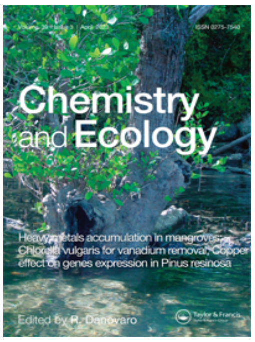

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School of Environmental Studies, Cochin University of Science and Technology, Ernakulam, India

ABSTRACT
The investigation focused on identification and quantification of microplastics in surface waters of Chalakudy River, Kerala. Microplastics were detected in the surface waters of the study area with a recovery rate of 108.33 mg particles L^{-1}. The abundance of microplastics ranged from $15.13 \pm 4.13 - 170 \pm 17.75$ particles L^{-1} (mean: 55.81 ± 34 particles L^{-1}). A maximum number of microplastics were obtained from site C_3 and the least from site C_8. The weight distribution of microplastic on sites exhibited strong positive correlation with the abundance ($r =$ 0.83). Microplastics of size <20 µm were in higher abundance in the study area. Microscopic examination revealed fragments (47.06%) as predominant plastics and the dominant colour was brown/mud (26.99%). Abundance of coloured plastics indicated the probability of damage to aquatic life. Raman spectrum analysis revealed that Low-Density Poly Ethylene (40%) as the predominant polymer that could be observed at all the sampling sites. Lower-sized microplastics would cause accidental ingestion by organisms. The estimated release of a higher average number of microplastic particles (55.81 ± 4.25) into the marine environment is of serious concern. The observed overall abundance and recovery rate of microplastics in the study area indicated the status of contamination due to a multitude of sources.

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KEYWORDS
Microplastics; plastic fragments; surface water; Chalakudy river

Introduction

Discussions on the pollution due to plastic garbage were initiated just after the plastic industrial booms; whereas the report on micro-litter was published in the late 90s [1]. The term microplastics have been attributed to plastics with particle diameters <5 mm [2]. It possesses various shapes from completely spherical to elongated fibres [3]. Based on their source of production, the microplastics were classified into (i) primary and (ii) secondary microplastics. Primary microplastics are small particles that are made intentionally as a precursor for more plastic products and the secondary microplastics originate due to fragmentation of larger plastic products [3–5]. According to the study reports, it is clear that our aquatic systems carry plenty of plastics. Unscientific and untreated disposal of

CONTACT S. K. Maneesh Kumar maneesh307@cusat.ac.in School of Environmental Studies, Cochin University of Science and Technology, Ernakulam 682022, Kerala, India
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plastic wastes into the water stream is the major source of pollution due to microplastics in the aquatic environment [6]. Urban expansion and industrialisation abetted the generation of plastic wastes on land and eventually came to the river systems. The wastewater treatment plants also contribute to the microplastic load in the riverine systems. An efficient wastewater treatment plant can retain microplastics from effluent [7]; however, the inadequacy and the lack of proper monitoring systems result in the release of microplastic through industrial discharges. Accumulated microplastics in the rivers will be the key source of marine microplastics [8, 9]. The presence of microplastics in the water and sediment will lead to accidental entanglement by the aquatic organisms. The presence of microplastics causes stress due to the leakages of additives or the associated pollutants [10, 11] and also leads to bioaccumulation or biomagnification of compounds such as polycyclic aromatic hydrocarbons that are carcinogens or endocrinogens [12].

Chalakudy River is the fifth lengthiest river of Kerala which flows through Thrissur, Palakkad and ends up in Ernakulam district. The local people are very much dependent on the river for various purposes like drinking, bathing, washing, recreational activities, local fishing and also famous for natural water tourism. Kerala Water Authority has been taking the water for drinking water plants located in specific zones of the river. Literature survey revealed a few investigations available on the physicochemical characteristics of the Chalakudy River. Human interference through agriculture, urbanisation, and industrialisation induced an alteration of hydro-chemical parameters [13]. The nutrient mobility study reported that the phosphorous loading capacity was different in various parts of the river due to geographical aspects and anthropogenic activities [14]. A water quality study in the Chalakudy River revealed that industries contribute a higher load of pollution to the river manifested by lower DO levels and higher phosphate content as well as hardness [15]. Microbiological examination of the Chalakudy River recorded a high concentration of coliform bacteria [16]. Significant alterations have been observed in the Chalakudy River especially the river flow pattern and the region underwent tremendous environmental changes as a result of changes in land use pattern, agricultural expansion, deforestation, increased urbanisation, etc. [17]. All the investigations pointed out the deterioration in the environmental quality of the river system. Data on the distribution/identification of microplastics in the study area have not been available to date. Hence the investigation aims to identify and quantify the microplastic distribution and evaluate the contamination status of the surface waters of river Chalakudy.

