RESEARCH ARTICLE

Seasonal Dynamics of Microplastic Pollution in the River Ganga: A Case Study from Bihar

Varsha and Sushil Kumar Singh*

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Abstract

Microplastics (MPs) are pervasive and have an impact on all types of habitats, including rivers. In recent years, the amount of research on MPs in rivers has significantly increased. Globally, microplastic (MPs) particles are discovered in environmental compartments and are the subject of much research, particularly in aquatic environments. With a focus on seasonal differences between the pre-and post-monsoon periods, this study investigates the temporal patterns of microplastic pollution in the Ganga river in Bihar, India. Three locations along the river were sampled, and the concentrations of MPs in both seasons were compared using a paired t-test. The average concentration of all studied sites of MPs before monsoon is 1044.5 ± 317.81, and post-monsoon is 624.16 ± 247.08. The findings showed that the pre-monsoon season showed a considerable rise in MP levels. This surge is probably caused by both human activity, which intensifies during this season, such as agricultural runoff and garbage disposal, and the decreased river flow, which concentrates MPs in the water column. To manage the invasion of MPs, the study's findings emphasize the necessity of increased monitoring and mitigation activities, especially before the monsoon season. This study advances our knowledge of the dynamics of MP pollution in the Ganga River and emphasizes the need for seasonally appropriate conservation measures for this essential water supply.

Highlights

- MPs levels were higher before the monsoon compared to after the monsoon.
- A paired t-test showed significant seasonal differences in MPs concentrations.
- Fibers and fragments were the most commonly detected MPs.
- HDPE and LDPE are the dominating plastic polymers.

Keywords: Micro plastics Environment Temporal, Human activities, Mitigation, Waste disposal

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Introduction

MPs have been widely found in rivers, coastal areas, and oceans all over the world, and they are becoming a growing danger to the health and stability of many land and water ecosystems. (Hidalgo Ruz *et al*., 2012; Martin *et al*., 2017). MPs are small synthetic polymers; ranging in size from 100 µm to 5 mm. They enter the environment in two main ways: either directly from human activities, such as in the form of tiny plastic particles used in products like makeup and face cleansers (called primary MPs), or indirectly when larger plastics break down due to physical, chemical, or microbial processes (secondary MPs) (Cai *et al*., 2018; de Sá *et al*., 2018). Rivers are a key source of plastic pollution, with an estimated 2 million tonnes of MPs being carried into the ocean each year (Lebreton *et al.,* 2017). Around 80% of plastic waste that enters the ocean from land is believed to be transported by rivers (Law and Thompson, 2014; Horton *et al.,* 2017). As a result, the role of rivers in plastic transport has drawn significant attention, leading to extensive research on various rivers around the world, including the Los Angeles River (Moore *et al.,* 2005), Danube (Lechner *et al.,* 2014), Yangtze Estuary (Zhao *et al*., 2014), Rhine (Mani *et al.,* 2015), Selenga River (Battulga *et al*., 2019), and Beijiang River (Tan *et al.,* 2019), Ciwalengke River (Alam *et al.,* 2019). Since freshwater MP research is still in its infancy, lots of information about their temporal and spatial distributions, as well as their links to possible sources remain unknown. Several studies have examined MP contamination in the Ganga, one of the most significant and idolized rivers in India, with an emphasis on seasonal fluctuations. Very little research has looked at how seasonality affects MP concentrations, and even fewer have looked at changes that occur during the wet season. MP concentrations in the early and late wet seasons are probably different because of things like flow dependency and the flush effect (Watkins *et al.,* 2019).

Numerous studies have recorded the patterns of microplastic pollution in rivers over time, emphasizing how seasonal variations impact the levels of MP concentrations. In general, river systems exhibit varying MP levels depending on the season, with notable differences between before and after monsoon season. Research indicates that MP concentrations tend to be higher in the period before rainfall. One of the primary reasons for this is the reduced flow of the river, which leads to the accumulation of MPs. Studies by Jambeck *et al.,* (2015) and Kumar *et al.,* (2021) suggest that during the pre-monsoon

Department of Botany, Patliputra University Patna, Bihar – 800020, India.

***Corresponding author:** Sushil Kumar Singh, Department of Botany, A.N. College (PPU) Patna, Bihar – 800013, India, Email: sushilkumarppu@gmail.com

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period, rivers in the Indian subcontinent, including the Ganga, experience lower water levels, which limits the dilution and dispersal of microplastics.

