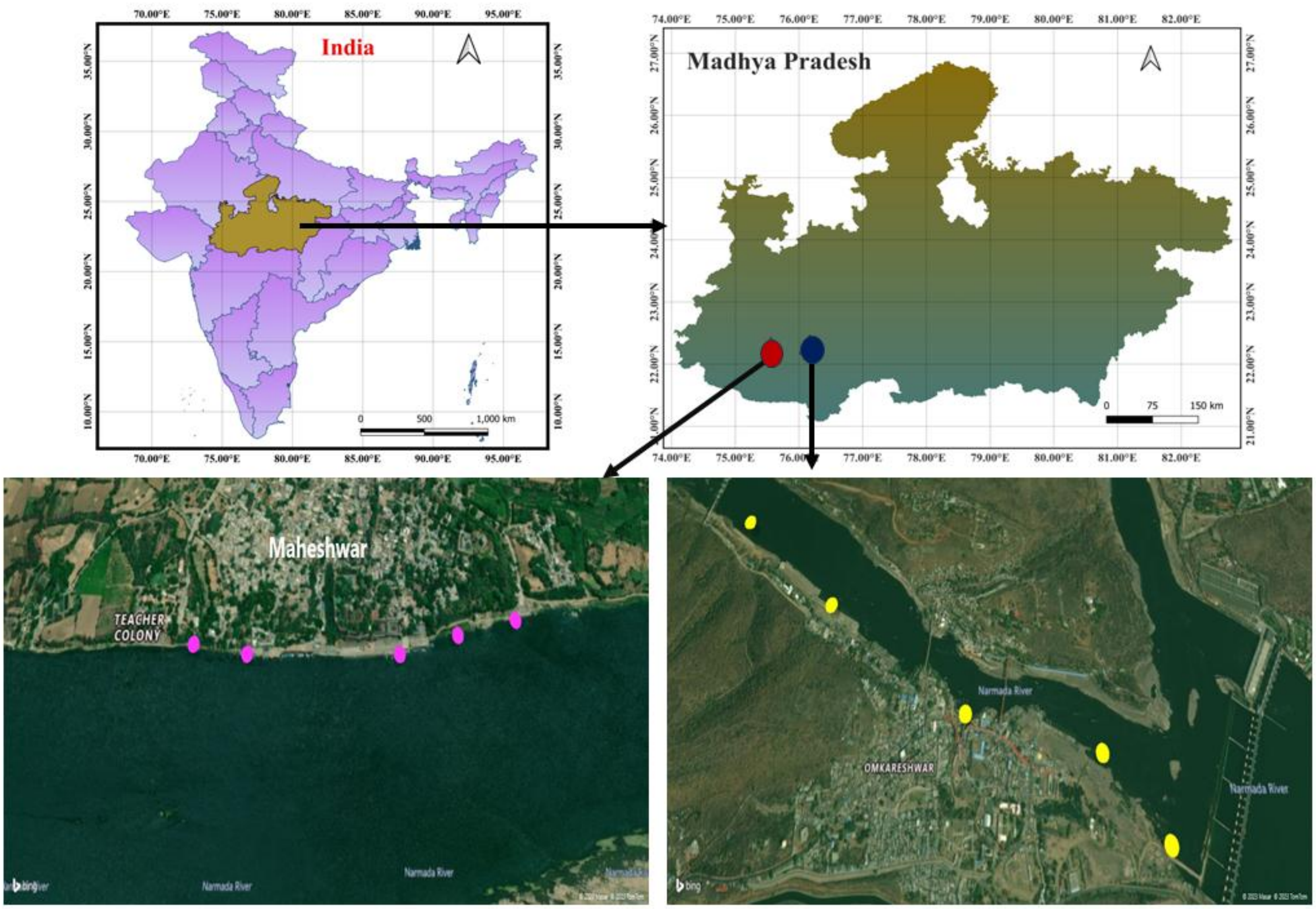

Figure-1: Map displays the sample location in the Omkareshwar (S1 to S5) and Maheshwar city (S6 to S10) of Madhya Pradesh, India.

Table-1: Sampling location in studied water and sediments in Omkareshwar and Maheshwar along the Narmada River.

S. No.	Sample locations	Sampling coordinates	Water sample code	MPs abundance in water (items/L)	Sediments sample code	MPs abundance in sediments (items/kg)
1.	Navinghat	22°14'57.1"N 76°08'23.8"E	OW1	4.0	OS1	104.0
2.	Nagar ghat	22°14'48.2"N 76°08'40.3"E	OW2	5.0	OS2	72.0
3.	Gaumukhghat	22°14'37.0"N 76°09'02.4"E	OW3	8.0	OS3	137.0
4.	Narmada river ghat	22°14'34.8"N 76°09'18.8"E	OW4	11.0	OS4	169.0
5.	Omkareshwar Dam	22°14'24.6"N 76°09'32.2"E	OW5	1.0	OS5	45.0
6.	Peshwa ghat	22°10'12.3"N 75°35'30.2"E	MW6	3.0	MS6	84.0
7.	Near to fort	22°10'11.2"N 75°35'23.7"E	MW7	6.0	MS7	148.0
8.	Coasts of Ahilya Fort	22°10'09.9"N 75°35'17.2"E	MW8	2.0	MS8	154.0
9.	Matangeshwarghat	22°10'09.9"N 75°35'00.5"E	MW9	10.0	MS9	123.0
10.	Sati ghat	22°10'10.6"N 75°34'54.6"E	MW10	13.0	MS10	160.0
	Mean ± SD			6.3 ± 3.8		119.6 ± 39.6

Utilizing a stainless-steel spoon and aluminium foil, the sediment samples were collected. Each sampling has a sediment depth of 5 to 8 cm and a sampling area of 15 x 15 square meters. For each sampling station, 1 kilogram of sediments were collected. The collected sample were stored at 5°C in a refrigerator up to further examination.

