Occurrence of Microplastics in the Gastrointestinal Tracts of Edible Fishes from South Indian Rivers

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Abstract
Microplastics (MPs) in the gastrointestinal (GI) tracts of the five fish species from the Kollidam and Vellar rivers of Tamil Nadu, Southern India were evaluated. A total of 315 MPs were isolated from GI tracts of 23 fishes (Chanos chanos, Chanda nama, Chelon macrolepis, Carangoides malabaricus and Gerrus filamentosus) sampled from both rivers. MPs ranged from 109 to 129 μm (119 ± 79.7) and 181 to 284 μm (122 ± 92.6) in size, with fibres (85.7%) and fragments (14.3%) being the most common ones in the fishes from Kollidam and Vellar river, respectively. The colour pattern of ingested MPs was dominated by blue, transparent, red, yellow and black in collected fishes from both rivers. In this study, MPs were higher in fishes with omnivore feeding habits due to their broad diet habits. Moreover, urban wastes, fishing and agricultural activities are the possible primary sources of MPs in both rivers.

Keywords Abundance · Fibre · Fragment · Kollidam river · Vellar river

Introduction
Plastic pollution has become a severe threat to the environment around the globe due to mismanagement and poor recycling rates of plastics. India lifted to the 15th position among the plastic polluting country in the list of nations with lower recycling rates in plastic waste treatment (Geyer et al. 2017). Microplastics (MPs) are particles < 5 mm and widespread in all global water bodies. Secondary MPs originated from environmental processes such as photodegradation, thermal stress and tidal actions (de Sá et al. 2018). Fishing practices and terrestrial activities contribute nearly 20% and 80% of MPs, respectively (Cole et al. 2011). MPs enter the rivers and disturb the river, estuarine, and marine ecosystems (Dris et al. 2015). MPs have been found in zooplankton, amphipods, polychaete, echinoderms, crustaceans, fishes, birds and mammals (Desforges et al. 2015; Long et al. 2015; Rummel et al. 2016; Herzke et al. 2016; Hurley et al. 2017; Fossi et al. 2018).

A wide range of organisms is ingesting the MPs, which adversely affects the biology and physiology of organisms. MPs showed detrimental effects on feeding, intestinal tract blockage, false sensation of satiation, reproduction, and energy metabolism in aquatic animals (Cole et al. 2013; Xu et al. 2018; Jiang et al. 2020). Earlier studies reported the accumulation of MPs in marine organisms, including fish and shellfishes (Jonathan et al. 2021; Selvam et al. 2021). Nevertheless, the information on the accumulation of MPs in freshwater organisms is limited, including in India. Hence, the present study aimed to evaluate MPs pollution status (abundance, size, shape, colour, and surface topography) in the Kollidam and Vellar rivers of South India with reference to edible fishes. The selected rivers for the study serve as habitats for the various faunal diversity and livelihood for the local fishermen communities until they end up in the Bay of Bengal. Kollidam and Vellar rivers flow in sub-parallel patterns to each other. Both rivers are geographically located in the Cuddalore district along the southeast coast of Tamil Nadu, India. Kollidam River is the Northern distributary of the Cauvery River splits from Cauvery near Sirangam of Tiruchirappalli district. It flows about 150 km among six significant districts such as Tiruchirappalli,
Tanjore, Ariyalur, Mayiladuthurai, and Cuddalore and ends up in the Bay of Bengal near Sirkali in Nagapattinam district. Vellar river originates in the Chittori hills of the Eastern Ghats in the Salem district of Tamil Nadu at an elevation of 900 m; it has a total length of 210 km and consists of 22 urban parts of eight districts, its watershed covers 2.14 lakh hectares (NWM 2017). It runs through Salem and Cuddalore districts in Tamil Nadu and confluences with the Bay of Bengal near Parangipettai in the Chidambaram district. Urban, fishing, and agricultural activities are the primary sources of MPs in both rivers.

