Toxicology International, *32(3) : 589-600; 2025. DOI: 10.18311/ti/2025/v32i3/45432*

Online ISSN : 0976-5131; Print ISSN : 0971-6580

Toxicology International

Journal Homepage: https://informaticsjournals.co.in/index.php/toxi



Microplastic Contamination in Edible and Inedible Tissues of *Labeo rohita* Across Rajasthan and Haryana: A Comparative Assessment

Khushboo Yadav and Meena Godha*

School of Life and Basic Sciences, Jaipur National University, Jaipur - 302017, Rajasthan, India; meena.godha@jnujaipur.ac.in

Abstract

This study investigates the presence, morphology, and chemical composition of Microplastics (MPs) in edible (muscle and skin) and inedible (gastrointestinal tract and gills) tissues of the freshwater fish Rohu (*Labeo rohita*), collected from ten locations across Rajasthan and Haryana. A total of 300 fish samples were analysed using alkali digestion followed by visual inspection, Fourier Transform Infrared Spectroscopy (FTIR), and Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS). MPs were detected in 100% of the samples, with significant spatial variation in abundance (ranging from 46.3 to 109 particles per fish), and the control group showed the lowest levels (13.9 particles per fish). Fibres were the predominant form (>78%), followed by fragments and pellets, with blue being the most frequent colour. Commonly detected polymers included Polyethylene (PE), Polypropylene (PP), Polyvinyl Chloride (PVC), and Polystyrene (PS). The FTIR spectra also indicated co-contamination with toxic substances like lead oxide and polysiloxanes. The presence of MPs even in muscle tissues suggests translocation beyond the digestive tract, raising concerns about human consumption. These findings highlight the urgent need for waste management reforms and further monitoring of freshwater ecosystems to safeguard food safety and public health.

Major Findings: Microplastics were detected in all *Labeo rohita* samples, with fibres as the dominant type and polyethylene and PVC as the major polymers. Contamination varied by site and was highest in edible tissues, raising food safety concerns.

Keywords: Aquaculture, Edible Fishes, FTIR, Microplastics, SEM, Spectroscopy

1. Introduction

The increasing evidence of microplastics' pervasiveness in a variety of ecosystems, including freshwater, marine, and terrestrial settings, has raised serious concerns about their impact on the environment[1]. Plastic fragments less than 5mm are referred to as tiny plastic particles, and they can come from primary and secondary sources. First coined by Thompson *et al.* (2004), the term "microplastic" refers to both intentionally manufactured small plastic particles (primary MPs) and fragments resulting from the degradation of larger plastics (secondary MPs)[2]. Microplastics are comparatively a newer class of pollutants, which have come into notice over the last few years, but an enormous hazard to the environment has come from their excessive production and usage in several goods and sectors[3]. Due to their inherent qualities, chemical inertness, mechanical resistance, pressure resistance, durability, adaptability, flexibility, and low cost of manufacture, as well as the thermal stability provided

*Author for correspondence

Article Received on: 15.08.2024 Revised on: 21.05.2025 Accepted on: 28.05.2025

by the stabilisers and additives employed during the production process, these materials are widely utilised[4,5]. The amount of plastic used by consumers has grown by around 20 times in the past 60 years, while manufacturing has surged drastically from 15 million tons (Mt) in 1964 to 359Mt in 2020, and will be reaching 500Mt by 2025 with an estimated peak of 1124Mt by 2050[6-8]. With only about 9% of these produced plastics to go for recycling, more than 80% waste is tragically burned, disposed of in landfills, and discharged into the environment, endangering both the ecosystem and public health[9,10]. Furthermore, it is important to note that plastic wastes account for about 75.0% of marine waste materials since they are inflexible and do not biodegrade[11]. Microplastics are broadly divided into primary microplastics and secondary microplastics. Primary microplastics are defined as being purposefully produced small particles, such as the cosmetic microbeads found in face cleansers[12]. Primary microplastics are purposefully introduced into commercial and consumer goods, including paints, diapers, pharmaceuticals, cosmetics, detergents, and pesticides[13]. Unintentionally, microplastics can also arise from the breakdown of bigger polymers brought on by biological, chemical, or physical causes like tyre debris, breakdown of plastic bottles, fishing gears, plastic cans, toys, furniture, etc. These microplastics are referred to as secondary microplastics[14]. There are five main kinds of microplastics: pellets, films, foam, fibres, and fragments[15]. Furthermore, depending on their chemical makeup, microplastics may be divided into six groups: polyethylene, polystyrene, polypropylene, polyurethane, polyvinyl chloride, and polyethylene terephthalate[16]. Due to the fact that they can store and absorb harmful organic and inorganic pollutants, including heavy metals and persistent organic pollutants, these microscopic particles have a substantial negative influence on the environment, especially aquatic bodies[17]. Moreover, microplastics are known to be stable and incapable of breaking down, which allows them to linger in the environment for many years. Bioaccumulation is a part of the life cycle of microplastics. Usually, this cycle starts when primary or secondary microplastics are released into aquatic and terrestrial ecosystems, and then they are transported into water systems[18]. As a result, microplastics make their way up the trophic levels through the food chain of aquatic species, where they bioaccumulate in the tissues of zooplankton, small fish, bigger fish, and other organisms. It has been demonstrated that ingesting these contaminants can have harmful consequences on aquatic life, such as impairing the immunological and digestive systems and perhaps resulting in the death of fish, oysters, mussels, and sea turtles[19,20]. Consumption of aquatic products is an attribute of many socio-cultural groups of people because of their excellent nutritional profile and numerous health benefits. Eating fish and seafood has a lot of health advantages since they are high in high-quality proteins and bioactive substances. Fish is an important source of long-chain Omega-3 fatty acids, particularly Docosahexaenoic Acid (DHA) and Eicosapentaenoic Acid (EPA), which are linked to a lower risk of developing chronic conditions, including diabetes, obesity, heart disease, and some types of cancer[21]. But contrary to the well-studied benefits of eating seafood, bioaccumulation of microplastics along with other pollutants is unfolding as a serious health hazard. Research has demonstrated that human brain cells may be cytotoxically affected by microplastics[22]. Microplastics not only contain harmful chemicals but also have a huge surface area that allows them to absorb other pollutants, such as antibiotics, worsening the issue of microplastic contamination. Moreover, because humans can excrete microplastics or release them into the environment as plastic debris, the cycle of microplastics in the ecosystem never stops[23]. The breakdown of bigger plastic trash, the release of wastewater containing microplastics, and the usage of plastic materials in aquaculture operations are some of the causes that might contribute to microplastic pollution in aquaculture. Aquaculture systems may be impacted by these microplastics if they find their way into aquatic ecosystems[24,25]. Due to their physical durability, chemical resistance, and low degradation rates, MPs persist in aquatic environments and pose serious risks to biota. These particles not only enter aquatic systems via surface runoff, sewage, and atmospheric deposition but can also act as vectors for hazardous substances such as heavy metals, antibiotics, and persistent organic pollutants[11,23]. Once ingested, MPs can accumulate in organisms and transfer along trophic levels, potentially reaching human consumers[22].