The decreased flow rates also cause an accumulation of microplastics in the river from land-based sources like industrial effluents, household garbage, and agricultural runoff. Anthropogenic Activities: The pre-monsoon season is also linked to increased human activity, including the disposal of urban garbage and agriculture. Agriculture in the Ganga Basin is a major source of microplastic contamination, according to Sarkar *et al*., (2019). This is particularly relevant in the pre-monsoon season when a lot of fertilizers and pesticides—which frequently contain microplastics—are used. Additionally, contributing to the amount of microplastics in the river is the use of plastic mulch and other agricultural inputs. On the other hand, microplastic concentrations usually drop during the post-monsoon season. The reason behind this is that the monsoon season's high river discharge and heavy rains act to clear the river system of accumulated microplastics. A substantial flushing impact is produced by the monsoon rains, which dilute concentrations of microplastics and carry them downstream or out to sea, according to studies by Singh *et al.,* (2020) and Gupta *et al.,* (2022). Over the post-monsoon period, this periodic cleansing lowers the total microplastic burden in the river. Microplastics are carried into the main river channel by surface runoff during the monsoon, which also dilutes them and moves them from the riverbanks and nearby land regions. However, the post-monsoon period's greater flow rates and turbulent weather can cause sediments, possibly including microplastics that are stuck in the sediment, to resuscitate. However, as demonstrated by Mishra *et al*., (2021), the overall result is usually a reduction in measurable microplastic concentrations in the water column post-monsoon. The purpose of this research is to expand our knowledge of the transport and accumulation of microplastics in riverine systems by investigating the seasonal dynamics of microplastic pollution in the River Ganga, with a particular emphasis on the Bihar region. When comparing the seasonal differences in microplastic concentrations in the Ganga River between the pre-monsoon and post-monsoon periods, the paired T-test is employed. As this research compares the variations in microplastic concentrations at the same sampling sites throughout two distinct seasons, the paired t-test is especially appropriate. Research into how seasonal dynamics, such as fluctuations in river flow and precipitation, affect microplastic pollution in the river is provided by this method, which also assists in determining if the observed seasonal variations in microplastic levels are statistically significant.

MATERIALS AND METHODS

Study Area

Three different locations along the Ganga River's banks in Eastern India provided the water samples for the MP analysis. Samples were collected before and after the monsoon in April to May and November to December 2023 at three sites in the region: Doriganj (S1), Patna City (S2), and Barh (S3). One of them is the semi-urban environment site one located near Doriganj block (84.836295°, 25.727691°), site second is an urban environment near the city Patna in a residential area (85.207449°, 25.61206°), and site third Barh block (85.714197°, 25.494913°) respectively Patna district, Bihar, which part of the Ganga River Basin as shown in Fig. 1. Patna is the state of Bihar's most populous and fastest-growing metropolis, with around 3741652 residents and a land size of 3202 km^2 (PMC, 2023). The Ganga River traverses 445 kilometers in Bihar, most of which is in the Patna district. The surface water of the River has higher amounts of MPs than previously reported in studies (Napper *et al*., 2023; Nayal and Suthar, 2022; Rajan *et al*., 2023; Singh *et al*., 2021).

Water sample collection and processing of MPs

In April and May of 2023, as well as in November and December of the same year, duplicate water samples were taken at each site, set apart by 100 m. The process of extracting MPs from the water was adapted from previously published studies (Han *et al.,* 2020; Miller *et al.,* 2017; Y. Mao *et al.,* 2020), with some adjustments made based on the demands. Two distinct mess sieve size ranges, 4.75 mm and 150 µm, were used in the field to sieve the 500 L of water that were collected using a steel bucket for the Grab sampling procedure. Next, a 1-liter stainless steel jar containing the filtrate was filled and cleaned. Samples were transported to the laboratory and initially kept at ambient temperature, then refrigerated at 4°C until further processing. According to Masura *et al.,* (2015), the water sample filtrate was treated with a 30% hydrogen peroxide solution at 70°C until the organic matter was broken down. After samples were well-digested, they were combined with 5 M NaCl and kept overnight to avoid disturbance. The settled material was then disposed of, and the floating particles were collected on filter paper (Whatman TM GF/F glass filters with a 47 mm diameter and 1.2 µm pore size) and placed over a Buckner flask that was attached to a vacuum pump. The floating particles were then separated using a siphoning procedure. After being rinsed with distilled water and dried at 50°C, the solid particles on the filter were used for further characterization. Every procedure involved the absence of plastic equipment, and great care was taken to prevent the material from becoming contaminated with other plastics or fibers.