Materials and Methods

Fishes were collected from the Vellar river at Bhuvanagiri, Chidambaram district (11°26′23.00″ to 11°26′27.15″ N, 79°33′53.35″ to 79°33′57.05″ E) and Kollidam river at Kollidam, Mayiladuthurai district (11°19′58.30″ to 11°20′23.19″ N, 79°42′42.82″ to 79°43′07′71″ E) with the help of local fishermen from February to May 2020 (Fig. 1). Both sampled sites are freshwater environments and directly connected with the urbanised zones and regular fishing activities. The collected fishes were anaesthetised, stored in a sterile sample container, and then transported to the laboratory for further process. Fishes were cleaned with de-ionised water to remove the debris and minimise external MPs contamination. The lengths and weights of sampled fish ranged between 11.7 to 27.8 cm and 21.77 to 217.72 g, respectively (Table S1 supplementary material). Collected fishes were identified based on their morphological features using standard manuals and the data obtained from the Fish Base website. Identification keys of length, shape, depth, mouth, distribution, nature of fish spines, and scales were used to identify sampled fishes (Jayaram 1999; Froese and Pauly 2021). Twenty-three fishes were examined for taxonomical classification from Kollidam (n = 13) and Vellar (n = 10) rivers. From these five fishes such as Chanos chanos (n = 5), Chelon macrolepis (n = 9), Chanda nama, (n = 3), Gerrus filamentosus (n = 4), and Carangoides mala- baricus (n = 2) were taxonomically identified.

Each fish’s gastrointestinal tract (GI) was dissected in plastic-free containment and rinsed using ultrapure water to reduce the chances of plastic contamination. Dissected guts were transferred into sterile glass containers for digestion. Digestion of fish guts and extraction of MPs was done using the alkaline digestion method of Karami et al. (2017). Extracted MPs were viewed under the Magnus stereomicroscope with 20–40x magnification and treated with a hot needle test to observe the melting points of the particles to confirm the MPs (de Witte et al. 2014). Particles were imaged using an Ultrascope 9.0v camera, and size was measured with ImageJ software v.1.50i (http://imagej.nih.gov). The morphological characterisation of MPs was done using the distinguishing method criteria like size, shape, and colour (Hidalgo-Ruz et al. 2012; Li et al. 2016). Extracted MPs from both rivers were quantified and picked up using 0.3×0.15 mm tip-sized micro forceps and segregated for surface morphological analysis using a field emission scanning electron microscope (FE-SEM) (FEI Quanta 250 FEG).

For quality control, the sampled fishes were rinsed with filtered de-ionised water, and stainless-steel containers with icepacks were used to transfer the fishes to the laboratory. The laminar chamber stage was cleaned before the dissection of fishes to avoid cross-contamination between each fish. Natural cotton lab coats were used inside the laboratory to maintain quality control. Glassware was rinsed using filtered de-ionised water before the dissection of GI tract samples. Samples were not exposed to any open environmental conditions. The incubator, ultra-probe sonicator, centrifuge, orbital shaker, vacuum filtration unit with pump, laminar airflow, and stereo zoom microscope were cleaned with 90% ethanol and kept sterile before use. Pre-filtered de-ionised water was used to prepare the chemicals for sample processing. Before chemical preparation, the filtered de-ionised water was allowed for MPs examination and confirmed as no evidence for MPs contamination. Moreover, procedural and laboratory environmental blank samples were prepared using the same concentration of chemicals without the GI tract of fish, followed by examining and confirming the absence of MPs. The filters consisting of MPs were only exposed to air during microscopic examination inside the laminar chamber. The data obtained from all the parameters were expressed in mean±SD. Significance variations in properties of MPs were determined by one-way analysis of variance (ANOVA) followed by Duncan’s multiple range test at p<0.05 using SPSS (16.0) software.
Table 1  Abundance and Length of MPs in the GI tracts of fishes collected from the Kollidam and Vellar river

| Site          | Species                  | No. of MPs | MPs/ Indiv. | Length of MPs (µm) | Mean length | Level of Significance<0.05 |
|---------------|--------------------------|------------|-------------|-------------------|-------------|---------------------------|
| Kollidam      | C. chanos                | 50         | 10.0 ± 5.5a | 18.4              | 333.9       | 121 ± 72.6a               | 0.473 |
|               | C. macrolepis            | 39         | 7.8 ± 3.1a  | 11.6              | 273.4       | 109 ± 74.1a               |          |
|               | C. nama                  | 39         | 13 ± 14**   | 32.1              | 267.1       | 129 ± 75**                |          |
|               | ∑                         | 128        |             |                   |             |                           |          |
| Vellar        | C. macrolepis            | 59         | 14.8 ± 5.6a* | 13.0              | 506.2       | 202 ± 97.8b*              | 0.004 |
|               | G. filamentosus          | 91         | 22.8 ± 4.9a* | 19.4              | 377.5       | 284 ± 83.3a*              |          |
|               | C. malabaricus           | 37         | 18.5 ± 7.8b* | 19.6              | 487.6       | 181 ± 95.4b*              |          |
|               | ∑                         | 187        |             |                   |             |                           |          |
| ∑ Kollidam + Vellar |             | 315        |             |                   |             |                           | 0.056 |