Fishes are particularly vulnerable due to their direct exposure and feeding behaviour. Species like *Labeo rohita*, an Indian major carp widely consumed across India, including in Rajasthan and Haryana, are at risk due to their omnivorous feeding and habitat proximity to human activity. Recent studies from Kerala, West Bengal, and the southern coastal regions of India have confirmed

MP contamination in various freshwater and marine species, including edible fish[26-28].

Despite these growing concerns, limited data exist on MP contamination in freshwater ecosystems of northern India, particularly in commonly consumed fish like *Labeo rohita*. Most studies have focused on marine species or selected regions, leaving a significant gap in understanding spatial variation in freshwater fish contamination across states like Rajasthan and Haryana. This study addresses that gap by investigating MP abundance, morphology, and polymer composition in edible and inedible tissues of *Labeo rohita* collected from ten geographically distinct sites, including a clean-water control. The novelty of this work lies in its comparative design, tissue-level analysis, and incorporation of both instrumental and morphological characterisation methods, offering comprehensive insights into MP contamination and exposure risk. The study hypothesised that fish sourced from urban or semi-urban sites with poor waste management will exhibit higher MP loads and that MPs will not be confined to gastrointestinal tissues but also be present in edible tissues like muscle and skin, posing direct risks to human consumers.

2. Materials and Methods

2.1 Sample Collection

Freshwater fish species of the Cyprinidae family, *Labeo rohita,* were collected sequentially from a total of ten sites in a span of almost two years, from January 2022 to October 2023, in the areas of Rajasthan (mainly Jaipur), Haryana, with n=30. Overall, 300 fish were collected from the mentioned sites. Fishes were collected from the local fish vendors as well as from the local fish farms for inclusion of both varieties of fish being eaten in the area. Fishes were wrapped in aluminium foil and put in ice boxes during transportation to the university lab, where they were kept at -20°C until further processing. The rationale behind selecting Rohu for the present study was because of its nutritional value, cultural importance, adaptability in a variety of recipes, and accessibility through aquaculture. *Labeo rohita* is a popular fish among non-vegetarians in Rajasthan and Haryana. Also, it was easily available at every selected site. Along with the ten test sites, one control was also set up in the university pond, from where fish samples were also analysed for microplastic contamination. Figure 1 and Table 1 refer to the location of sample collection sites.

2.2 Contamination Check

Conical flasks, petri dishes, filtering units, glass slides and other glassware were carefully cleaned with soap solution before being cleaned with distilled water. To prevent MP contamination in the air, oven-dried glassware was then wrapped with aluminium foil and carefully placed inside insulating boxes. Conical flasks and petri plates were brought out and utilised for the extraction procedures on the day of extraction. Every safety measure was adopted to reduce the possibility of contamination of the sample while it was being processed. Throughout, nitrile gloves of the highest calibre were worn. Every time, glassware was carefully cleaned before being used. In addition, a

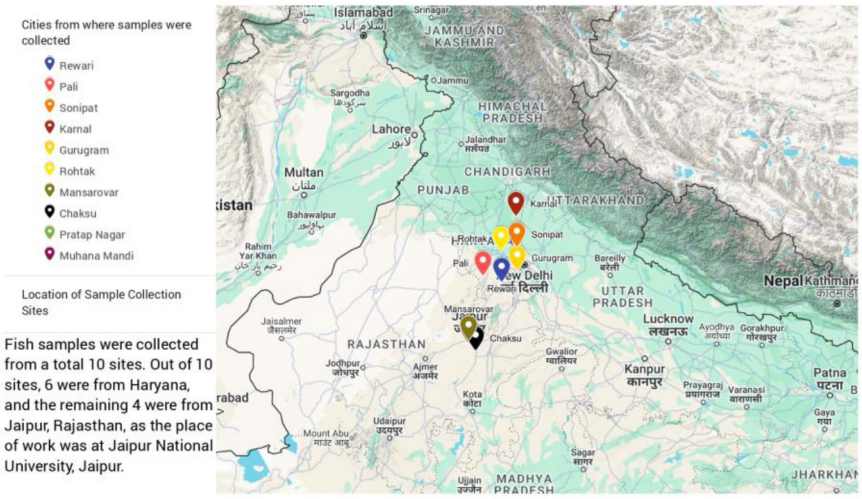


Figure 1. Location map of the collection sites of fish.

Table 1. Details of the fish mean weight and mean length employed in the current investigation for MPs analysis

Sample No.	Area of Study	No. of Individuals	Mean Weight	Mean Length
1	Local Fish Market, Jaipur, Rajasthan	30	241.6 ±26.11	24.5±2.76
2	Local Fish Market, Rewari, Haryana	30	238.43±17.21	26.66± 3.42
3	Fish farm Sonipat, Haryana	30	234.43± 20.56	24.76± 2.63
4	Fish farm Karnal, Haryana	30	222.73± 17.54	25.03± 2.53
5	Chaksu Lake, Jaipur, Rajasthan	30	232.4±13.94	24.73± 2.28
6	Mansarovar Lake, Jaipur, Rajasthan	30	235.36±13.61	25.13± 2.34
7	Fish Vendor, Pali, Haryana	30	221.63± 13.73	25.13± 3.27
8	Local Fish Market, Gurugram	30	227.16± 11.00	25.43± 2.58
9	Muhana Mandi, Jaipur	30	233.4± 10.81	25.7± 1.82
10	Local Fish Vendor, Rohtak	30	215.1± 9.36	19.1±2.18
CONTROL	University campus pond	30	180.2± 14.19	18.3± 1.93

quality control blank was added to check for airborne contaminants. There was no visible microplastic compound on the blank filter paper.

2.3 Sample Preparation

Fishes were cleansed with tap water and then double-distilled water to prevent contamination before MP extraction. The weight and length of each fish were measured to the closest 0.1g and 0.1 millimetre, respectively. Table 1 shows the mean weight and length of the sample fish. To prevent airborne contamination, dissection was done in a laminar flow. Alcohol was used to clean the workstation before to dissection and any further processing. A thorough visual examination was done to check for any fragments of plastic inside the body of the organism. The dissected organs were separated into edible tissues (muscles and skin) and inedible tissues (Gastro Intestinal Tract and gills), and weighed and then transferred to a 250ml conical flask containing 10% Potassium Hydroxide (KOH). Alkali Digestion using 10% KOH was done to completely digest the fish tissues[29,30]. 10% KOH was added in the ratio of 3:1. The Volume of KOH was three times the volume of the organs being put into the conical flasks. In order to prevent the loss of MPs with varying densities, the density separation was not performed.