Materials and methods

Study area

Chalakudy River is the fifth-longest river in Kerala with a total drainage area of 1704 km^2, shared by Kerala (1404 km^2), and Tamil Nadu (300 km^2) [18]. The length of the mainstream is 145 km. Anamalai hills of Western Ghats have been regarded as the origin of the Chalakudy River with its four main tributaries including Parambikulam, Kuriarkutti, Sholayar, Karappara and Anakayam. In Kerala, it flows westward through Palakkad, Thrissur, and Ernakulam districts [19]. According to ENVIS Centre, Kerala the river receives an average annual rainfall of 3600 mm and an annual stream flow of 169.3 mm^3. The river is ideal for its flora and fauna diversity. It has been considered one of the richest river systems in the region concerning freshwater fish diversity [20] along with the relics of thick riparian vegetation. As far as the species richness is considered, the Cyprinids were the top family, followed by Bagrid catfishes and hill stream loaches [20]. Among others, Horabagrus nigricollaris and Sahyadria chalakkudiensis are endemic to the Chalakudy River [21]. Chalakudy riverine ecosystem is under the threat of anthropogenic stress on account of demographic pressure and urbanisation. The effluents from household, municipal sources and industrial operations are discharged directly into the river without proper treatment. The river has lost its pristine flow and got polluted after the Kerala flood of 2018–2019 [22]. Most of the livelihood depends on the river for farming, agriculture, fishing, tourism, etc., also small to large-scale industries are situated very near the river catchment area. All these processes add to the probability of high microplastic contamination in this river system. Hence microplastic monitoring in the Chalakudy River is of utmost importance in the current scenario.

Sample collection and microplastic isolation

Surface water samples (0–5 cm depth) from eight sites of Chalakudy River (Figure 1, Table 1) during the pre-monsoon season were collected with aid of steel buckets. The samples were carefully subsampled to steel cans to prevent cross-contamination. The sites were selected based on geographical features and anthropogenic influences such as tourist spots, human settlements, agriculture, and urbanisation (Figure 2). After the collection, samples were brought to the laboratory and processed without delay. The laboratory and the working platforms were previously cleaned and used non-plastic materials (lab coat, spoon, trays, etc.) to avoid microplastic contamination from other sources.

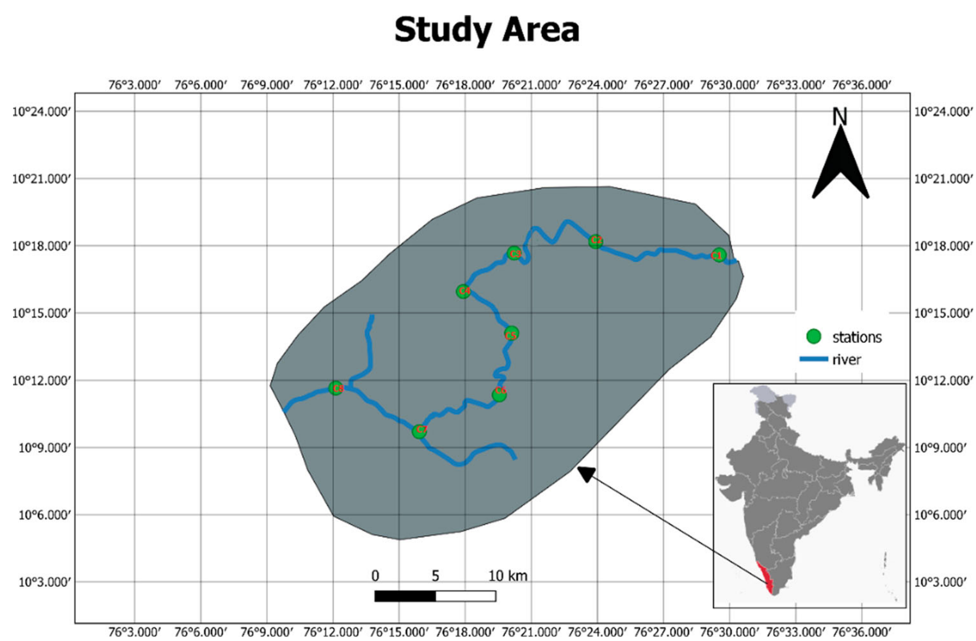

Figure 1. Geographical location of sampling sites in Chalakudy River.