Extraction of microplastics: MPs have been identified using previous research analysis conclusions[18], with some changes. For 24 hours at 70ºC, this sediment sample had been air-dried in an oven and weight the sediment sample. Following drying, 100 g of every specimen were taken out and separated through sieves of 0.125 mm, 0.355mm, 1mm, and 5mm mesh sizes. The remaining sediment sample, greater than 5mm size was discarded. After that, the sediment collection had been preserved for microplastic separation.

To eliminate the organic and minerals content (leaves, pollen, flower, and wood) that previously existed in the samples, 30% H_2O_2 (hydrogen peroxide solution) were used for digesting the specimen in a beaker. On a magnetic stir plate, the mixture was heated to 70°C and stirred for at least 50 minutes at a speed of 200 revolutions per minute. If there is any organic material left in the sample, add some H_2O_2 and continue till every last bit of the organic matter has been degraded. The higher-density polymeric substances were enabled to float using the density separation method once the previous organic compounds were completely digested. The mixture of the sample was separated using NaCl that had a high density. PVC, PEs, PE, PP, PA and PS are the polymer that float in supernatant of NaCl solution and sediment get settled down. To confirm that every common plastic had been correctly isolated from silt, we added $ZnCl_2$ to the samples containing little, floatable pieces. On a heating plate, Contents had been stirred for about 20 minutes at 200 rpm using a magnetic stirrer. Then we could possibly separate the floated microplastics from other dense particles. After that, the liquid supernatant that was extracted from the sample was filtered with a vacuum filtration pump.

Sample characterization: Microscopic analysis: The MPs particle captured on filter paper were systematically assessed by employing the previous defined parameters under a stereomicroscope (Leica S9i) at a magnification of 40x10. As seen in Figure-2, different colours of MPs were examined under a microscope at a high magnification. It is necessary to remove and characterize any biomass or other inorganic as well as organic substance which is attached to an MP. The filter paper was separated into four equal parts in order to minimize counting errors during quantification. Each filter paper needs to be counted four or five times in order to achieve accurate results. The initial step in finding suspect MPs particles was to separate out using tweezers and identify them according to their appearance and characteristicsas described in previous studies[6,19].

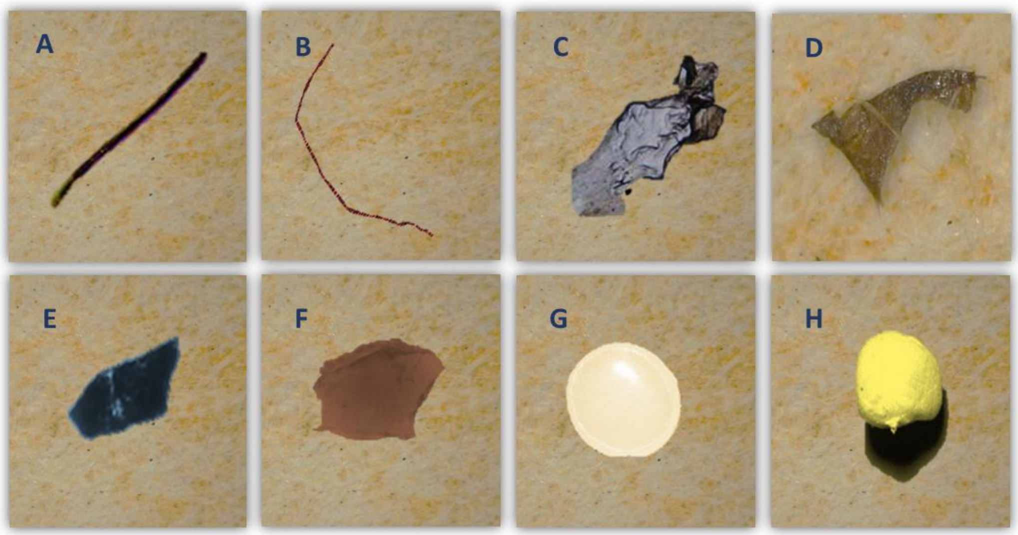

Figure-2: Various MP types identified in the examined samples, Types: 1. Fibers (A and B); 2. Film (C and D); 3. Fragments (E and F); and 4. Foam/ pellet (G and H).

FTIR: Fourier Transform Infrared Spectroscopy (PERKIN-ELMER Spectrum Two) was used to identify and measure the chemical composition of the microplastics sample. The measurements were carried out in transmission mode between 400cm^{-1} and 4000cm^{-1} at a scanning resolution of 2cm^{-1}. Through the utilization of the provided FTIR data, Origin software was utilized to analyse the polymer.

Ecological Risk Assessment: Polymer Hazard Index (PHI): For determining the risk of MPs, their lacks a defined methodology. Previous investigations established the framework for an ecological risk evaluation for MPs contaminants in Narmada River[20,21]. The negative environmental impact caused by the various polymers in microplastics was evaluated using the Polymer Hazard Index, or PHI. It was computed using each polymer's hazard score as well as the percentage variation in microplastic across every site[20,21].

$$PHI = \sum Pn \times Sn \quad (1)$$

where Sn is the hazard scores developed[20] to evaluate the possible dangers posed by various polymers based on their toxicity, PHI is the Polymer Hazard Index, and Pn is the in terms of percentage proportion of microplastic gathered from every site.

Pollution load index: As seen in Table-2, the pollutant load index (PLI) [23,24], which is computed using the formula described below, has been frequently used to estimate pollution levels in the sampling site of river.

$$CFi = C_I/C_0 \quad (2)$$

$$PLI = \sqrt{CFi} \quad (3)$$

where in each MP concentration was divided by its minimal MPs concentration (C_0) to determine the corresponding MP concentration factors (CFi), or PLI of MPs in each site.