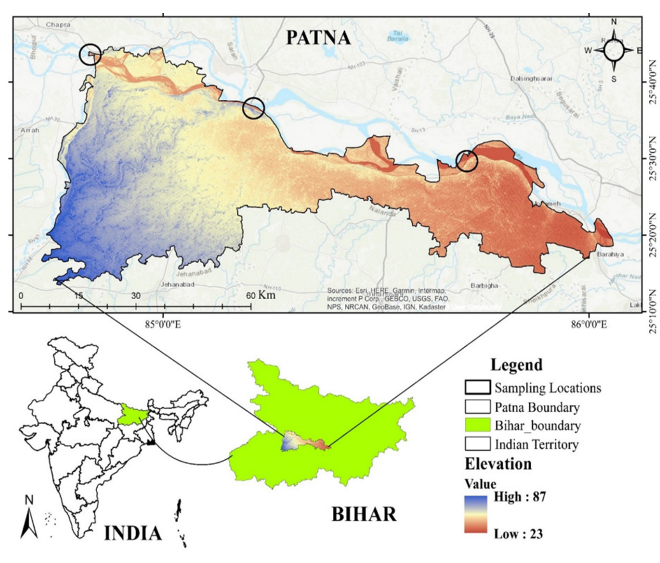

Fig. 1: Location map of the three study sites

Visual and Chemical Identification of MP

A CMOS 5 MP digital camera coupled to a Magnus microscope was used to visually identify MPs isolated from the samples. 4X and 10X objectives were used to capture images at various magnifications. By dipping filter paper into various squares, a representative area was chosen for counting and qualitative investigation. MPs were classified and recognized based on their shape, size, color, and number when they were suspected. MPs that resembled fibrous threads were categorized as fibers by Free *et al.,* (2014), whereas thin, flat MPs were categorized as films, jagged, hard MPs as pieces, uneven, slightly flattened MPs as foams, and spherical forms were categorized as microspheres. According to other reports, identified MPs were further categorized according to size fractions (>1, 1–2, 2–4, and <4 mm) and color (white, black, translucent, red, blue, green, and yellow, pink, orange) (Singh *et al.,* 2021).

Chemical Characterization by Fourier-Transform Infrared Spectroscopy (FT-IR) of MPs Polymer

FTIR (Spectrum 400, PerkinElmer) in attenuated total reflection (ATR) mode was used to identify the chemical composition of MPs that was observable. Each sample was taken and scanned for 3 seconds, or 256 times, and then the FTIR spectrum was analyzed at a resolution of 2 cm^{1} in the 400 to 4000 cm^{-1} scanning range. After that, a baseline correction was carried out. Similar to (Qi *et al*., 2020; Parashar and Hait, 2023a) only samples exhibiting a match rate greater than 70% were analyzed about known polymer spectra to determine the species of the identified MP spectrums.

MPs quantification and statistical analysis

Microsoft Excel 2019 was used for statistical data Like Mean MP count and standard deviation (SD). Origin 2019 is used to process and analyze MP's physical attributes and graphical depiction. To assess the variations in microplastic concentrations between the pre-and post-monsoon seasons, the study used the paired T-test. Significant variations ($p < 0.05$) were evaluated in the findings of the sample analysis.

Results

MPs Concentration in the River Water

MPs were found in the river water samples were gathered for further investigation. The averages and standard deviations (SD) of the MPs findings in both the seasons from Doriganj, Patna, and Barh are shown in Tables 1 and 2. The study's total MP abundance before and after the monsoon season is shown in Figs 2 and 3. Furthermore, Fig. 4 displays optical microscope images of the MPs acquired for this study. At each sampling site in the pre-monsoon, the mean MP concentrations (n = 6) were 752.5 ± 44.54 (S1), 1383 ± 48.08 (S2), and 998 ± 16.97 (S3); in the post-monsoon, they were 407 ± 29.69 (S1), 893 ± 39.59 (S2), and 572.5 ± 41.71 (S3).