2.3.1 Alkali Digestion

Alkaline treatment of the organic tissues results in softening of the tissues, followed by complete digestion. KOH is the best solvent for the digestion of fish tissues, as proven by earlier studies[29]. Microplastic particles are non-biodegradable, so they were not affected by the treatment of KOH, and after the digestion process, microplastics could be extracted. According to Dehaut *et al.* (2016) and Karami *et al.* (2017), inedible tissues were incubated at 60°C for 24 hours and inedible tissues at 40°C for 72 hours, with constant shaking in between. Each sample underwent a filtering step following incubation[29,30]. Filtration was performed using Whatmann filter paper grade 540 toughened ashless. By setting up filter paper cones and carefully pouring the materials into them, gravity filtering was carried out. Filter sheets were allowed to air dry after finishing the filtering process. For additional sampling, which included optical microscopy, FTIR, and SEM, the filtrate was disposed of, and filter sheets were allowed to air dry.

2.4 Identification and Characterisation

2.4.1 Visual Identification

Visual identification of microplastics was done at magnifications 4X, 10X, and 40X using a stereomicroscope of the Olympus brand, model SZ61, with a light-emitting diode base. The surface of plastic particles was bright and sharp compared to any organic matter, which allows for the separation of microplastics from other organic components under a microscope. A hot-needle test was used for further confirmation. When microplastics come into contact with a heated needle, they often shrink or bend.

After that, microplastics were examined and categorised according to factors, including size, colour,

and shape. Morphologically, particles with irregularly flat shapes were classified as fragments, particles with elongated thread-like features as fibres, and particles with defined shapes as pellets. The particles were separated into groups according to colour: blue, red, black, pink, and others (orange, brown and yellow) (Figures 2 and 3).

2.4.2 FTIR Analysis

FTIR analysis was done on FT-IR Spectrum 2 (Perkin Elmer) in ATR mode. Attenuated Total Reflectance mode was used as the sample was in a solid state. The wavelength in the analysis ranged from 4100- 400cm^{-1}. Before loading the sample, it was ensured that the sample platform was clear and empty. It was sterilised with a wipe of alcohol. The default adjustment for the background scan was a resolution above 4 and a scan time of 16. Once the background scan was over, the sample was placed on the platform, and the knob was rotated and screwed to secure the sample. This step was done carefully to avoid damage to the sample.

After loading the sample, the sample measurement was started. FT-IR gave a result in the form of spectra showing peaks of different functional groups present in the sample. These peaks were further analysed and matched using spectral libraries to find the prominent functional group in the sample. After the sampling was done, the knob was unwinded and the sample was removed from the platform and wiped with alcohol again to make the area sterilised.

2.4.3 SEM Analysis

A popular method for identifying and characterising microplastics in a variety of environmental matrices is scanning electron microscopy, or SEM. SEM offers high-resolution pictures that provide specific details on the size, shape, and surface morphology of microplastic particles[31]. Using morphological and elemental characteristics, a SEM can identify microplastics in samples. When used in conjunction with Energy Dispersive X-ray (EDX) analysis, SEM can differentiate

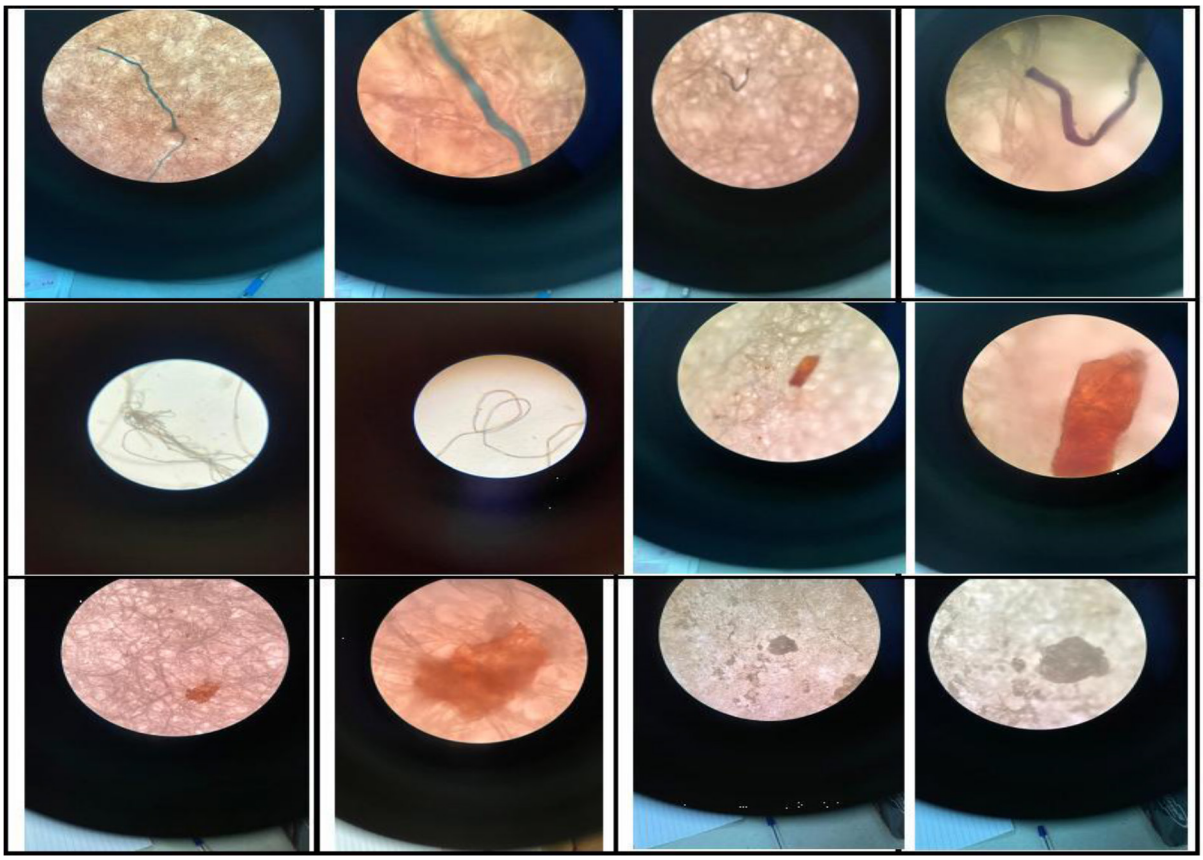


Figure 2. An array of different colors and shapes of microplastics identified on visual examination; 4X and 10 X views of some fibers and fragments are shown in the adjacent pictures.