Table-2: Pollution Load Index (PLI) for the contamination of MPs in the surface water and sediment of the Narmada River.

Sampling sites	PLI in Water	Sampling sites	PLI in Sediments
OW1	2.0	OS1	10.2
OW2	2.2	OS2	8.5
OW3	2.8	OS3	11.7
OW4	3.3	OS4	13.0
OW5	1.0	OS5	6.7
MW6	1.7	MS6	9.2
MW7	2.4	MS7	12.2
MW8	1.4	MS8	12.4
MW9	3.2	MS9	11.1
MW10	3.6	MS10	12.6
PLI River	2.2		10.6
Risk category	I		II

Results and Discussion

Abundance: MPs have been identified in collected sample, particularly in surface water in the Narmada River Basin. In surface water, MP concentrations varied between 1 to 13 items/L (Figure-3, Table-1). Sampling location, OW5, least abundance of MPs was discovered. At site OW4, MW9, and MW10, the highest abundance was discovered.

According to observed concentration, MP in the sediments vary between 45 to 169 items/kg. The lowest concentration was discovered at OS5, and the highest frequency was discovered at OS4 and MS8 and MS10. We found relatively low MP concentrations in present study in sediment, and surface water than previous studies[10,25]. This could be because there were no substantial sources of contamination in the research area. Microplastic in sample with an approximate availability was chosen for the study objective to investigate the relationship between occurrence of MPs and proximity to town areas. The sampling sites OW4, MW9, and MW10 were the residential tourist hotspot and near to agricultural area at the river site. Site OW3, OW2, and MW7 were the tourist spot, reaming zone are near to agricultural field.

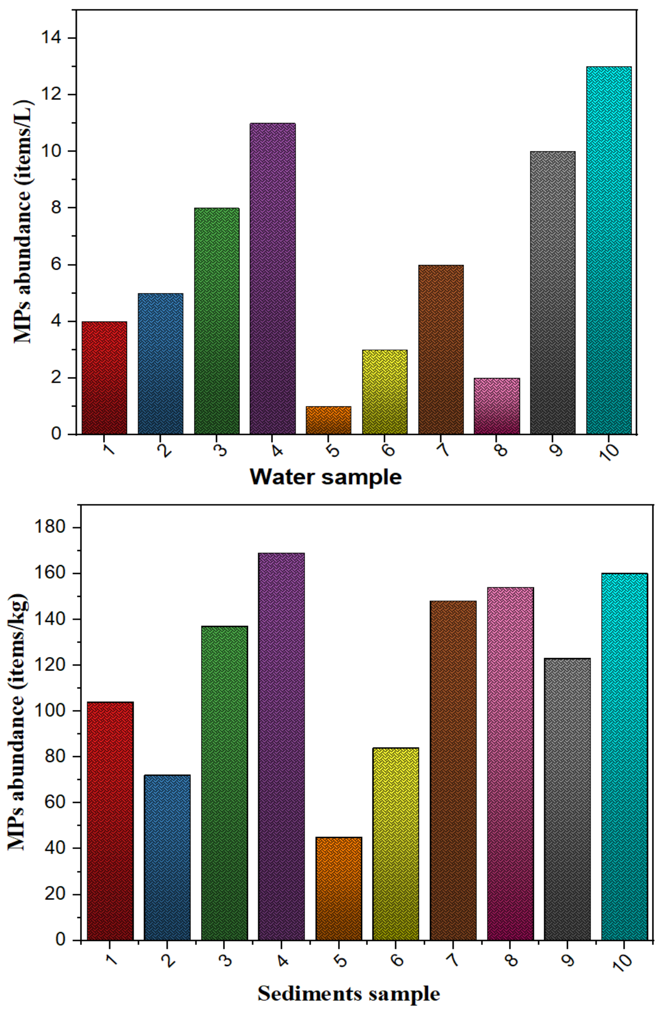

Figure-3: Bar graph illustrating the fluctuations in MPs abundance in sediments and surface waters of sampling site of Narmada River.

According to the data analysis, MPs pollution was highest in the town centre and declined as one moved towards the town border, i.e., the result was observed in the findings presented by [26].

Sampling spot OS3, OS4, MS8 and MS10, implies that agricultural practices also have an impact on MP distribution along with residential and tourist factors. Examples of practices that potentially worsen MP pollution include plastic mulching of agricultural soils, agricultural drainage, and composting[27-29]. As a result, MP levels increased in rural agricultural areas. It follows that various manufacturing processes and living activities can have an impact on how MPs are distributed.

Structural characteristics and morphology: MPs that were extracted from sample on 2.5µm filter paper were chosen for further stereomicroscopic analysed morphology. According to this investigation, MPs were more common in surface with fibers than in sediments with fragments (Figure-4). Methodological problems make observing MPs a difficult task even today[26]. The quantity of different shape of MPs were fibers, fragment, films, and foam/pellets were 61.9%, 11.1%, 19.0%, and 8.0% respectively in water sample, based on the morphology of MPs. According to the majority of research findings[18, 30], fibers were the most prevalent kind of MPs in both surface water. The Narmada River is a significant location for the residents of the area. Numerous fibers MPs may enter the water body as a result of their regular activities, such as washing, fishing, and swimming[10]. The MPs in the sediment had various shape, majority of them were fragments (34.2%), fibers (32.4%), foam/ pellets (21.1%) and film (12.3%). The degradation of plastics in sediments, which serves as a significant MP sink, causes the lysis of several large MPs, which increases the amount of fragment type microplastics in sediment samples[31].