MPs Characterization of water of the Ganga River

The findings showed that, in every place under investigation, fibers and pieces were the most commonly detected morphologies, followed by films and foams. The distribution of MPs is shown in Figs. 2(b) and 3(b) based on their unique shape. Furthermore, a list of the MP values for each study location concerning size, shape, and color in both seasons can be seen in Tables 1 and 2. Throughout the study, a range of MP particle sizes—from less than 1 mm to more than 4 mm—were recorded. The percentage of microplastics decreased as the particle size increased; larger particles made up a smaller part of the total, while particles smaller than 1 mm made up the biggest portion. (Figs 2 and 3). In site 1, most of the particles were smaller than 1-mm, making up the largest share (62.52%). Particles between

Table 1: MPs (items/m^3) as mean and SD based on their counts, shape, size, and color at the studied sites in pre-monsoon

Count									
S1	752.5±44.54								
S2	1383±48.08								
S3	998±16.97								
Size	<1 mm	1 - 2 mm	2 - 4 mm	>4 mm					
S1	470.5±16.26	174.5±17.67	76±5.65	31.5±4.94					
S2	726±16.97	415±11.31	199±5.65	43±14.14					
S3	513.5±6.36	249.5±3.53	137.5±2.12	97.5±4.94					
Shape	Fibers	Fragments	Films	Foams	Microbeads				
S1	340.5±12.02	192±5.65	123±15.55	67.5±6.36	29.5±4.94				
S2	500±21.21	433.5±3.53	262±8.48	102.5±6.36	85±15.55				
S3	485.5±13.43	203.5±3.53	160±2.82	93±1.41	56±2.82				
Color	Blue	Black	White	Red	Transparent	Orange	Yellow	Green	Pink
S1	105±2.82	101.5±14.84	199±5.65	60.5±6.36	149.5±3.53	35±4.24	24±2.82	42±4.24	36±5.65
S2	224.5±10.60	151±4.24	259±5.65	206±1.41	248±11.31	62.5±6.36	108±16.97	75±18.38	49±9.89
S3	170±2.82	92±5.65	300±5.65	101.5±4.94	188.5±9.19	40±8.48	47.5±6.36	37.5±7.77	21±4.24

Table 2: MPs (items/m3) as mean and SD based on their counts, shape, size, and color at the studied sites in post- monsoon

Count									
S1	407±29.69								
S2	893±39.59								
S3	572.5±41.71								
Size	<1 mm	1 - 2 mm	2 - 4 mm	>4 mm					
S1	262±11.31	98.5±4.94	26.5±4.94	20±8.48					
S2	490.5±27.57	208.5±4.24	122±11.31	72±5.65					
S3	377±7.07	117±15.55	52±14.14	26.5±4.94					
Shape	Fibers	Fragments	Films	Foams	Microbeads				
S1	211±9.89	101.5±12.02	57±4.24	24±1.41	13.5±2.12				
S2	424.5±2.12	244.5±14.84	127±8.48	71±9.89	26±4.24				
S3	294.5±14.84	154±2.82	57.5±2.12	39±15.55	27.5±6.36				
Color	Blue	Black	White	Red	Transparent	Orange	Yellow	Green	Pink
S1	62±4.24	40.5±2.12	83±4.24	46.5±4.94	82.5±4.94	27.5±3.53	40.5±2.12	13.5±2.12	11±1.41
S2	127.5±10.60	107±7.07	199±7.07	98.5±2.12	139±5.65	38±2.82	72±9.89	62.5±9.19	49.5±9.19
S3	114.5±7.77	104.5±4.94	46.5±7.77	88±8.48	18±2.82	34.5±0.70	76.5±3.53	79±4.24	11±2.82

1 to 2 mm made up 23.18%, those between 2 to 4 mm were 10.09%, and particles larger than 4 mm were 4.18%. Similarly, the proportion of MPs at S2 followed the order: <1 mm (52.49%), >1 to 2 mm (30%), >2 to 4 mm (14.38%), >4 mm (3.10%) and at S3 the proportion of MPs followed the order: < 1-mm (51.45%), > 1 and 2 mm (25%), > 2 to 4 mm (13.77%), > 4 mm (9.76%) in the pre-monsoon period. For post monsoon also the particles <1-mm made up the largest share (64.37%), and then particles between >1 and 2 mm (24.20%), >2 to 4 mm (6.51%), >4 mm (4.91%). Similarly, the proportion of MPs at S2 followed the order: <1 mm (54.92%), >1 to 2 mm (23.34%), >2 to 4 mm (13.66%), >4 mm (8.06%) and at S3 the proportion of MPs followed the order: < 1 mm (65.85%), > 1 and 2 mm (20.43%), > 2 to 4 mm (9.08%), > 4 mm (4.62%)The color distribution of MP was categorized into nine groups in the current study: White MPs made up 26.44 to 30.06% of all detected MPs across all study sites in pre-monsoon and 8.12 to 20.39% in post-monsoon, while blue MPs made up 17.03% in pre-monsoon and 20% in post-monsoon as Fig. 2 illustrates, the percentage of colored MPs was very low at 2.10 to 1.92% pink and included a spectrum of colors including red, blue, pink, green, transparent and yellow in both the seasons.