Table 1. Sampling locations and geographical co-ordinates.

Sl No.	Site codes	Site names	Latitude	Longitude
1	C_1	Athirapilly	10^{0}17′33.24″ N	76^{0}29′32.43″ E
2	C_2	Pump House	10^{0}18′10.31″ N	76^{0}23′53.62″ E
3	C_3	Chalakudy temple	10^{0}17′40.01″ N	76^{0}20′12.93″ E
4	C_4	Ashtamichira	10^{0}15′53.28″ N	76^{0}17′54.37″ E
5	C_5	Moozhikulam Bridge	10^{0}11′20.03″ N	76^{0}19′32.17″ E
6	C_6	Annammanada	10^{0}14′05.80″ N	76^{0}20′05.70″ E
7	C_7	Choukakadavu	10^{0}09′41.75″ N	76^{0}15′54.02″ E
8	C_8	Moothakunnam Bridge	10^{0}11′36.92″ N	76^{0}12′04.77″ E

Samples collected from respective sites were sieved through a vacuum filtration unit with the aid of Whatman (GF/B) filter paper of 1 µm size. Using deionised water and a clean Nickel spatula the residue in the filter paper was transferred into a clean and dry 500 mL glass beaker. The beaker was covered with aluminium foil and kept in an oven at 60°C until the residue become completely dried. To extract microplastic from the dried residue, we followed the National Oceanic and Atmospheric Administration (NOAA) protocol [23] along with the American Society of Limnology and Oceanography Methods [24]. To digest organic matter, the dried solids were subjected to the wet peroxide oxidation (WPO) method. About 20 mL of 0.05M Fe (II) solution followed by hydrogen peroxide (30%) solution was added to the sample and heated to the mixture at 60°C. The WPO mixture is subjected to density separation using salt $ZnCl_2$ to separate microplastic particles through floatation. The mixture was then placed in a density separator and kept overnight. The supernatant was filtered using Whatman (GF/B) filter paper. The filter paper was kept in pre-cleaned Petri plates and allowed to dry for 24 h.

Microplastic identification

After estimation procedure, the dried filter paper was focused under Light microscope (Optika Lite 2.0 Microscope, Italy) at 10X magnification. The particles were counted and

Figure 2. Representative images of sampling sites.

classified based on shape, colour, and size [25–27]. The length of the particle was measured using IMAGE-J software. Identification of the polymers was done using Raman spectroscopy (WITee, Alpha 300RA, Germany) with a 50X objective having an integration time of 10 s. Microplastic weight was assessed by the standard gravimetrical method [23]. Descriptive statistics were employed to estimate mean, median, average, and spatial variability (ANOVA) using Microsoft Excel (2013).

Results and discussion

Abundance of microplastics

River water samples were analysed multiple times and microplastics (MPs) were detected from all the eight sites. Among the sites, about 1786 particles were recovered from a total of 32 L of water (Table 2, Figure 3). The microplastic abundance ranged from 15.13 ± 4.13 to 170 ± 17.75 particles L^{-1} of water with a mean abundance of 55.81 ± 34 particles L^{-1}. Microplastic abundance exhibited significant spatial variation ($P < 0.05$) and displayed similarity with published data [28]. The investigators recorded abundance from three rivers (Akerselva, Hobølelva, and Gryta) of Norway; reported 138 particles m^{-3}, 140 particles m^{-3}, and 1067 particles m^{-3} respectively. Observation revealed that site C_3 exhibiting a high value for the number of particles and C_8 with the lowest value (Figure 3). About 170 particles were obtained from C_3 with a standard deviation of 17.75 particles L^{-1} of water and C_8 recovered only 15.13 particles with a standard deviation of 4.13 particles L^{-1}. The concentration of the microplastics depends on the characteristics of various plastic materials and the environmental condition prevailing around the water bodies [29, 30]. The site C_3 is located very close to the national Highway over bridge, a temple, and also many houses, apartments, and small-scale industries situate on the banks of the river near this site. The river width is more at this location and the flow of water is comparatively less in this area. Our results were in close agreement with a