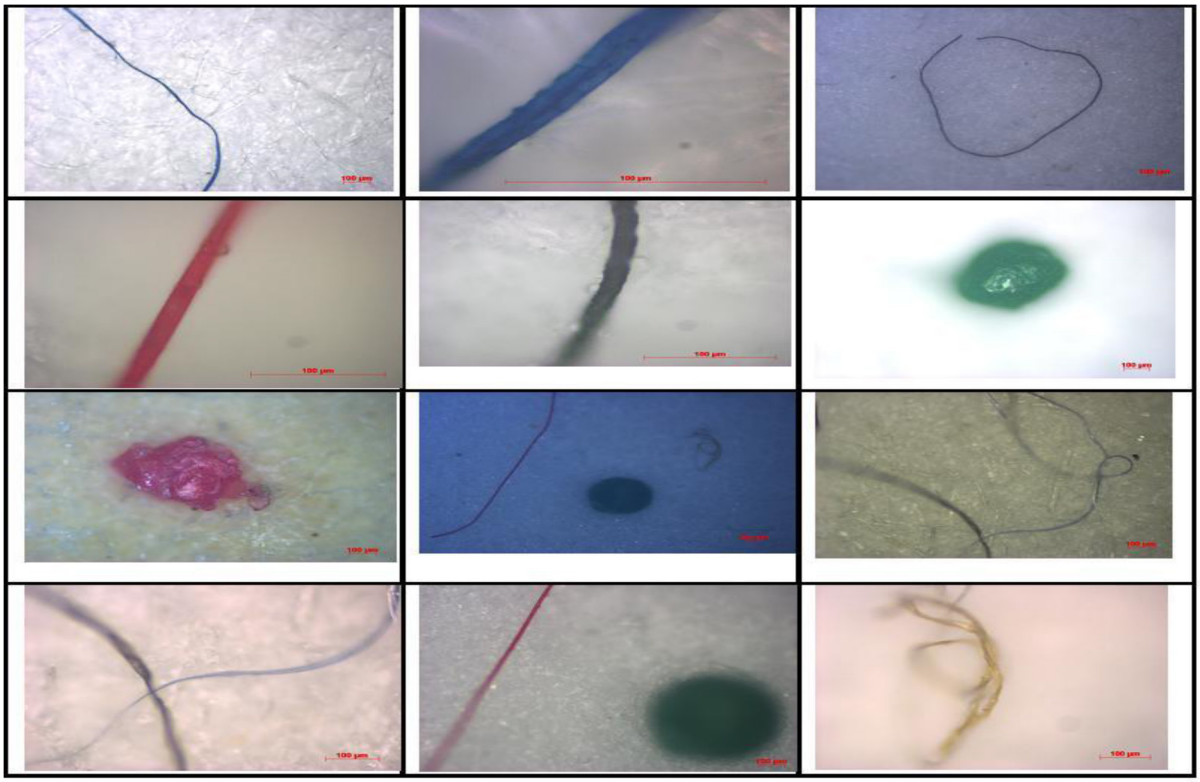


Figure 3. Images of microplastic particles taken from the inverted optical microscope attached with computer screen system.

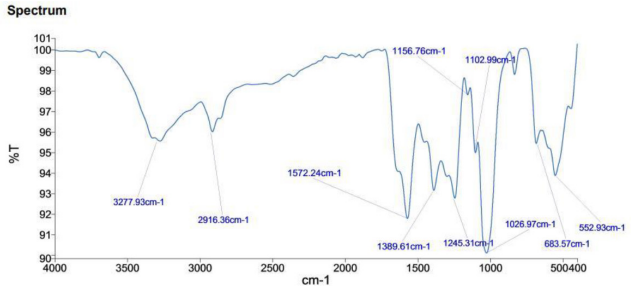


Figure 4. FTIR showing characteristic peaks of PE at 2916 cm^{-1} and 1389 cm^{-1} associated with C-H bending vibrations.

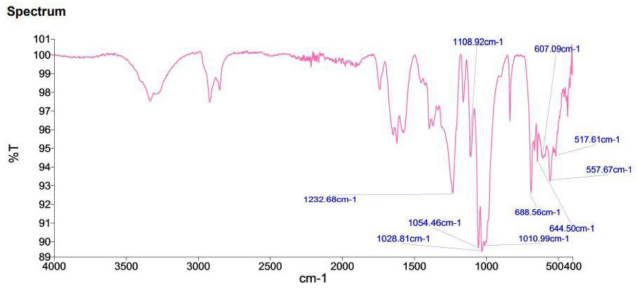


Figure 5. Characteristic peaks of PVC at 1232, 1108, 1054, 1028, 1010, 688 and 644 cm^{-1} indicating multiple C-O vibrations and C-Cl stretching vibrations.

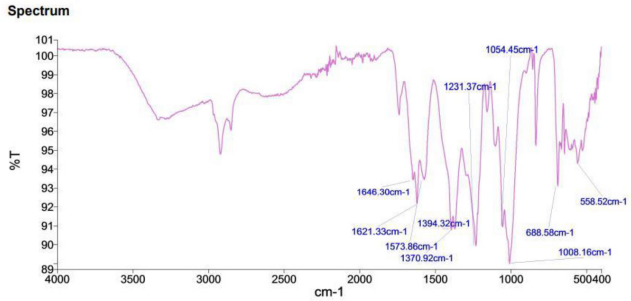


Figure 6. FTIR peaks of 1646, 1621 and 1573 cm^{-1} indicating aromatic C=C stretching characteristic of PS.

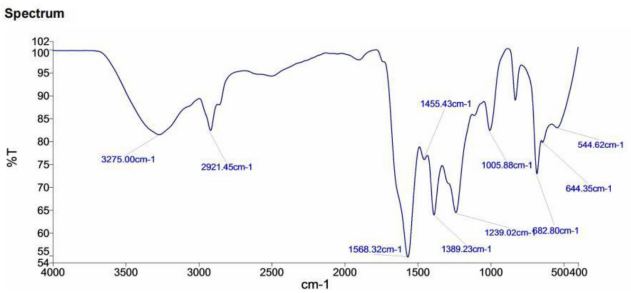


Figure 7. Characteristic peaks of 2921, 1455 and 1389 cm^{-1} indicating presence of C-H bending vibrations of PP.

between plastic microfilaments sourced from petroleum and organic ones based on a Carbon/Oxygen (C/O) ratio greater than 1[32]. SEM has been used in a number of investigations to identify microplastics. These studies include the visualisation of microplastics in sewage[33], sediments[34], sand[35], mussels[36] etc. For the present study, FESEM-EDS analysis of random samples was done to see the morphology and structure of various kinds of microplastics extracted.

2.5 Statistical Analysis

A one-way ANOVA was conducted to determine whether there were significant differences in the microplastic abundance in fishes collected from various sites, as well as from the control group. The analysis included 11 groups, with 30 observations in each group. The assumptions of normality and homogeneity of variances were checked using Levene's test for homogeneity. Post hoc comparison was done using Tukey's HSD. The result showed significance at the 0.005 level ($p<0.005^*$), indicating that there was a significant difference between the abundance of microplastics found from ten different sites and the control group.

3. Results and Discussion

3.1 Microplastic Abundance Across Sites

MPs were detected in all fish samples across the ten study sites, confirming their widespread presence in aquatic ecosystems of both Rajasthan and Haryana. MP abundance ranged from 46.3 particles/individual (Rohtak, Haryana) to a maximum of 109 particles/individual (Rewari, Haryana) (Table 2). The control group fish reared in the university's clean pond showed significantly lower MP abundance (13.9 particles/individual), validating the link between environmental exposure and MP accumulation (Figure 9). Notably, fish collected from market sources consistently exhibited higher MP loads than those from aquaculture farms, indicating probable contamination through open water exposure, handling, or packaging. These findings align with previous studies that highlight market-sourced or urban area fish as more susceptible to contamination[27,37].