Mean values within each site sharing the same alphabetical letter superscripts are not statistically significant at P < 0.05; *denotes the significant difference of MPs between all fish species from both locations (one-way ANOVA and subsequent post hoc multiple comparisons with DMRT)

**Results and Discussion**

In the present study, 315 MPs were isolated from the GI tracts of fishes sampled from both river sites. A total of 128 and 187 MPs were isolated from GI tracts of fishes from the Kollidam and Vellar rivers, respectively. Among fishes from the Kollidam river, the maximum number of MPs were isolated from C. chanos, followed by C. macrolepis and C. nama. In fishes sampled from the Vellar river, a higher abundance of MPs was found in G. filamentosus, followed by C. macrolepis and C. malabaricus (Table 1). The MPs level in fish/individuals did not show any significant (p>0.05) difference in-between the species collected from each sampling location. However, the total number of MPs per individual was significantly (p<0.05) higher in the fishes collected from the Vellar river than that of the Kollidam river, which denotes the higher amount of MPs pollution Vellar compared to the Kollidam river. This might be due to the discharge of MPs from the urbanised areas near the Vellar river basin than the Kollidam river (Table 1). The feeding habits of fishes, trophic levels and the availability of MPs in the ecosystem can affect the ingestion of MPs. In this study, all examined fishes, such as G. filamentosus, C. malabaricus and C. macrolepis, from the Vellar river showed a high level of MPs per individual, suggesting that these species possess omnivore feeding habits that facilitate feeding on wide verities of diet. However, the carnivore fish C. nama from the Kollidam river showed higher MPs per individual than omnivore fishes (C. macrolepis and C. chanos), suggesting that this fish feeding might be associated with MPs ingested prey. Similarly, MPs are in fishes with the same feeding habits, such as Cyprinus carpio, Carassius auratus, Hypophthalmichthys molitrix, Pseudorasbora parva, Megalobrama amblycephala, and Hemiculter bleekeri sampled from Taihu Lake, China has been observed (Jabeen et al. 2017). Also, 10–13 MPs per individual in the fishes such as Catostomus commersonii, Pimephales promelas, Carpoides cyprinus, Notropis stramineus, Notropis hudsonius, Fundulus diaphanus, Micropterus sp., Notropis atherinoides, Neogobius melanostomus, and Cyprinella sipiloptera has been noticed from the major tributaries of Lake Michigan, the USA (McNeish et al. 2018) which is similar to the outcome of the present study.

The mean length of 128 MPs isolated from the fishes C. nama, C. chanos and C. macrolepis from the Kollidam river was recorded from 32.14 to 267.08 µm, 11.60 to 273.38 µm, and 18.40 to 333.91 µm, respectively. MPs in C. macrolepis, G. filamentosus, and C. malabaricus sampled from the Vellar river showed lengths between 13.01 and 506.24 µm, 19.40 to 377.53 µm, and 19.63 to 487.611 µm respectively. The mean length of MPs isolated from fishes of the Kollidam river showed an insignificant (p>0.05) difference compared to each other. The mean length of MPs isolated from fishes of the Kollidam river showed an insignificant (p>0.05) difference compared to other. The mean length of MPs isolated from G. filamentosus showed a significant (p<0.05) increase compared to MPs isolated from other fishes from the Vellar river. However, the mean length of MPs isolated from C. malabaricus showed an insignificant (p>0.05) difference sampled from the Vellar river (Table 1). Moreover, the mean length of MPs was significantly (p<0.05) higher in the fishes collected from the Vellar river than that of the Kollidam river, which indicates the ingestion of an increased range of MPs by fishes in the Vellar river compared to the Kollidam river (Table 1). The high abundance of MPs of different sizes might be caused by indirect and false ingestion of fishes in the Vellar river rather than the Kollidam river. Food selection with suitable sized particle feeding of fishes can cause the difference in MPs ingestion (Cole et al. 2013). Also, the much deviation in the MPs isolated from the GI tract of fishes indicated that the high rate of fragmentation led to ingestion by fishes as false feeding in the sampled environments. Similar to our study, 0.3 to 0.6 mm size MPs have been observed in C. Carpio, Carassius cuvieri, Lepeomis macrochirus, Micropterus salmoides, Silurus asotus, and Channa argus from Han River, South Korea (Park et al.
A South-West Nigerian Eleyele Lake report revealed that the fishes (Coptodon zillii and Oreochromis niloticus) ingested 124 and 126 μm sized MPs (Adeogun et al. 2020). In the present study, the size of MPs is much smaller than in the above-cited previous studies. Moreover, the smaller plastic particles can serve as vectors for carrying metals and organic compounds like polychlorinated biphenyls (PCBs), organochlorines, dioxins, etc., to the organisms (Wang et al. 2020; Hildebrandt et al. 2021).