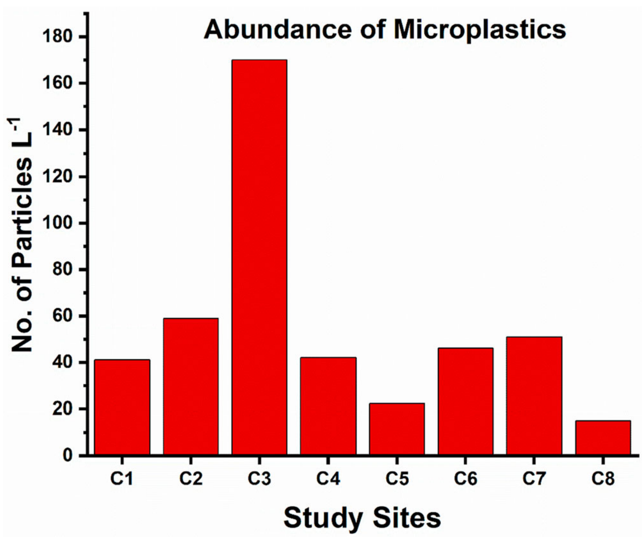

Figure 3. Spatial distribution of microplastics in the study area.

Table 2. Distribution of microplastics at different sites.

Sites	Black	Blue	Red	Transparent	Brown	Green	Yellow	White	Total	Sites	Mean	Particle L^{-1}
C_{1a}	34	0	7	46	39	38	6	1	171	C_1	164.5	41.13 ± 1.63
C_{1b}	51	2	4	28	55	17	1	0	158			
C_{2a}	65	2	7	69	64	44	0	0	251	C_2	235.5	58.88 ± 3.88
C_{2b}	43	11	0	41	82	38	4	1	220			
C_{3a}	207	177	60	88	189	30	0	0	751	C_3	680	170 ± 17.75
C_{3b}	160	141	31	57	171	48	1	0	609			
C_{4a}	53	0	4	27	34	49	0	6	173	C_4	168	42 ± 1.25
C_{4b}	32	7	0	41	53	28	1	1	163			
C_{5a}	6	7	3	34	15	28	2	0	95	C_5	89	22.25 ± 1.5
C_{5b}	19	11	1	21	15	16	0	0	83			
C_{6a}	47	1	3	34	34	52	4	3	178	C_6	184.5	46.13 ± 1.63
C_{6b}	78	9	0	23	47	32	2	0	191			
C_{7a}	54	1	1	75	63	19	0	0	213	C_7	204	51 ± 2.25
C_{7b}	39	7	2	53	89	5	0	0	195			
C_{8a}	9	0	1	23	2	9	0	0	44	C_8	60.5	15.13 ± 4.13
C_{8b}	16	11	4	31	12	2	1	0	77			

similar investigation [31]; where the authors recorded maximum abundance at a site located near a huge populated area and having small-scale industries. It has already been reported that the geographical features of the study area and the population density are also reasons for the high microplastic concentration [32]. C_2 was noticed to be the site with the second highest abundance (Figure 3), which is located at the Thaytupara check dam followed by C_7, situated at Choukakadavu (inter junction of Chalakudy and Periyar Rivers). The higher level of microplastics observed may be due to the slow pace of the river flow. Meanwhile, the lower abundance was observed at sites having comparatively higher flow rate.

Danube (Europe's second largest river), can release an average amount of 316.8 ± 4664.6 items per 1000 m^3 into the Black Sea, which results in a mass load of 4.8 ± 24.2 g per 1000 m^3 [33]. A similar observation suggests that the Italian Po River has been transporting about 120 tonnes of plastic litter per year to the Mediterranean Sea [34]. The present investigation estimated an average of 55.81 ± 4.25 particles L^{-1} of water (Table 2) being released into the marine environment from the Chalakudy River itself.