Regarding the color composition (Figure-5), black colour was dominated in water sample (23.8%) followed by, red (20.6%) and white (19.0%). In contrast, white (28.3%), made up the majority of the MPs in the sediments, followed by, black (22.2%), red (19.9%). The local boating and fishing activists that were produce a lot of black fibers created as fishing nets and other ropes detached. There are several black fibre MPs in the water because the detachment's density is comparable to that of water. Plastic bags in the colours black, red, blue, white were also frequently used at the time. They were deposited in the silt, where they cracked and produced a significant amount of white and, blue colour debris[32]. As a result, regional economic activity can influence how MPs are distributed.

MPs particle size distribution: Surface water, sediments, were predominately made up of MPs with tiny sizes 125 to 355µm [10]. The majority of the MPs in small-sized MPs (<125 - 1000µm) found in surface water were 88.9%, and MPs size (355–5000µm) in sediments were 85.8% observed in this investigation. In the current study, the small MPs in water and sediments were greater in compared to described in the previous research studies[33,34]. We measured MPs size and discovered that the huge abundance of MP particles in sediment were 355 to 1000µm size, while the large number of micro plastics particle in water was observed<355 µm in size (Figure-6).

Smaller MPs may readily flow with the water as one of the causes. While bigger MPs are deposited in the sediment during sedimentation process. Quantity of MPs in the sediment rose exponentially as MP particle size decreased, which was in good agreement with the findings[26]. Furthermore, water sample is abundant with small size MPs as a result of the frequent water flow events in monsoon, which generate the large number of small microplastics in the sediments formed by disintegration[27,35]. Small MPs of reduced particle size made migration easier.

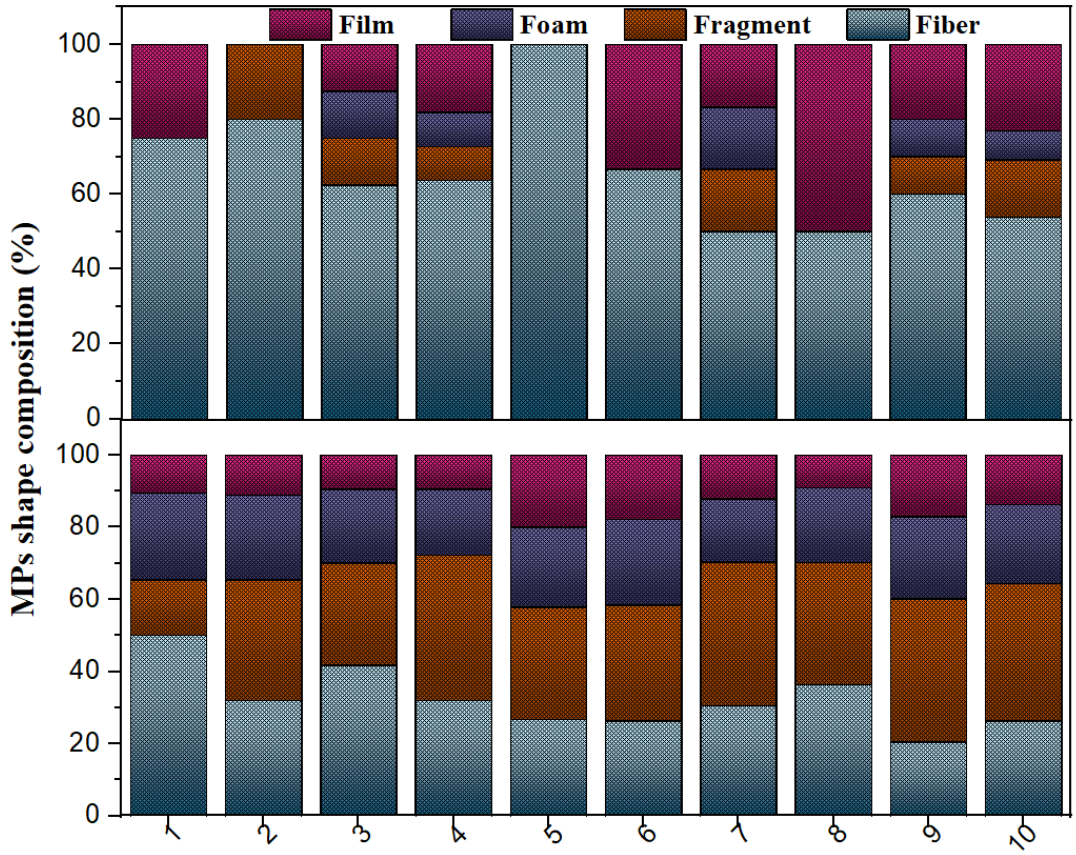

Figure-4: Bar graph showing variation in microplastic shape found in A) water, and B) sediments sample of the river.