The ANOVA test revealed significant variation in MP abundance across sites ($p < 0.005$), confirming that location and local environmental conditions, such as water quality, sewage exposure, and waste disposal

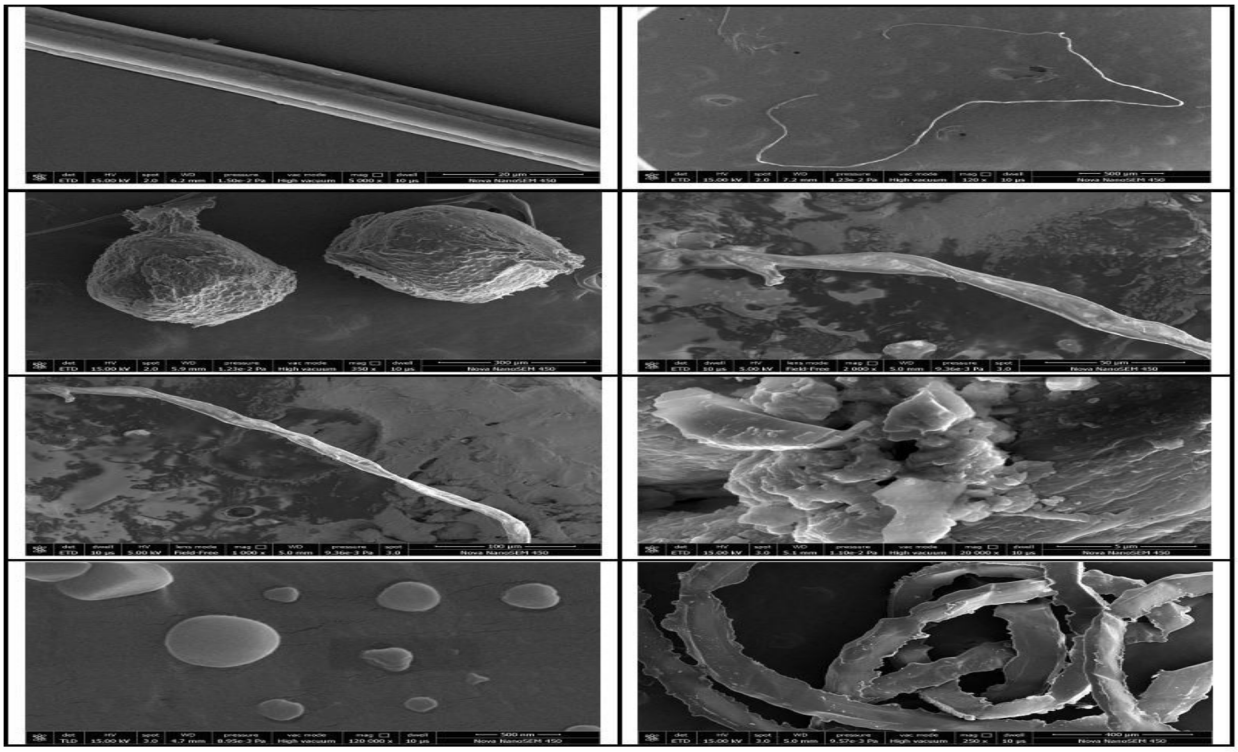


Figure 8. Scanning electron microscope images of various shapes of microplastics retrieved from the study.

practices, are critical determinants of contamination levels.

3.2 Tissue-Wise Distribution

MPs were recovered from both edible and inedible tissues. Across all samples, the tissue-wise distribution was: Muscle: 39.06%; Skin: 33.73%; Inedible tissues (GIT and gills): 27.19%. This finding supports earlier hypotheses that MPs can translocate beyond the digestive tract and accumulate in edible tissues via transcytosis or absorption through intestinal mucosa[28,38].

3.3 Morphological and Visual Characterisation

Visual and microscopic analysis categorised the MPs into three primary morphotypes: Fibres: 78.16%; Fragments: 16.19%; Pellets: 5.64% (Figure 10). Fibres were typically blue, red, or black in colour (Figure 2–3), consistent with textiles, fishing nets, and household sources[15,39]. The dominance of fibres suggests significant contamination from domestic wastewater, synthetic clothing, and aquaculture equipment, reflecting findings from other Indian and Asian freshwater studies[26,40].

3.4 FTIR and Polymer Identification

FTIR analysis confirmed the presence of multiple polymer types: PE, PVC, PP and Polystyrene (PS). Characteristic peaks such as 2916cm^{-1} (CH_2 stretching for PE) and 688–644cm^{-1} (C-Cl stretch for PVC) were consistently observed (Figures 4–7). These polymers are widely used in packaging, consumer goods, and fishing gear, indicating both urban and aquaculture-related sources of plastic pollution. Notably, lead oxide and polysiloxanes were also detected, suggesting chemical leaching of toxic compounds alongside MPs, a finding of significant toxicological concern that has been echoed in earlier studies[23,32].

3.5 SEM-EDS Findings

SEM imaging (Figure 8) showed irregular surfaces, cracks, and erosions on MP particles, indicative of environmental degradation. EDS confirmed high carbon-to-oxygen ratios (>1), distinguishing synthetic polymers from natural organic particles. These morphological traits point to long-term environmental exposure and reinforce the persistence and bioavailability of MPs in freshwater systems[31,41].

3.6 Comparative Insight with Other Indian Studies

The findings mirror trends reported in other Indian regions. For instance, Kerala mackerels showed higher MP load in gill tissues[26], Ganga River studies on *Labeo rohita* also noted fibre predominance in muscle and gut tissues[38] and studies in Tamil Nadu and Odisha found 80–95% of MPs were fibres, with PE and PP as common polymers[37,39]. Another study conducted on the common fishes of the Bay of Bengal, India, revealed the presence

Table 2. MP abundance in the samples tissue-wise

Sample No.	Area of Study	MP Abundance (Items/Individual)	Average No. of Microplastic Particles in the Tissues		
			Muscle Tissue	Skin Tissue	Inedible Tissue
1	Local Fish Market, Jaipur, Rajasthan	51.37	20.1	14.77	16.5
2	Local Fish Market, Rewari, Haryana	109.00	43.93	35.6	29.47
3	Fish farm Sonipat, Haryana	69.23	27.27	25.73	16.23
4	Fish farm Karnal, Haryana	62.73	26.4	21.57	14.77
5	Chaksu Lake, Jaipur, Rajasthan	96.13	37.6	32.33	26.2
6	Mansarovar Lake, Jaipur, Rajasthan	55.67	21.57	19.37	14.73
7	Fish Vendor, Rewari, Haryana	73.13	30	24.87	18.27
8	Local Fish Market, Gurugram	68.03	24.43	22.2	21.4
9	Muhana Mandi, Jaipur	90.07	34.2	31.17	24.7
10	Local Fish Vendor, Rohtak	46.30	17.73	15.53	13.03
CONTROL	University campus pond	13.97	4.13	5.07	4.77

of 16.38 to 31.88 microplastics per individual, with PE, PP and cellulose being the most common polymers and 95.18% fibers of the total microplastics[27]. Mackerels and sardines from the Malabar coast, India, showed the presence of fragments and fibres in abundance[42]. Commercial fish species like sardines, mackerels and anchovies from Adyar and Ennore regions of the Southern coast of India showed the presence of PE, PP, PS, PVC and PET as the most abundant polymers, with fibres and fragments constituting 68% of the total microplastics[43]. Presence of PE, PP, PS, and PVC as abundant polymers has also been shown in various studies done in various parts of the country[41,44-47]. While methodologies vary (some report particle count per gram, others per individual), the pattern is clear: MPs are pervasive across India's freshwater fish, and fibres dominate the pollution profile.