Weight of microplastics

The weight of microplastics was determined by using gravimetrical analysis (Table 3, Figure 4). Around 108.33 mg weight was observed from all the sites in which site C_3 resulted in a high weight (23.425 mg L^{-1}) and site C_8 has the lowest value (4.65 mg L^{-1}). The findings revealed that Chalakudy River carry ≈13.54 mg of microplastics L^{-1} of water ultimately releasing to marine environment. The result of the study is comparable with already published data [35], according to which about 0.22 g of plastic fragments per dry weight were determined from the Ottawa river, Canada. Published data revealed 0.34–0.64 g plastic fragments per dry weight of sample recorded in rivers Elbe, Mosel, Neckar, and Rhine, Germany [36]. The weight distribution strongly correlated with microplastic abundance (Pearson's correlation: $r = 0.83$; Figure 5). Since C_3 exhibited the maximum number of microplastic particles, the maximum weight was also recorded at C_3 accordingly. Meanwhile, the minimum weight was noticed at site C_8 due to the lower observed particles count.

Classification of microplastics based on size

Microplastic particles in the surface water were classified into five ranges: <20 μm; 20–60 μm; 60–100 μm; 100–500 μm; and >500 μm (Table 4). The major portion of total

Table 3. Weight distribution of microplastics in different sites.

Sites	Weight of MPs L^{-1} (mg)
C_1	9.95
C_2	18.15
C_3	23.425
C_4	12.525
C_5	7.45
C_6	14.4
C_7	17.775
C_8	4.65

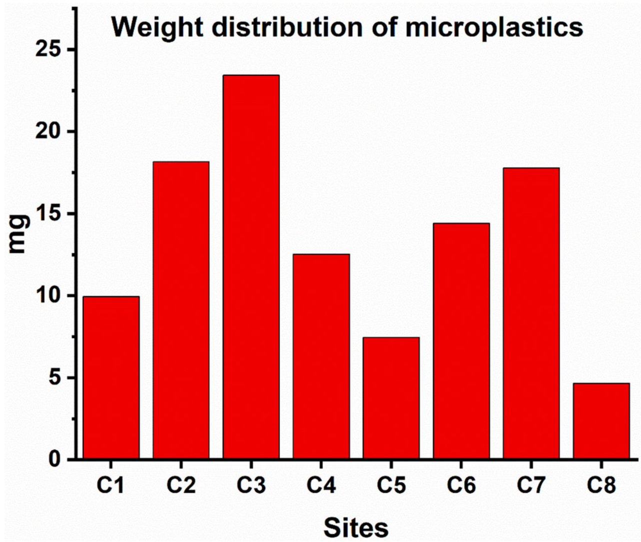

Figure 4. Microplastic weight distribution in different study sites.

microplastics was under the 20–60 µm range (39.19%) followed by <20 µm (29.37%), 60–100 µm (16.63%), 100−500 µm (11.51%), and >500 µm has the lowest concentration (3.30%). Assessment of size distribution showed that the smaller-sized particles were high in river Chalakudy (Figure 6) which exhibited significant spatial variations ($P < 0.05$). The size of microplastic is reduced due to the flow of water by the forces shearing on plastics of larger size. When the size of the particle is small in water, it would be difficult to remove them through wastewater treatment and can cause ingestion by aquatic organisms [37, 38]. Aquatic organisms like fishes and bivalves can get exposed

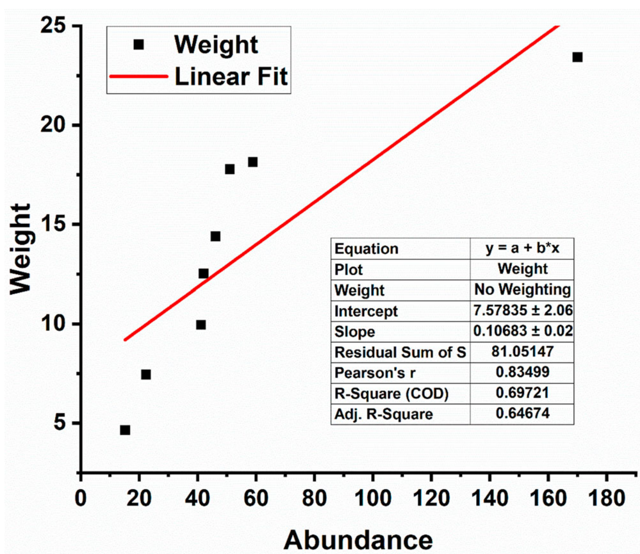

Figure 5. Correlation of microplastic abundance versus weight distribution.