Polymer Composition of MPs

In this study, four types of MPs were found i.e. LDPE (low-density polyethylene), PES (polyesters), PS (polystyrenes) and high-density polyethylene (HDPE) in pre-monsoon season and five MP types were identified, in post monsoon including polyvinyl chloride (PVC), polyethylene Terephthalate), LDPE (low-density polyethylene) PP(Polypropylene), HDPE (High-density polyethylene). The MP polymer type detected at all investigated sites is shown in Fig. 2. The results showed that HDPE (50%) and PS (28%) make the biggest proportion of MPs, followed by LDPE and PES 17 and 5%, respectively in pre-monsoon and LDPE (44%) and PET (28%) accounted for the largest proportion of MPs, followed by PVC (17%), HDPE (6%) and PP (5%). Fig. 5 shows the FTIR spectra of some identified MPs.

Statistical Analysis of Pre- and Post-Monsoon Microplastic Concentrations Using Paired t-Test

A paired t-test was conducted to compare the MP concentrations in the River Ganga between the pre-monsoon and post-monsoon seasons. The mean concentration of microplastics in the pre-monsoon samples was 1044.5 units, whereas, in the post-monsoon samples, it was 624.17 units (Fig. 6) The variance in the pre-monsoon samples was 101004.25, compared to 61051.08 in the post-monsoon samples. The results indicate a significant decrease in microplastic concentrations in the River Ganga from the pre-monsoon to the post-monsoon period. The high t-statistic (10.057) and low *p-values* (0.00487 one-tailed, 0.00974 two-tailed) strongly suggest that the observed difference is not due to random chance. The monsoon season's high river discharge, which probably dilutes microplastic concentrations, is the cause of this decline. Further lowering the amount of microplastics in the water column is possible if they settle into sediments during the post-monsoon season. Fig. 5. displays the average total microplastic concentration throughout two seasons: pre-monsoon and post-monsoon. A significant linear association between the matched pre- and post-monsoon samples is also indicated by the Pearson correlation of 0.998, indicating that although concentrations decline, the distribution pattern is stable across the seasons. This study's results emphasize the importance of considering seasonal changes when assessing microplastic pollution in rivers since these variations can have important consequences for managing water quality and the overall health of the river ecosystem.

Factors Affecting Variations in MPs Concentrations

The natural river flushing process that occurs throughout the monsoon season is probably responsible for the notable drop in microplastic concentrations following the monsoon. The monsoon's enhanced water volume and flow rates have the potential to wash microplastics downstream or lessen their