3.7 Implications and Environmental Significance

The consistent detection of MPs in edible tissues presents serious implications for food safety and human health. Given that synthetic polymers can adsorb and transport heavy metals and persistent organic pollutants, regular consumption of contaminated fish may contribute to chronic exposure in humans[22,25]. Furthermore, the bioaccumulation in lower trophic organisms could disrupt aquatic food webs and ecosystem stability. These risks demand urgent attention toward improved wastewater treatment, regulation of plastic disposal and surveillance of aquaculture systems. Taken together, these investigations demonstrate the pervasiveness of

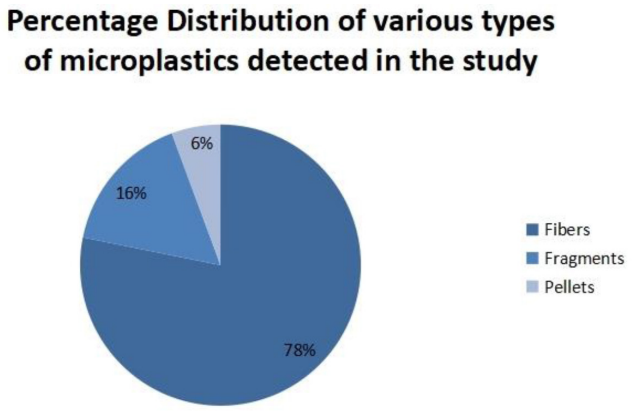


Figure 10. Pie chart showing the percentage distribution of various microplastics detected in the study.

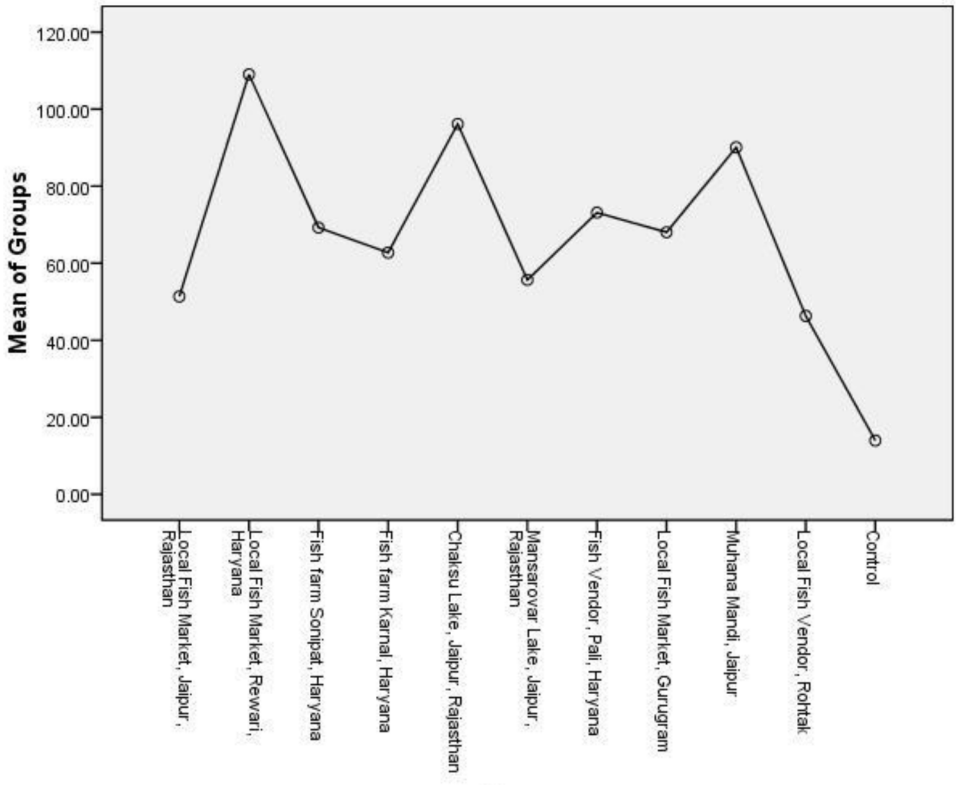


Figure 9. Graph showing mean of the total number of microplastics recovered from each site and their comparison with each other.

microplastics in edible fish species in India and the pressing need for all-encompassing approaches to address this problem in terms of both human health and the ecosystem.

4. Conclusion

This study provides compelling evidence of widespread MP contamination in both edible and inedible tissues of *Labeo rohita* collected from multiple locations in Rajasthan and Haryana. All samples tested positive for MPs, with significantly higher abundance in fish sourced from urban fish markets compared to those from aquaculture farms and the controlled pond environment. Fibre-type microplastics were predominant (>78%), and the most frequently identified polymers included PE, PP, PVC, and PS.

The detection of MPs in muscle and skin tissues commonly consumed by humans raises immediate concerns about food safety and chronic exposure to plastics and associated toxicants such as lead oxide and polysiloxanes. Instrumental characterisation confirmed that microplastics not only persist in aquatic environments but also undergo weathering, making them more likely to interact with pollutants and biological systems.

This study demonstrates the urgent need for:

- **Stringent plastic waste management**, especially near water bodies and fish farms.
- **Routine monitoring** of edible aquatic species for microplastic contamination.
- **Public health guidelines** addressing safe consumption of freshwater fish.
- **Standardised national protocols** for sampling and reporting microplastic data across freshwater systems.

This is the first comparative tissue-specific assessment of microplastics in *Labeo rohita* from Rajasthan and Haryana, filling a critical gap in North Indian freshwater pollution research. Continued research is essential to explore the toxicological impacts of these contaminants and to inform policy interventions that protect both ecological and human health.

5. Acknowledgements

The authors sincerely acknowledge the institute and lab support of Jaipur National University for providing the facility to conduct research in the premises. The authors extend their sincere thanks to MRC-MNIT (Material Research Centre- Malviya National Institute of Technology), Jaipur, where the optical microscopy, FT-IR and SEM analysis were done.

6. Funding

The first author received a research fellowship from the University Grants Commission under the scheme NET-JRF in Life Sciences. All the expenditures in this study were covered from the fellowship amount.