The morphological distribution of MPs in this study indicated that the fibres were the dominant in the GI tract of fishes sampled from both rivers, constituting nearly 85.71% of the total 315 MPs, followed by fragments with fragments of 14.29%. MPs isolated from fishes belonging to the Kollidam river were categorised as fibres and fragments with 83.59% and 16.41%, respectively. Among the fish species from the Kollidam river, C. chanos had the maximum number of fibres, followed by C. nama and C. macrolepis, whereas the fragments were found in the order of C. macrolepis>C. chanos>C. nama (Fig. 2; Table S2 and Fig. S1-S3 supplementary material). In the Vellar river, the GI tract of G. filamentosus showed a maximum level of fibres, followed by C. malabaricus and C. macrolepis. Meanwhile, the fragments were foremost in the GI tract of C. macrolepis compared to other fishes (Fig. 2; Table S2 and Fig. S4-S6 supplementary material). In the present study, a maximum level of fibres suggests that the mismanaged fishing gears and textile wastes are the primary sources of the MPs invasion in fish guts. Likewise, the alien fish Piaractus brachypomus sampled from Ramsar wetland Vembanad Lake, Kerala, India, accounted for 50% of fibres in their GI tracts (Devi et al. 2020). Similarly, fish Gambusia holbrooki from Melbourne, Australia, in more numbers of fibres than other shaped MPs (Su et al. 2019). Defragmentation of plastic wastes into secondary MPs is the major contributor to plastic litter in the rivers. In the present study, fibre-shaped MPs were predominantly distributed in all sampled fishes.

This might be due to discharges of plastic debris originating from the leftovers and fragmented fishing gears, agricultural and urban discharges to the rivers.

The colour-wise distribution of MPs in fishes guts showed significant differences in their accumulation pattern sampled from Kollidam and Vellar rivers. The blue-coloured MPs, followed by transparent were dominant in the GI tract of fishes sampled from both rivers (Fig. 3; Table S3 and Fig. S1-S6 supplementary material). MPs in the GI tract of fishes sampled from the Kollidam river showed the colours in the order of blue>transparent>red>white>yellow, whereas the river Vellar showed in the order of blue>transparent>red>yellow>white (Fig. 3; Table S3 supplementary material). In this study, blue-coloured MPs were dominant in the GI tract of fishes, these coloured fibres and fragments can be derived from textile wastes and fishing gears (Browne et al. 2008; Li et al. 2016). These particles might be similar to the feeds in aquatic conditions, which led to false feeding by fishes (Ory et al. 2018). The remaining-coloured MPs might be direct false feeding or transferred from other prey. Similarly, the Dicentrarchus labrax, Diplodus vulgaris, and Platichthys flesus from Mondego estuary western coast of Portugal showed dominant blue, transparent and black coloured MPs particles (Bessa et al. 2018). Further, different proportions of colours on ingested MPs from the GI tracts were observed on fish species of O. niloticus and Cirrhinus molitorella from the Rivers of Guangdong province, south China (Sun et al. 2021). MPs’ colour distribution can significantly affect fishes’ ingestion rate due to the difficulty in differentiating the feeds. Moreover, transparent MPs are non-identical in the aquatic systems, blue is used in fishing nets and textile waste, and their different colours and buoyance resemble the planktonic feeds.