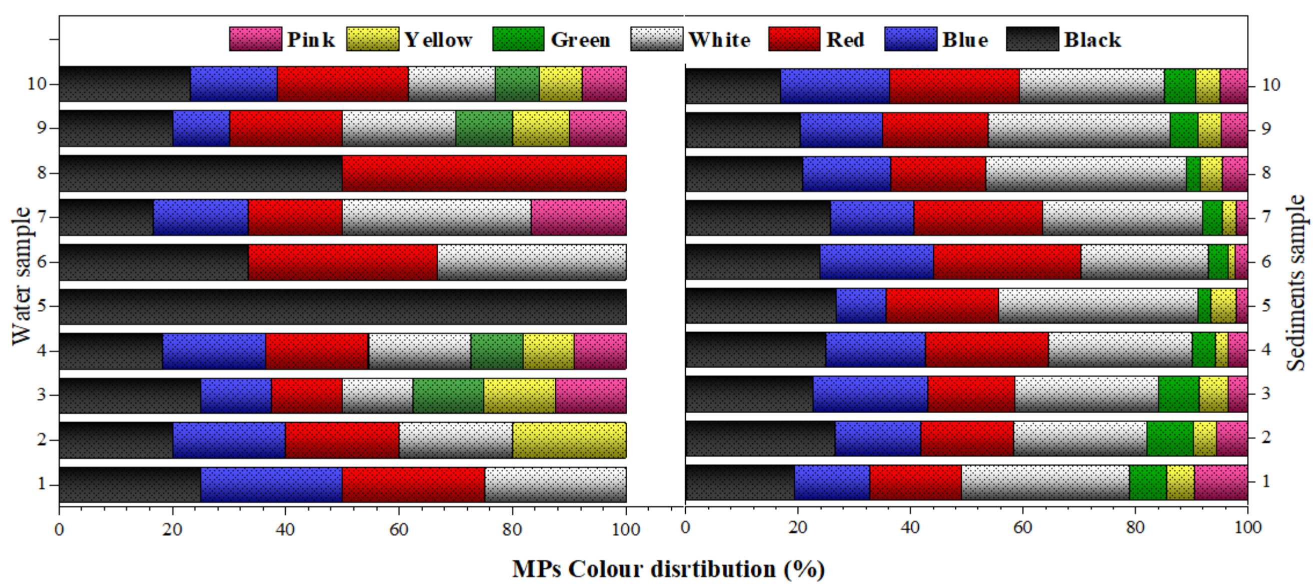

Figure-5: Variations in color of microplastics (%) observed in surface water and sediments.

Polymer composition of MPs: PEs, PVC, and PP were the two most prevalent polymer kinds of MPs in the Narmada River (Figure-7). The largest PEs and PP percentages were found in surface water, at 33.3% and 20.6%, respectively. PA and PE percentages were 17.5% and 11.1%, respectively. In contrast, sediment contained 27.9%, 21.3%, and 18.0% of PVC, PS, and PP respectively. Higher percentage of PEs, PVC, PP and PS may be found in Narmada River as a result of broken thread of clothes, disposable glass, beads, pellets, styrene foams and plastic poly bags carried by tourist actions, mulching in agriculture. High concentration of PP and PS in aquatic environment may be mostly owing to the comparable density of polypropylene and polystyrene to water, which caused PP, and PS to float according to the flow rate of water. Furthermore, PEs makes up a significant portion of synthetic fibers. Washing clothes may introduce significant amounts of PEs, resulting in a high PEs content[36]. Sediment levels of PE contamination were relatively high. PE was widely utilized to make plastic film, containers, and other items. This supply of PE came from daily human activities, which fit with MPs' shape-characteristics. Pipe, and tap used in water supply is primary source of polyvinylchloride. In this investigation we found that its pollution was comparatively minimal. Highest concentration of PVC type of microplastics found in residential area. As a result, the Narmada River area's human activities have a big impact on where MPs are distributed. The daily routine activities of human should be considered while discussing the source analysis of MPs pollution.

Source analysis: We separated the studies site into different groups (living areas, tourism field, and agricultural regions) to investigate how anthropogenicactions affect the dispersal of microplastics. In dwelling spaces, MPs abundance was much higher than in other functional categories because of the correlation between MPs abundance and population density. The findings demonstrated that MPs were more abundant in residential region than another region. Living quarters were located in town centres. Due to increased human activity due to the high population density, the danger of MPs emission increased[26,27]. For instance, tire degrading can release MPs into the atmosphere, which eventually find their way into aquatic environments[37]. This could also account for the observation of PVC contamination in only inhabited regions. The greatest difficulty may be presented by MPs pollution in agricultural areas. Mulch and bags are needed for agricultural activities, which may result in enormous amounts of MPs being produced in agricultural areas by mechanical shreds and other aging techniques.

MPs are more likely to move to far-off places in tourist zones. In contrast to previous research[38], we discovered the lowest MP levels in tourist locations. This is mostly because there are so many MPs and there is a correlation between urbanization and plastics[39]. Their research work conducted in an urban centre, which is significant, and the findings do not completely rule out the impact of certain sources of pollution[38]. Additionally, with a ratio of 89.85%, tourist locations had a significant concentration of MPs with small particle sizes. Additionally, PE, PS, and PP were the three main MPs components in tourist locations. According to the present research work, low density MPs had a higher likelihood of floating in the water column. According to previous work[40], microplastics of small size had great efficiency to travel long path with water. This description of MPs in tourist locations may encourage the long-distance transportation of MPs there. As a result, human activities in several functional areas are related to the distribution features of MPs. Large MPs were further available to provide the surface to carry of heavy metals, PAHS and other organic contaminants, which were present in high amount in industrial and agricultural drainag[41].