7. References

1. Osman AI, Hosny M, Eltaweil AS, Omar S, Elgarahy AM, Farghali M, *et al*. Microplastic sources, formation, toxicity and remediation: a review. Environ Chem Lett. 2023; 21(4):2129-2169. https://doi.org/10.1007/s10311-023-01593-3 PMid:37362012 PMCid:PMC10072287
2. Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AWG, *et al*. Lost at Sea: Where is all the plastic? Science. 2004; 304(5672):838-838. https://doi.org/10.1126/science.1094559 PMid:15131299.
3. Osman AI, Farrell C, Al-Muhtaseb AH, Al-Fatesh AS, Harrison J, Rooney DW. Pyrolysis kinetic modelling of abundant plastic waste (PET) and *in-situ* emission monitoring. Environ Sci Eur. 2020; 32(1):112. https://doi.org/10.1186/s12302-020-00390-x
4. Al-Salem SM, Lettieri P, Baeyens J. Recycling and recovery routes of plastic solid waste (PSW): A review. Waste Manag. 2009; 29(10):2625-2643. https://doi.org/10.1016/j.wasman.2009.06.004 PMid:19577459.
5. Tiwari R, Azad N, Dutta D, Yadav BR, Kumar S. A critical review and future perspective of plastic waste recycling. Sci Total Environ. 2023; 881:163433. https://doi.org/10.1016/j.scitotenv.2023.163433 PMid:37061055.
6. Wagner M, Engwall M, Hollert H. Editorial: (Micro) plastics and the environment. Environ Sci Eur. 2014; 26(1):16. https://doi.org/10.1186/s12302-014-0016-3 PMid:27752414 PMCid:PMC5044938.
7. Kumagai S, Nakatani J, Saito Y, Fukushima Y, Yoshioka T. Latest trends and challenges in feedstock recycling of polyolefinic plastics. J Jpn Petrol Inst. 2020; 63(6):345-364. https://doi.org/10.1627/jpi.63.345
8. Bui XT, Vo TDH, Nguyen PT, Nguyen VT, Dao TS, Nguyen PD. Microplastics pollution in wastewater: Characteristics, occurrence and removal technologies. Environ Technol Innov. 2020; 19:101013. https://doi.org/10.1016/j.eti.2020.101013
9. Geyer R, Jambeck JR, Law KL. Production, use, and fate of all plastics ever made. Sci Adv. 2017; 3(7). https://doi.org/10.1126/sciadv.1700782 PMid:28776036 PMCid:PMC5517107.

10. Arboleda J, Umeozor E. Plastic to oil: Saudi Arabia and global perspectives. Riyadh, Saudi Arabia; 2023. https://doi.org/10.30573/KS--2023-DP09
11. Wang T, Wang L, Chen Q, Kalogerakis N, Ji R, Ma Y. Interactions between microplastics and organic pollutants: Effects on toxicity, bioaccumulation, degradation, and transport. Sci Total Environ. 2020; 748:142427. https://doi.org/10.1016/j.scitotenv.2020.142427 PMid:33113705.
12. Zhang K, Hamidian AH, Tubić A, Zhang Y, Fang JKH, Wu C, *et al*. Understanding plastic degradation and microplastic formation in the environment: A review. Environ Pollut. 2021; 274:116554. https://doi.org/10.1016/j.envpol.2021.116554 PMid:33529891.
13. Duis K, Coors A. Microplastics in the aquatic and terrestrial environment: Sources (with a specific focus on personal care products), fate and effects. Environ Sci Eur. 2016; 28(1):2. https://doi.org/10.1186/s12302-015-0069-y PMid:27752437 PMCid:PMC5044952.
14. Andrady AL. The plastic in microplastics: A review. Mar Pollut Bull. 2017; 119(1):12-22. https://doi.org/10.1016/j.marpolbul.2017.01.082 PMid:28449819.
15. Anderson PJ, Warrack S, Langen V, Challis JK, Hanson ML, Rennie MD. Microplastic contamination in Lake Winnipeg, Canada. Environ Pollut. 2017; 225:223-231. https://doi.org/10.1016/j.envpol.2017.02.072 PMid:28376390.
16. He S, Jia M, Xiang Y, Song B, Xiong W, Cao J, et al. Biofilm on microplastics in aqueous environment: Physicochemical properties and environmental implications. J Hazard Mater. 2022; 424:127286. https://doi.org/10.1016/j.jhazmat.2021.127286 PMid:34879504.
17. Van Emmerik T, Kieu-Le TC, Loozen M, van Oeveren K, Strady E, Bui XT, *et al*. A methodology to characterize riverine macroplastic emission into the ocean. Front Mar Sci. 2018; 5. https://doi.org/10.3389/fmars.2018.00372
18. Xiang Y, Jiang L, Zhou Y, Luo Z, Zhi D, Yang J, *et al*. Microplastics and environmental pollutants: Key interaction and toxicology in aquatic and soil environments. J Hazard Mater. 2022; 422:126843. https://doi.org/10.1016/j.jhazmat.2021.126843 PMid:34419846.
19. Caron AGM, Thomas CR, Berry KLE, Motti CA, Ariel E, Brodie JE. Ingestion of microplastic debris by green sea turtles (*Chelonia mydas)* in the Great Barrier Reef: Validation of a sequential extraction protocol. Mar Pollut Bull. 2018; 127:743-751. https://doi.org/10.1016/j.marpolbul.2017.12.062 PMid:29475719.
20. Hipfner JM, Galbraith M, Tucker S, Studholme KR, Domalik AD, Pearson SF, *et al*. Two forage fishes as potential conduits for the vertical transfer of microfibres in Northeastern Pacific Ocean food webs. Environ Pollut. 2018; 239:215-222. https://doi.org/10.1016/j.envpol.2018.04.009PMid:29655068.
21. Murti PDB, Dwiloka B, Radjasa OK, Ngginak J. Opportunity and benefits of functional food from the sea: A Review. Trop Life Sci Res. 2021; 11(2):87. https://doi.org/10.31938/jsn.v11i2.297
22. Schirinzi GF, Pérez-Pomeda I, Sanchís J, Rossini C, Farré M, Barceló D. Cytotoxic effects of commonly used nanomaterials and microplastics on cerebral and epithelial human cells. Environ Res. 2017; 159:579-587. https://doi.org/10.1016/j.envres.2017.08.043 PMid:28898803.
23. Li J, Zhang K, Zhang H. Adsorption of antibiotics on microplastics. Environ Pollut. 2018; 237:460-467. https://doi.org/10.1016/j.envpol.2018.02.050 PMid:29510365.
24. Iheanacho S, Ogbu M, Bhuyan MS, Ogunji J. Microplastic pollution: An emerging contaminant in aquaculture. Aquac Fish. 2023; 8(6):603-616. https://doi.org/10.1016/j.aaf.2023.01.007
25. Wu H, Hou J, Wang X. A review of microplastic pollution in aquaculture: Sources, effects, removal strategies and prospects. Ecotoxicol Environ Saf. 2023; 252:114567. https://doi.org/10.1016/j.ecoenv.2023.114567 PMid:36706522.
26. Athiramol PS., Thomas S, Jacob AM. Microplastic contamination in Indian Mackerel (*Rastrelliger kanagurta*) and Finletted Mackerel (*Megalaspis cordyla*): Exploring occurrence and variability in skin and gill tissues. Uttar Pradesh J Zool. 2024; 45(3):71-79. https://doi.org/10.56557/upjoz/2024/v45i33876
27. Sultana S, Anisuzzaman Md, Hossain MdK, Rana MdS, Paray BA, Arai T, *et al*. Ecological risk assessment of microplastics and mesoplastics in six common fishes from the Bay of Bengal coast. Mar Pollut Bull. 2024; 204:116544. https://doi.org/10.1016/j.marpolbul.2024.116544 PMid:38824706.
28. Pandey N, Verma R, Patnaik S, Anbumani S. Abundance, characteristics, and risk assessment of microplastics in indigenous freshwater fishes of India. Environ Res. 2023; 218:115011. https://doi.org/10.1016/j.envres.2022.115011 PMid:36502908.
29. Dehaut A, Cassone AL, Frère L, Hermabessiere L, Himber C, Rinnert E, *et al*. Microplastics in seafood: Benchmark protocol for their extraction and characterization. Environ Pollut. 2016; 215:223-233. https://doi.org/10.1016/j.envpol.2016.05.018 PMid:27209243.
30. Karami A, Golieskardi A, Choo CK, Romano N, Ho Y Bin, Salamatinia BA. A high-performance protocol for extraction of microplastics in fish. Sci Total Environ. 2017; 578:485-494. https://doi.org/10.1016/j.scitotenv.2016.10.213 PMid:27836345.
31. Mariano S, Tacconi S, Fidaleo M, Rossi M, Dini L. Micro and Nanoplastics Identification: Classic methods and innovative detection techniques. Front Toxicol. 2021; 3. https://doi.org/10.3389/ftox.2021.636640 PMid:35295124 PMCid:PMC8915801.
32. Raharinaivo LR, Batigny A, Raquez JM, Mincheva R, Bittencourt C, Maherizo TGF, *et al*. Differentiation