The surface morphological characteristics of MPs were carried out with a cluster of MPs picked up from the filter obtained from the extraction step. The complex surface topography of the extracted MPs indicates the linear strings.
due to the heavy accumulation of fibres in the GI tracts of fishes collected from both sites. The surface of the MPs strings was convex, rough non-porous and with many folds (Fig. S7 supplementary material). These strings appeared irregular and had a brittle body with sharp and blunt edges. These damages may be caused by environmental factors like continuous mechanical disturbances caused by water current flow in the river and photo-oxidative weathering of MPs caused by UV radiation (Kalogerakis et al. 2017; Ding et al. 2019). The damage and peeled spots were observed on the MPs strings’ surface (Fig. S7).

**Conclusions**

MPs in the GI tract of fishes sampled from the Vellar and Kollidam rivers indicate MPs pollution in both rivers. Further, the fibre content was higher in the GI tract of fishes sampled from both rivers, suggesting that the mismanaged fishing gears, textiles, and urban waste materials might be the primary source of fibres in the fishes. The overall occurrence of MPs elevated in the fish *C. macrolepis* sampled from the Vellar river compared to the same species from the Kollidam river, indicating a higher MPs pollution in the Vellar river. Therefore, these findings suggest that the MPs were added to fishes’ diets, which may carry them to the next level of the ecosystem’s food chain with potential risks. Moreover, both Kollidam and Vellar rivers end up in the Bay of Bengal and can serve as a carrier of MPs to the marine environment.

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**References**

Adeogun AO, Ibor OR, Khan EA, Chukwuka AV, Omogbemi ED, Arukwe A (2020) Detection and occurrence of microplastics in the stomach of commercial fish species from a municipal water supply lake in southwestern Nigeria. Environ Sci Pollut Res 27:31035–31045. https://doi.org/10.1007/s11356-020-09031-5

Bessa F, Barria P, Neto JM, Frias JGRL, Otero V, Sobral P, Marques JC (2018) Occurrence of microplastics in commercial fish from a natural estuarine environment. Mar Pollut Bull 128:575–584. https://doi.org/10.1016/j.marpolbul.2018.01.044

Browne MA, Dissanayake A, Galloway TS, Lowe DM, Thompson RC (2008) Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis* (L.). Environ Sci Technol 42(13):5026–5031. https://doi.org/10.1021/es800249a

Cole M, Lindeque P, Fileman E, Halsband C, Goodhead R, Moger J, Galloway TS (2013) Microplastic ingestion by zooplankton. Environ Sci Technol 47:6646–6655. https://doi.org/10.1021/es400663f

Cole M, Lindeque P, Halsband C, Galloway TS (2011) Microplastics as contaminants in the marine environment: A review. Mar Pollut Bull 62(12):2588–2597. https://doi.org/10.1016/j.marpolbul.2011.09.025

de Sá LC, Oliveira M, Ribeiro F, Rocha TL, Futter MN (2018) Studies of the effects of microplastics on aquatic organisms: What do we know and where should we focus our efforts in the future? Sci Total Environ 645:1029–1039. https://doi.org/10.1016/j.scitotenv.2018.07.207

De Witte B, Devriese L, Bekert K, Hoffman S, Vandermeersch G, Cooreman K, Robbens J (2014) Quality assessment of the blue mussel (*Mytilus edulis*): Comparison between commercial and wild types. Mar Pollut Bull 85:146–155. https://doi.org/10.1016/j.marpolbul.2014.06.006

Desforges JPW, Galbraith M, Ross PS (2015) Ingestion of Microplastics by Zooplankton in the Northeast Pacific Ocean. Arch Environ Contam Toxicol 69(3):320–330. https://doi.org/10.1007/s00244-015-0172-5

Devi SS, Sreedevi AV, Kumar AB (2020) First report of microplastic ingestion by the alien fish Pirapitinga (*Piaractus brachypomnus*) in the Ramsar site Vembanad Lake, south India. Mar Pollut Bull 160:111637. https://doi.org/10.1016/j.marpolbul.2020.111637

Ding J, Li J, Sun C, Jiang F, Ju P, Qu L, Zheng Y, He C (2019) Detection of microplastics in local marine organisms using a multi-technology system. Anal Methods 11:78–87. https://doi.org/10.1039/c8ay01974f

Dris R, Imhof H, Sanchez W, Gasperi J, Galgani F, Tassin B, Laißofsch C (2015) Beyond the ocean: contamination of freshwater ecosystems with (micro-)plastic particles. Environ Chem 12:539. https://doi.org/10.1071/en141172