Table 4. Size distribution of microplastics at different sites.

Sites	<20 µm	20–60 µm	60–100 µm	100–500 µm	>500 µm
C_1	38	78.5	19	28.5	0.5
C_2	73	68.5	33.5	46.5	14
C_3	194	241.5	149	81	14.5
C_4	46.5	73	24	13.5	11
C_5	32.5	37	12.5	5.5	1.5
C_6	50.5	83	25	16	10
C_7	71	94.5	21	10.5	7
C_8	19	24	13	4	0.5

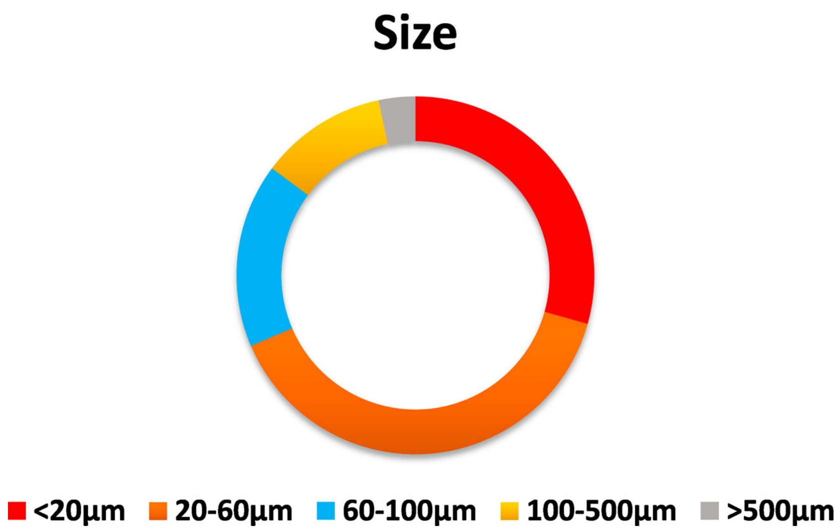

Figure 6. Classification based on the size of microplastics in the study area.

to these particles present in the water column because of their feeding strategies [37]. The toxic effect of MPs in freshwater systems is not well understood, although it has been estimated that between 32% and 100% of freshwater invertebrate organisms ingest MPs [39]. Studies on freshwater invertebrate species confirmed the fact that ingestion of MPs can occur [24]. Plastics with a size range >500 µm were considered micro pellets which were in higher abundance at sites C_2 and C_3. Site C_2 is located at the Thaytupara check dam which is very near the water pumping site. There is a canal/thodu which flows near the Water Theme Parks and houses and opens to site C_2. Site C_3 is located near the national Highway over the bridge. Larger-sized MPs cause negative impacts on ecosystems such as blocking light penetration and subsequent decline in photosynthesis, but smaller particles destroy the algal cell wall by surface adsorption [40].

Classification based on the shape of microplastics

Microplastics were classified based on shape into fragments, fibres/lines, foams, pellets, and films. The result revealed that about 47.06% are fragmented, following film (39.50%), and the other shapes of particles were very less in concentration (Table 5).

Table 5. Classification of microplastics based on its shapes.

Sites	Foam	Fragments	Fibres/line	Pellet	Film
C_1	1	80.5	4	18	61
C_2	3.5	126	3.5	29	73.5
C_3	11	322.5	14	49.5	283
C_4	0.5	86.5	10	20	51
C_5	0.5	41.5	2	4.5	40.5
C_6	0.5	65.5	7	18	93.5
C_7	2.5	83.5	5	24.5	88.5
C_8	0.5	34.5	2.5	8.5	14.5