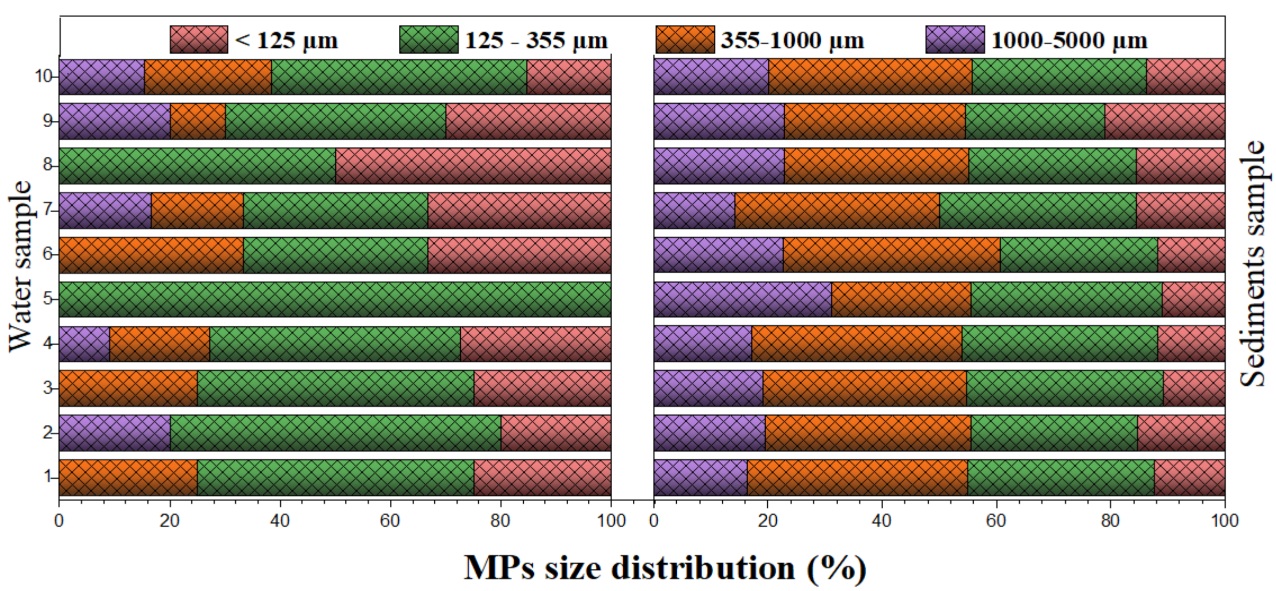

Figure-6: Diversity in microplastic size (%) in surface water and sediments along the sampling sites.

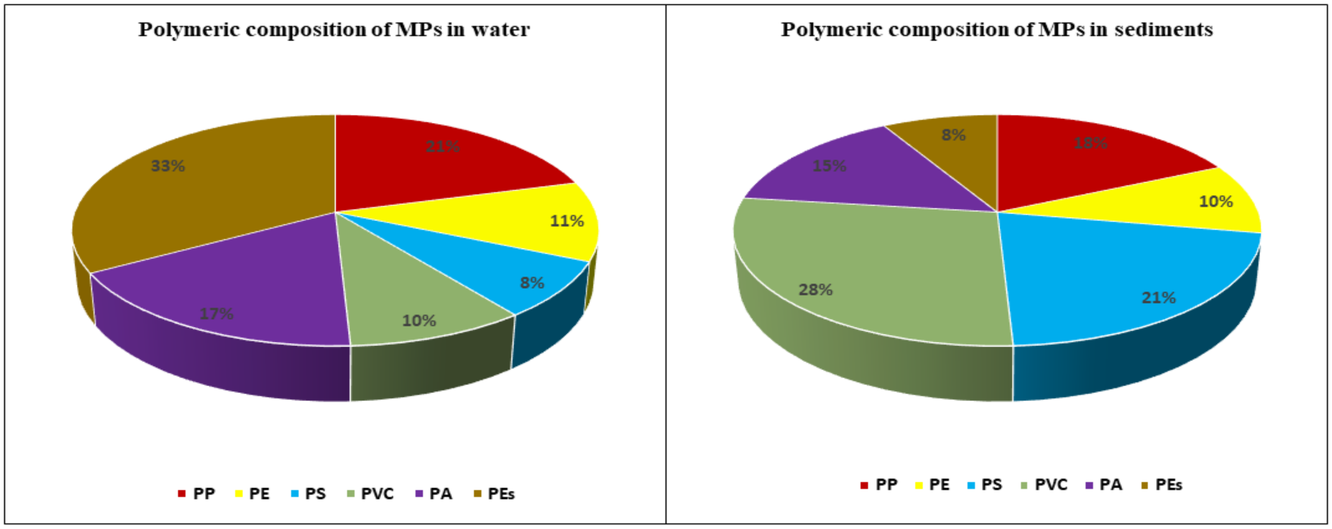

Figure-7: The percentage of microplastics of a particular polymer type found in water and sediment.

Ecological risk analysis: The results of every sampling site are expressed by the PLI levels in Table-2. The PLI value at sampling site OW5 was observed in least level 1.0 and the highest was 3.6 at MW10 in water. MS8 had the greatest PLI value (12.4) in the sediments sample, while OS5 had the lowest (6.7) PLI value. The MPs pollutant load index hazard category distribution in the water and sediments of the sampling regions was shown in Figure-8.

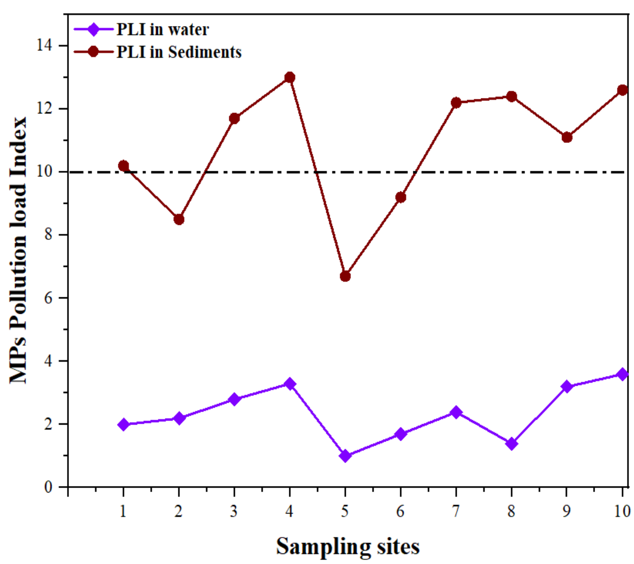

Figure-8: Pollution Load Index (PLI) for the contamination of MPs in the surface water and sediment of the Narmada River.

More threat of MPs pollution in sediments is indicated by Hazard Level II above the black dashed line than by Hazard risk Category I below the dashed line in water. MPs can be inhaled or consumed through food, dust, and water, so further research is required to determine the various ways that MP consumption may adversely affect humans[10,42].