Fossi MC, Pedà C, Compa M, Tsangaris C, Alomar C, Claro F, Ioakeimidis C, Galgani F, Hema T, Deudero S, Romeo T (2018) Bioindicators for monitoring marine litter ingestion and its impacts on Mediterranean biodiversity. Environ Pollut 237:1023–1040. https://doi.org/10.1016/j.envpol.2017.11.019

Froese R, Pauly D, Editors (2021) FishBase. World Wide Web electronic publication. www.fishbase.org, version (08/2021)

Geyer R, Jambeck JR, Law KL (2017) Production, use, and fate of all plastics ever made. Sci Adv 3:e1700782. https://doi.org/10.1126/sciadv.1700782

Herzke D, Anker-Nilssen T, Nøst TH, Götsch A, Christensen-Dalsgaard S, Langset M, Fangel K, Koelmans AA (2016) Negligible Impact of Ingested Microplastics on Tissue Concentrations of Persistent Organic Pollutants in Northern Fulmars off Coastal Norway. Environ Sci Technol 50:1924–1933. https://doi.org/10.1021/acs.est.5b04663

Hidalgo-Ruz V, Gutow L, Thompson RC, Thiel M (2012) Microplastics as contaminants in the marine environment: A review of the methods used for identification and quantification. Environ Sci Technol 46:3060–3075. https://doi.org/10.1021/es2031505

Hildebrandt L, Nack FL, Zimmermann T, Pröfrock D (2021) Microplastics as a Trojan horse for trace metals. J Hazard Mater Lett 2:100035. https://doi.org/10.1016/j.hazl.2021.100035

Jabeen K, Su L, Li J, Yang D, Tong C, Mu J, Shi H (2017) Microplastics in aquatic animals and their adverse effects in China. Environ Pollut 221:141–149. https://doi.org/10.1016/j.envpol.2016.11.055

Jayaram KC (1999) The freshwater fishes of the Indian Region, vol –6. Narendra Publishing House, Delhi, p 551

Jiang X, Chang Y, Zhang T, Qiao Y, Klobučar G, Li M (2020) Toxicological effects of polystyrene microplastics on earthworm (*Eisenia fetida*). Environ Pollut 259:113896. https://doi.org/10.1016/j.envpol.2019.113896

Jonathan MP, Sujitha SB, Rodriguez-Gonzalez F, Villegas LE, Hernández-Camacho CJ, Sarkar SK (2021) Evidences of microplastics in diverse fish species off the Western Coast of Pacific
Park TJ, Lee SH, Lee MS, Lee JK, Lee SH, Zoh KD (2020) Occurrence of microplastics in the Han River and riverine fish in South Korea. Sci Total Environ 708:134535. https://doi.org/10.1016/j.scitotenv.2019.134535

Rummel CD, Löder MG, Fricke NF, Lang T, Griebeler EM, Janke M, Gerdts G (2016) Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea. Mar Pollut Bull 102:134–141. https://doi.org/10.1016/j.marpolbul.2015.11.043

Selvam S, Manisha A, Roy PD, Venkatramanan S, Chung SY, Muthukumar P, Jesuraja K, Elgorban AM, Ahmed B, Elzain HE (2021) Microplastics and trace metals in fish species of the Gulf of Mannar (Indian Ocean) and evaluation of human health. Environ Pollut 291:118089. https://doi.org/10.1016/j.envpol.2021.118089

Su L, Nan B, Hassell KL, Craig NJ, Pettigrove V (2019) Microplastics biomonitoring in Australian urban wetlands using a common noxious fish (Gambusia holbrooki). Chemosphere 228:65–74. https://doi.org/10.1016/j.chemosphere.2019.04.114

Sun D, Wang J, Xie S, Tang H, Zhang C, Xu G, Zou J, Zhou A (2021) Characterisation and spatial distribution of microplastics in two wild captured economic freshwater fish from north and west rivers of Guangdong province. Ecotoxicol Environ Saf 207:111555. https://doi.org/10.1016/j.ecoenv.2020.111555

Wang W, Ge J, Yu X (2020) Bioavailability and toxicity of microplastics to fish species: a review. Ecotoxicol Environ Saf 189:109913. https://doi.org/10.1016/j.ecoenv.2019.109913

Xu B, Liu F, Brookes PC, Xu J (2018) Microplastics play a minor role in tetracycline sorption in dissolved organic matter. Environ Pollut 240:87–94. https://doi.org/10.1016/j.envpol.2018.04.113

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