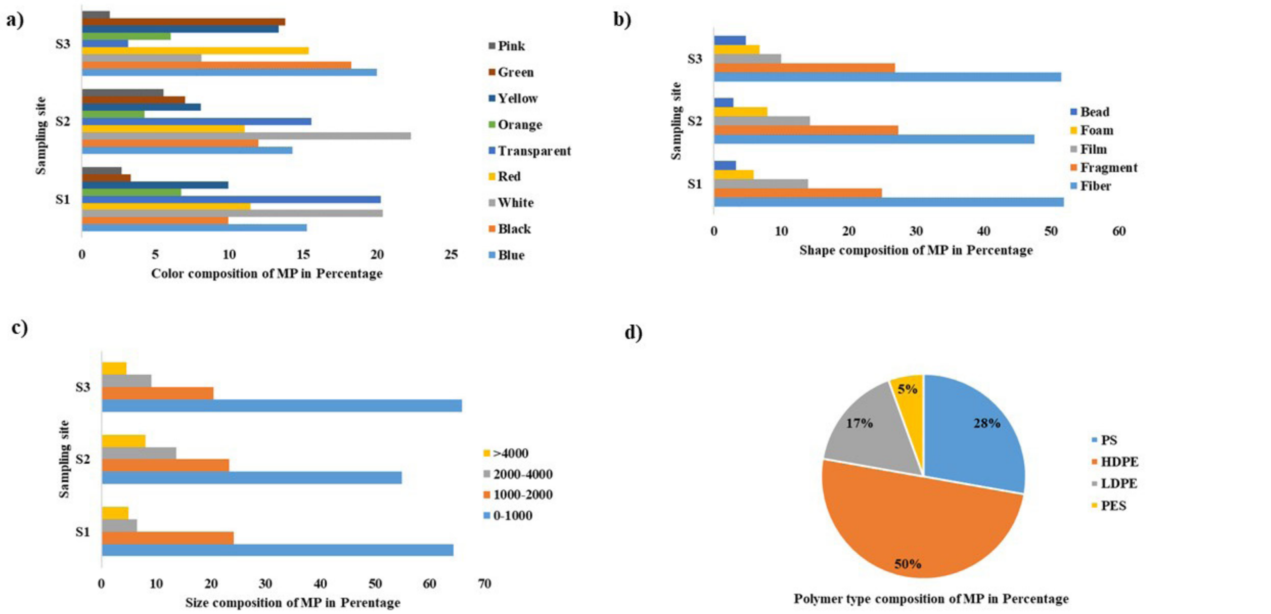

Fig. 2: River water MPs distribution, a) Color, b) Shape, c) Size in three sampling sites (S1, S2, and S3) and d) Polymer composition of MPs in overall studies in pre- monsoon

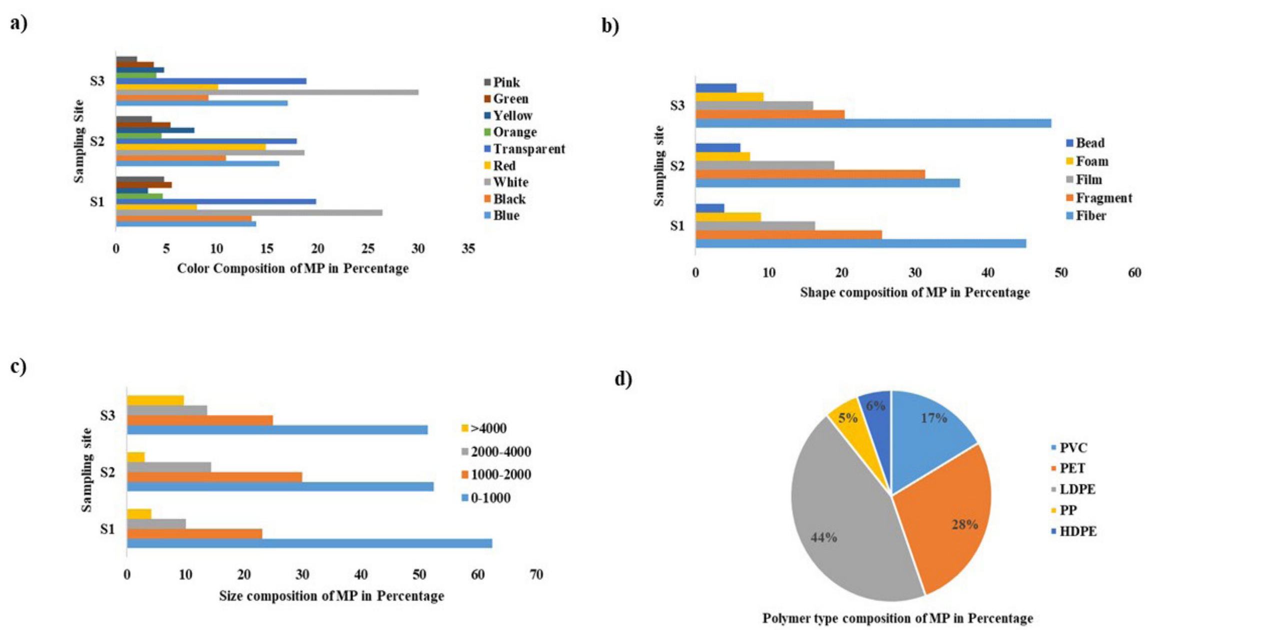

Fig. 3: River water MPs distribution, a) Color, b) Shape, c) Size in three sampling sites (S1, S2, and S3) and d) Polymer composition of MPs in overall studies in post-monsoon

concentrations in the river, which would lower the levels seen in the post-monsoon phase. The high Pearson correlation coefficient implies that the relative spatial distribution of microplastics in the river has not changed despite the overall decrease. This could suggest that although concentrations are lowered during the monsoon, sources of microplastic pollution (such as industrial runoff, municipal trash, or agricultural runoff) continue to exist and affect the microplastic load in the river system long after the monsoon season ends.