The study observed that 9.63% pellets, 2.69% fibres/lines, and foams were the least group around 1.12%. The present study recorded a high concentration of fragment particles at C_3 (Figure 7). The fragments, pellets, and film displayed spatial variation ($P < 0.05$); whereas foam and fibre did not display any spatial variation. Fragmented microplastics are formed from the degradation of large plastic fragments like beverage bottles, jars, fast food packages, and rice packs. The fragments were irregularly shaped and may be degraded from higher plastic forms through UV radiation or photo-oxidation. The dominance of fragments was recorded in the present investigation which was in good agreement with similar studies [26, 41–43]. About 34 MPs fragments were isolated from the Pasig River (Philippines) of which 28 fragments were categorised as smaller groups [41]; indicating advanced degradation and longer persistence of plastics. The size of fragments is enough that, they may be fed by small to large organisms [44]. This irregularly shaped microplastic may be ingested by small aquatic organisms like filter feeders and the internal organs of these organisms may get injured [45]. A few investigations evaluated the effect of irregular shapes of microplastics in organ wise distribution and swimming behaviours in sheepshead minnow; pointed out the accumulation of microplastics in the digestive system resulting in intestinal distention [46]. Fibres were mostly recorded at C_3; the sources of fibres are the fragmentation of fishing nets and

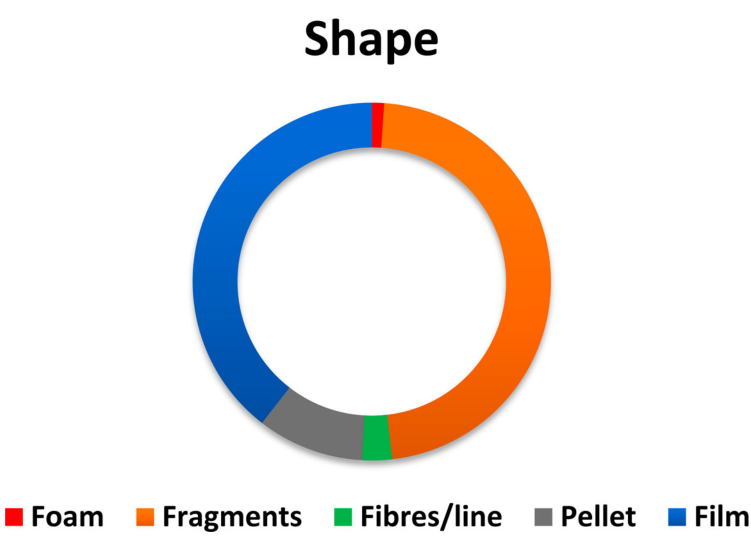

Figure 7. Classification based on the shape of microplastics in the study area.

Table 6. Classification of microplastics based on colour.

Sites	Black	Blue	Red	Transparent	Brown	Green	Yellow	White
C_1	42.5	1	5.5	37	47	27.5	3.5	0.5
C_2	54	6.5	3.5	55	73	41	2	0.5
C_3	183.5	159	45.5	72.5	180	39	0.5	0
C_4	42.5	3.5	2	34	43.5	38.5	0.5	3.5
C_5	12.5	9	2	27.5	15	22	1	0
C_6	62.5	5	1.5	28.5	40.5	42	3	1.5
C_7	46.5	4	1.5	64	76	12	0	0
C_8	12.5	5.5	2.5	27	7	5.5	0.5	0

rope and synthetic textiles. Washing clothes and fishing are common in majority of sites. These microfibers have a high subsurface-to-volume ratio which causes the absorption and retention of a wide range of environmental pollutants, increasing the risk of bioavailability [47,48]. Negative impacts of microplastics on fish arise due to accidental ingestion [49]. Biofouling enhances the probability of ingestion of microplastics as a food material [50] and reaches the human digestive system through the consumption of fish.

Classification based on colour

Samples were categorised into different colour groups which were observed using a Stereomicroscope. From the microscopic examination, mainly eight different colour groups (Table 6) were observed viz., red, blue, black, colourless, brown/mud colour, white, yellow, and green. Among these, brown (26.99%) and black (25.56%) were dominant coloured microplastics followed by transparent (19.98%), green (12.73%), blue (10.83%), and red (3.58%) (Figure 8). Yellow and white were detected in negligible amounts of 0.62%, and 0.33% respectively. One-way ANOVA revealed significant spatial variations for black, brown, transparent, green, yellow, and white coloured microplastics