PHI of the observed polymer shows the level of hazard category I, II, III, IV and V. The level of polymer hazard poses risk i e., specific target organ toxicity, acute toxicity, eye irritation, skin corrosion/irritation, carcinogenic, respiratory/skin sensitive.

Conclusion

The morphological characteristics of MPs in collected sample of water and sediment of a Narmada River environment were analysed in the current investigation. In surface water, the MP abundance was 1-13 items/L, and 45 - 169 items/kg. Water included 88.9%, while sediments were detected in 80.3% of the MPs less than 1mm. In sediment, fragments were the accounted in high proportion of 34.2%, whereas fibers were detected 61.9 % as highly occupied MPs in surface water. MPs were mostly composed of PEs, PP, PVC and, PS polymers. According to this study, the amount of MP pollution in several area is as follows: residential area > tourist zone> agricultural region. Furthermore, Particularly, in this region, single-use plastic products from tourist-related activities were the primary source of MPs. Furthermore, the Narmada River Basin had a danger level of I in water and hazard level II in sediments. More studies on the seasonal variations in MP occurrence in Narmada tourist environments and the transport pathways from terrestrial region to water, and sedimentis necessary in order to have a better understanding of MP transport in environments.

References

1. Akhter, S., Bhat, M. A., Ahmed, S., Siddiqi, W. A., Ahmad, S., & Shrimal, H. (2023). Profiling of Antibiotic Residues in Surface Water of River Yamuna Stretch Passing through Delhi, India. *Water*, 15(3), 527.
2. Tunali, M., Adam, V., & Nowack, B. (2023). Probabilistic environmental risk assessment of microplastics in soils. *Geoderma*, 430, 116315.

3. Mendes, A. M., Golden, N., Bermejo, R., & Morrison, L. (2021). Distribution and abundance of microplastics in coastal sediments depends on grain size and distance from sources. *Marine Pollution Bulletin*, 172, 112802.

4. Yin, Z. (2023). The pollution of microplastics in sediments: The ecological risk assessment and pollution source analysis. *Science of The Total Environment*, 859, 160323.

5. Apetogbor, K., Pereao, O., Sparks, C., &Opeolu, B. (2023). Spatio-temporal distribution of microplastics in water and sediment samples of the Plankenburg river, Western Cape, South Africa. *Environmental Pollution*, 323, 121303.

6. Gurjar, U. R., Xavier, K. M., Shukla, S. P., Takar, S., Jaiswar, A. K., Deshmukhe, G., & Nayak, B. B. (2023). Seasonal distribution and abundance of microplastics in the coastal sediments of north eastern Arabian Sea. *Marine Pollution Bulletin*, 187, 114545.

7. Sonbhadra, S., & Pandey, L. M. (2023). Assessment of Microplastics from Surface Water Bodies: Challenges and Future Scopes. *Water, Air, & Soil Pollution*, *234*(2), 80.

8. Bilal, M., Qadir, A., Yaqub, A., Hassan, H. U., Irfan, M., & Aslam, M. (2023). Microplastics in water, sediments, and fish at Alpine River, originating from the Hindu Kush Mountain, Pakistan: implications for conservation. *Environmental Science and Pollution Research*, 30(1), 727-738.

9. Kalčíková, G. (2023). Beyond ingestion: Adhesion of microplastics to aquatic organisms. *Aquatic Toxicology*, *258*, 106480.

10. Patidar, K., Ambade, B., Mohammad, F., & Soleiman, A. A. (2023). Microplastics as heavy metal vectors in the freshwater environment: Distribution, variations, sources and health risk. *Physics and Chemistry of the Earth, Parts A/B/C*, 131, 103448.

11. Dang, F., Wang, Q., Huang, Y., Wang, Y., & Xing, B. (2022). Key knowledge gaps for One Health approach to mitigate nanoplastic risks. *Eco-Environment & Health*, 1(1), 11-22.

12. Sheng, C., Zhang, S., & Zhang, Y. (2021). The influence of different polymer types of microplastics on adsorption, accumulation, and toxicity of triclosan in zebrafish. *Journal of Hazardous Materials*, *402*, 123733.

13. Singh, S., Chakma, S., Alawa, B., Kalyanasundaram, M., & Diwan, V. (2023). Identification, characterization, and implications of microplastics in soil–A case study of Bhopal, central India. *Journal of Hazardous Materials Advances*, *9*, 100225.

14. Kaur, M., Xu, M., Wang, L. (2022). Cyto-genotoxic effect causing potential of polystyrene microplastics in terrestrial plants. *Nanomaterials*, 12, 2024.

15. Liu, S. S., Jia, Y. W., Guo, X. Y., Zhao, J. L., Gao, Y., Sweetman, A. J., ... & Chen, C. E. (2023). Insights into the release of triclosan from microplastics in aquatic environment assessed with diffusive gradient in thin-films. *Science of the Total Environment*, 882, 163601.

16. Waskel, S., & Solanki, M. (2023). Heavy metal contamination of fish with relation to water quality of Narmada River, Madhya Pradesh.

17. Kochara, R., & Solanki, M. (2022). Evaluation of Physico-Chemical Parameters of Narmada River, MP, India.

18. Saha, M., Naik, A., Desai, A., Nanajkar, M., Rathore, C., Kumar, M., & Gupta, P. (2021). Microplastics in seafood as an emerging threat to marine environment: a case study in Goa, west coast of India. *Chemosphere*, 270, 129359.

19. Patidar, K., Ambade, B., Verma, S. K., & Mohammad, F. (2023). Microplastic contamination in water and sediments of Mahanadi River, India: An assessment of ecological risk along rural-urban area. *Journal of Environmental Management*, 348, 119363.