Discussion

Characteristics and Origin of MPs Concentrations in the Ganga River

The MPs in the Ganga region in Bihar declined from the pre-monsoon to the post-monsoon season, moving from upstream (Doriganj) to downstream (Barh). Singh *et al*., (2021) report that the MPs in the Bihar part of the Ganga have been gradually

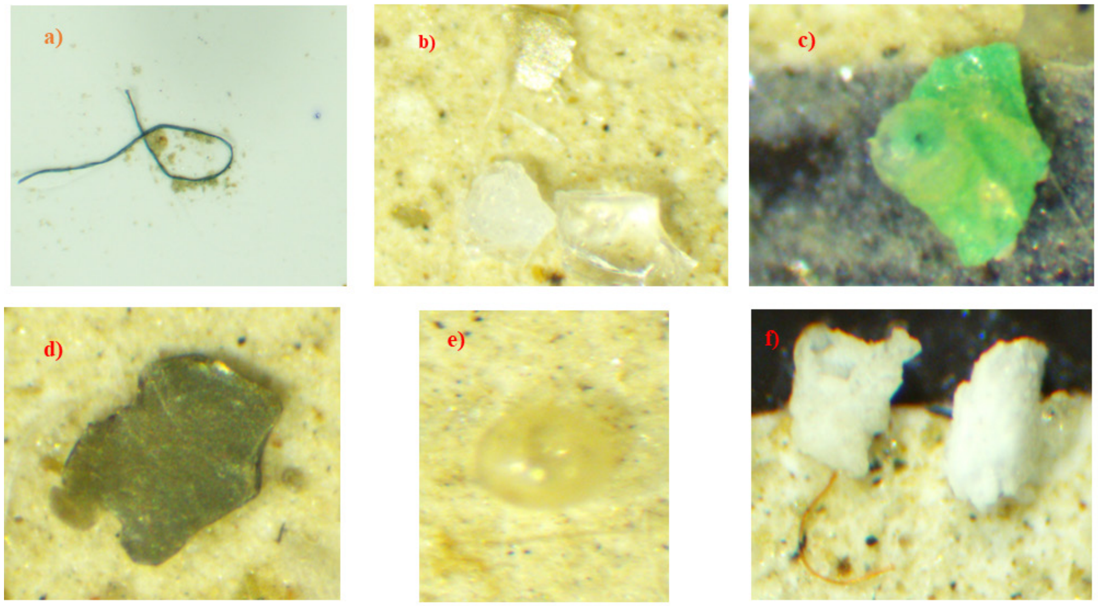

Fig. 4: Optical microscopic images of MPs (a) fibers, (b) film (c-d) fragment, (e) microbead, (f) foam

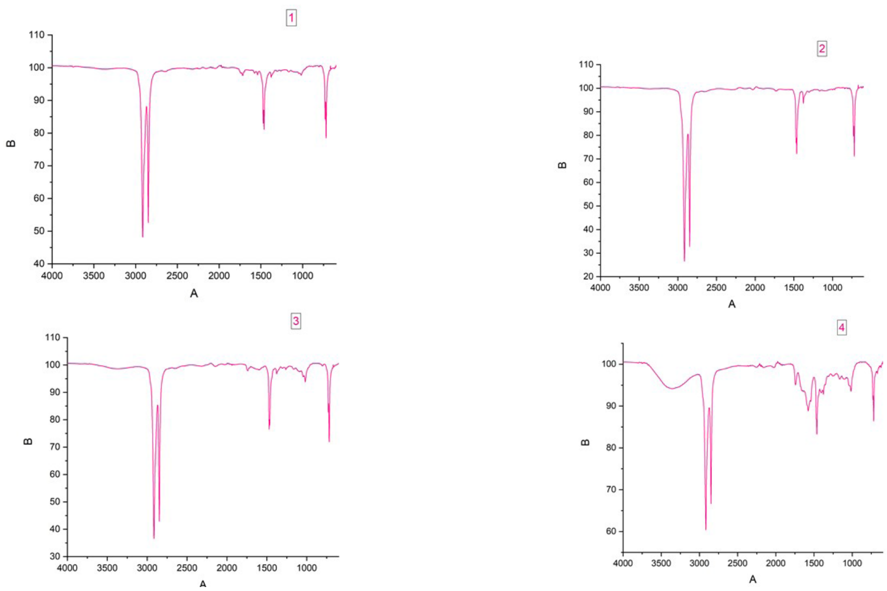

Fig. 5: FTIR spectra of the some identified MPs (1) HDPE (2) LDPE (3) LDPE (4) PP