of petro-sourced plastic microfilaments from organic microfilaments by SEM-EDX in environmental samples. Mar Pollut Bull. 2024; 205:116625. https://doi.org/10.1016/j.marpolbul.2024.116625 PMid:38925025.
33. Mahon AM, O'Connell B, Healy MG, O'Connor I, Officer R, Nash R, *et al*. Microplastics in sewage sludge: Effects of treatment. Environ Sci Technol. 2017; 51(2):810-818. https://doi.org/10.1021/acs.est.6b04048 PMid:27936648.
34. Wang W, Wang J. Investigation of microplastics in aquatic environments: An overview of the methods used, from field sampling to laboratory analysis. Trends Analyt Chem. 2018; 108:195-202. https://doi.org/10.1016/j.trac.2018.08.026
35. Tiwari M, Rathod TD, Ajmal PY, Bhangare RC, Sahu SK. Distribution and characterisation of MPs in beach sand from three different Indian coastal environments. Mar Pollut Bull. 2019; 140:62-273. https://doi.org/10.1016/j.marpolbul.2019.01.055 PMid:30803642.
36. Li J, Green C, Reynolds A, Shi H, Rotchell JM. Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. Environ Pollut. 2018; 241:35-44. https://doi.org/10.1016/j.envpol.2018.05.038 PMid:29793106.
37. Gayathri D, Gokula V, Sivasankari M, Ragavi M. Evaluation of microplastic contamination in commercially edible fresh water and marine fishes bought from fish markets, Tiruchirappalli, Tamil Nadu, India. Uttar Pradesh J Zool. 2023; 86-96. https://doi.org/10.56557/upjoz/2023/v44i83486
38. Kumari R. Chronic toxicity of microplastics on fish (*Labeo rohita*) and their impact on the freshwater ecosystem: A case study of Gangasagar pond, Darbhanga, India. Uttar Pradesh J Zool. 2024; 45(10):135-143. https://doi.org/10.56557/upjoz/2024/v45i104057
39. Oza J, Rabari V, Yadav VK, Sahoo DK, Patel A, Trivedi J. A systematic review on microplastic contamination in fishes of Asia: Polymeric risk assessment and future prospectives. Environ Toxicol Chem. 2024; 43(4):671-685. https://doi.org/10.1002/etc.5821 PMid:38353354.
40. Debbarma N, Gurjar UR, Ramteke KK, Shenoy L, Nayak BB, Bhushan S, *et al*. Abundance and characteristics of microplastics in gastrointestinal tracts and gills of croaker fish (*Johnius dussumieri*) from off Mumbai coastal waters of India. Mar Pollut Bull. 2022; 176:113473. https://doi.org/10.1016/j.marpolbul.2022.113473 PMid:35231784.
41. Fan C, Huang YZ, Lin JN, Li J. Microplastic constituent identification from admixtures by Fourier-transform infrared (FTIR) spectroscopy: The use of polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC) and nylon (NY) as the model constituents. Environ Technol Innov. 2021; 23:101798. https://doi.org/10.1016/j.saa.2023.122841 PMid:37269658.
42. Mashirin R, Chitra KC. Assessment of microplastic pollution across the Malabar Coast, India. Environ Qual Manag. 2024; 34(1). https://doi.org/10.1002/tqem.22273
43. Harikrishnan T, Janardhanam M, Sivakumar P, Sivakumar R, Rajamanickam K, Raman T, *et al*. Microplastic contamination in commercial fish species in southern coastal region of India. Chemosphere. 2023; 313:137486. https://doi.org/10.1016/j.chemosphere.2022.137486 PMid:36513204.
44. Ann E, Surya D, Thirunavukkarasu N, Sheeba ACN. Assessment of microplastics in the gastrointestinal tract of the Indian Major Carps from Periyakulam, Kurichi and Singanallur Lakes of Coimbatore, Tamil Nadu, India. Int J Zool Investig. 2022; 08(02):389-396. https://doi.org/10.33745/ijzi.2022.v08i02.048
45. Kumari N, Yadav DK, Yasha, Khan PK, Kumar R. Occurrence of plastics and their characterization in wild caught fish species (*Labeo rohita*, *Wallago attu* and *Mystus tengara*) of River Ganga (India) compared to a commercially cultured species (*L. rohita*). Environ Pollut. 2023; 334:122141. https://doi.org/10.1016/j.envpol.2023.122141 PMid:37419205.
46. Patterson J, Jeyasanta KI, Laju RL, Edward JKP. Microplastic contamination in Indian edible mussels (*Perna* and *Perna viridis*) and their environs. Mar Pollut Bull. 2021; 171:112678. https://doi.org/10.1016/j.marpolbul.2021.112678 PMid:34242958.
47. Hossain MS, Sobhan F, Uddin MN, Sharifuzzaman SM, Chowdhury SR, Sarker S, *et al*. Microplastics in fishes from the Northern Bay of Bengal. Sci Total Environ. 2019; 690:821-830. https://doi.org/10.1016/j.scitotenv.2019.07.065 PMid:31302547.