20. Lithner, D., Larsson, Å. and Dave, G. (2011). Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. *Sci. Total Environ*., 409(18), 3309–3324.

21. Pan, Z., Liu, Q., Jiang, R., Li, W., Sun, X., Lin, H., ... & Huang, H. (2021). Microplastic pollution and ecological risk assessment in an estuarine environment: The Dongshan Bay of China. *Chemosphere*, 262, 127876.

22. Nithin, A., Sundaramanickam, A., Saha, M., Hassanshahian, M., Thangaraj, M., & Rathore, C. (2023). Risk assessments of microplastics accumulated in estuarine sediments at Cuddalore, Tamil Nadu, southeast coast of India. *Environmental Monitoring and Assessment*, 195(7), 890.

23. Tomlinson, D. L., Wilson, J. G., Harris, C. R., & Jeffrey, D. W. (1980). Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer meeresuntersuchungen*, 33, 566-575.

24. Zheng, X., Sun, R., Dai, Z., He, L., & Li, C. (2023). Distribution and risk assessment of microplastics in typical ecosystems in the South China Sea. *Science of The Total Environment*, 163678.

25. Sarkar, D. J., Sarkar, S. D., Das, B. K., Manna, R. K., Behera, B. K., & Samanta, S. (2019). Spatial distribution of meso and microplastics in the sediments of river Ganga at eastern India. *Science of the Total Environment*, 694, 133712.

26. Xia, F., Liu, H., Zhang, J., & Wang, D. (2022). Migration characteristics of microplastics based on source-sink investigation in a typical urban wetland. *Water Research*, 213, 118154.

27. Shu, X., Xu, L., Yang, M., Qin, Z., Zhang, Q., & Zhang, L. (2023). Spatial distribution characteristics and migration of microplastics in surface water, groundwater and sediment in karst areas: The case of Yulong River in Guilin, Southwest China. *Science of The Total Environment*, 868, 161578.

28. Bigalke, M., Fieber, M., Foetisch, A., Reynes, J., & Tollan, P. (2022). Microplastics in agricultural drainage water: A link between terrestrial and aquatic microplastic pollution. *Science of the total environment*, 806, 150709.

29. Lwanga, E. H., Van Roshum, I., Munhoz, D. R., Meng, K., Rezaei, M., Goossens, D., ... & Ritsema, C. (2023). Microplastic appraisal of soil, water, ditch sediment and airborne dust: The case of agricultural systems. *Environmental Pollution*, 316, 120513.

30. Panno, S. V., Kelly, W. R., Scott, J., Zheng, W., McNeish, R. E., Holm, N., & Baranski, E. L. (2019). Microplastic contamination in karst groundwater systems. *Groundwater*, 57(2), 189-196.

31. Wu, X., Zhao, X., Chen, R., Liu, P., Liang, W., Wang, J., ... & Gao, S. (2022). Wastewater treatment plants act as essential sources of microplastic formation in aquatic environments: A critical review. *Water Research*, 221, 118825.

32. Kelly, M. R., Lant, N. J., Kurr, M., & Burgess, J. G. (2019). Importance of water-volume on the release of microplastic fibers from laundry. *Environmental science & technology*, 53(20), 11735-11744.

33. Robin, R. S., Karthik, R., Purvaja, R., Ganguly, D., Anandavelu, I., Mugilarasan, M., & Ramesh, R. (2020). Holistic assessment of microplastics in various coastal environmental matrices, southwest coast of India. *Science of the Total Environment*, 703, 134947.

34. Jayasiri, H. B., Purushothaman, C. S., & Vennila, A. (2013). Plastic litter accumulation on high-water strandline of urban beaches in Mumbai, India. *Environmental monitoring and assessment*, 185, 7709-7719.

35. Zhang, K., Xiong, X., Hu, H., Wu, C., Bi, Y., Wu, Y., ... & Liu, J. (2017). Occurrence and characteristics of microplastic pollution in Xiangxi Bay of Three Gorges Reservoir, China. *Environmental science & technology*, 51(7), 3794-3801.

36. Kim, N. H. (2017). Moisture transfer and pressure drop of humidifying elements made of non-woven fabric (Rayon/PET). *Journal of Mechanical Science and Technology*, 31, 3075-3082.

37. Luo, Z., Zhou, X., Su, Y., Wang, H., Yu, R., Zhou, S. & Xing, B. (2021). Environmental occurrence, fate, impact, and potential solution of tire microplastics: Similarities and differences with tire wear particles. *Science of the Total Environment*, 795, 148902.

38. Jin, X., Fu, X., Lu, W., & Wang, H. (2022). Fugitive release and influencing factors of microplastics in urbanized watersheds: a case study of the central area of Suzhou City. *Science of The Total Environment*, 837, 155653.

39. De Carvalho, A. R., Riem-Galliano, L., Ter Halle, A., &Cucherousset, J. (2022). Interactive effect of urbanization and flood in modulating microplastic pollution in rivers. *Environmental Pollution*, 309, 119760.

40. Alimi, O. S., FarnerBudarz, J., Hernandez, L. M., &Tufenkji, N. (2018). Microplastics and nanoplastics in aquatic environments: aggregation, deposition, and enhanced contaminant transport. *Environmental science & technology*, 52(4), 1704-1724.

41. Weber, C. J., Opp, C., Prume, J. A., Koch, M., & Chifflard, P. (2022). Meso-and microplastic distribution and spatial connections to heavy metal contaminations in highly cultivated and urbanised floodplain soilscapes–a case study from the Nidda River (Germany). *Soil Discussions*, 1-42.

42. Zhang, J., Wang, L., & Kannan, K. (2020). Microplastics in house dust from 12 countries and associated human exposure. *Environment International*, 134, 105314.