raised in comparison to previous years. In the pre-monsoon and post-monsoon periods of our study, the average number of particles/m3 in the river water was 1044.5 ± 317.81 and 624.16 ± 247.08, respectively. The most common MP particles were in the 0 to 1 mm size range (Fig. 2), and fibers and fragments were more common than microspheres, films, and foam. The Ganga River sampling site in the upstream northwest Doriganj area of the Patna district revealed significantly less MP abundance than the other two locations because it is located in a rural area. Comparing the Doriganj sampling site to the other locations, it was found that it was considerably more susceptible to regular sand mining. In the eastern half of the Patna district's center metropolitan region, which is a semi-urban area, the MPs identified a relatively high concentration of Barh sample sites. The Patna city sampling site exhibits the highest microplastic concentration in both seasons due to the region's large population density, moderately developed economies, and frequent use of plastic products. The two sampling locations, Barh and Doriganj, were located in semi-urban areas of Bihar. The degree of social and economic development is lower than at the Patna city sample site, and the usage of plastic products has declined.

Effects of Different Factors on the Concentration of MPs in the River at Different Seasons

There was a significant drop in MP concentration from pre-monsoon to post-monsoon for each test site (Figs 2 and 3). The accumulation of microplastics in the river due to its lower flow is

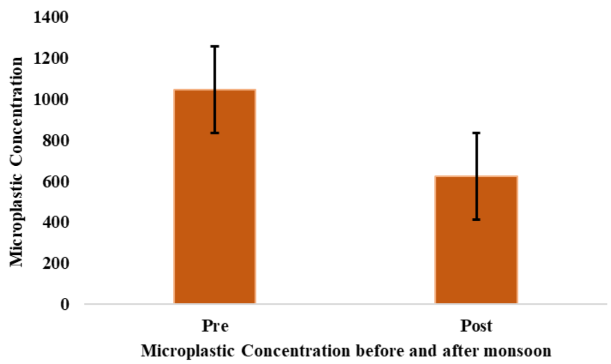

Fig. 6: Mean of total Microplastic concentration across two periods: pre-monsoon and post-monsoon

one of the main causes of this problem. The pre-monsoon season in the Indian subcontinent is thought to cause reduced water levels in rivers, such as the Ganga, which restricts the diluting and distribution of microplastics (Jambeck *et al.,* 2015; Kumar *et al.,* 2021). Because of the decreased flow rates, microplastics from land-based sources such as household garbage, industrial effluents, and agricultural runoff also keep entering the river. Intense human activities like agriculture and the disposal of urban garbage are also linked to the pre-monsoon season. Sarkar *et al.*, (2019) state that the Ganga Basin's agricultural practices are a major cause of microplastic contamination, especially in the pre-monsoon season when pesticides and fertilizers—which frequently contain microplastics—are widely applied. The microplastic burden in the river is further increased by the use of plastic mulches and other agricultural inputs. On the other hand, microplastic concentrations usually decrease after the monsoon season. This is explained by the fact that the monsoon season's high river discharge and heavy rains act to remove accumulated microplastics from the river system. According to research by Singh *et al.,* (2020) and Gupta *et al.,* (2022), the monsoon rains have a major flushing impact that reduces the concentrations of microplastics and moves them downstream or out to sea. During the post-monsoon phase, this yearly cleaning lowers the river's overall microplastic burden. In addition to diluting the microplastics, monsoon surface runoff moves them into the main river channel from nearby land areas and riverbanks. Sediments, including microplastics that are attached to sediment, may be resuscitated due to the post-monsoon period's greater flow speeds and turbulent circumstances. However, as Mishra *et al*., (2021) show, the overall result is usually a drop in measurable microplastic concentrations in the water column post-monsoon.

Conclusion

Microplastic concentrations in the River Ganga are regularly higher before rainfall, according to the literature. Reduced river flow, increased human inputs, and the lack of flushing effects brought on by monsoon rains are the main causes of this pattern. For the Ganga and other comparable river systems to experience less microplastic pollution, it is imperative to comprehend these temporal trends. To completely understand the dynamics of microplastic contamination in this important waterway, more study is needed, especially longitudinal studies that monitor microplastic levels across several years and monsoon cycles. There is a statistically significant difference between pre-and post-monsoon microplastic concentrations, as evidenced by the t-statistic (10.06) exceeding both the one-tailed (2.92) and two-tailed (4.30) crucial t-values and the *p-values* being below 0.05. This implies that after the monsoon, the concentrations have drastically dropped.

Conflict of Interest Statement

The authors state that they have no financial or personal connections that could have influenced the work in this paper.

Data Availability

Data will be provided upon request.

Acknowledgments

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Author's Contribution Statement

Varsha: Investigation, resources, formal analysis, visualization, writing - original draft.
Sushil Kumar Singh: Supervision, Conceptualization, Writing - review and editing.

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