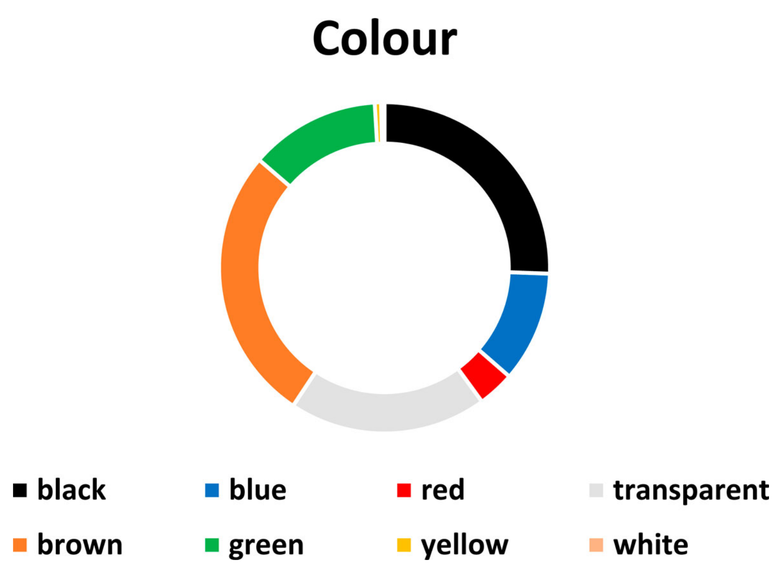

Figure 8. Classification based on colours observed in various sites.

($P < 0.05$); whereas blue and red colours did not display any significant spatial variations. The colour of these particles is based on the parent material or it may change during the degradation process. Coloured microplastics have been reported to be harmful to marine organisms since ingestion followed by trophic transfer is prominent [51, 52]. In the present study, coloured particles were higher and can cause damage to the aquatic environment. The abundance of coloured plastics in the river indicated the potential damage it may impose on aquatic life. The fibres with blue, red, green, and transparent colours were observed under the microscope. Unnatural colours and/or shininess were used as indicators of potential microplastics [53]. Microplastics of brown, red, orange, green, blue, violet and grey colours have been isolated from the Pasig River (Philippines) [41]. Similarly, other studies also recorded a high concentration of black-coloured particles [54, 55]. Meanwhile, this study recorded the dominance of brown/mud and black coloured microplastics. The mud-coloured microplastics may be swallowed by the sediment feeder fishes when they sink to the bottom. Similar investigations noticed the occurrence of microplastics in the digestive system of planktivorous fish [56], recording irregularly shaped particles in blue and transparent. Moreover the current state of knowledge on microplastic pollution suggested that the most frequently observed colours of microplastics in biota were blue and transparent [57]. In this study, the transparent colour recorded was about 19% and blue was 10%. Assessment of coloured microplastics helps to understand the bioaccumulation of these particles from the water column to aquatic biota.

Polymer identification

Polymer compounds of microplastic were determined by using Raman spectroscopy. Samples were subjected to the Raman spectrum analysis in which all eight samples exhibited the presence of plastic polymer compounds. Plastic polymers like HDPE, LDPE, PP, PVC, PA, PMMA, PET and other polymers were detected during the examination (Figure 9). Among the 8 sites, LDPE was obtained as the dominant polymer compound followed by HDPE, PA, PP, PVC, and PMMA in respective decreasing order (Figure 10). Among the results of PVC obtained from sites C_2 and C_5, PMMA particles were detected only at site C_5. Low-density polyethylene (LDPE) was recorded at all the sites, which constitute about 40% of total polymers and exhibited a range of 21.05–65% of total polymers (Table 7). The study identified different polymers and the result exhibited a maximum concentration of polyethylene. Polyethylene is a plastic-type ported in several investigations [24, 28, 30, 31, 42, 58, 59] which mainly originated from the fragmentation of rigid particles like squeeze bottles, carpets, etc., and also from packaging materials. The second highest type of plastic observed in this study was HDPE (16.06%), which has been used to make rigid plastics like milky jugs, household cleaner containers, juice bottles, etc. PA was the next category of plastic (13.25%), which has been used in textile materials like clothing and carpets. PP was also detected in the study area (12.5%), which is used to make fishing nets, floor coverings, ketchup and medicine bottles, etc., [58]. In the Chalakudy River, fishing is a source of income for people inhabiting nearby areas; the fishermen's community use cage culturing in some parts of the river. The cage for fish culture is usually created using polypropylene nets and allied plastic materials. In our study, 2.09% PVC and 1.20% PMMA were also detected from the sampling sites. PVC may be originated

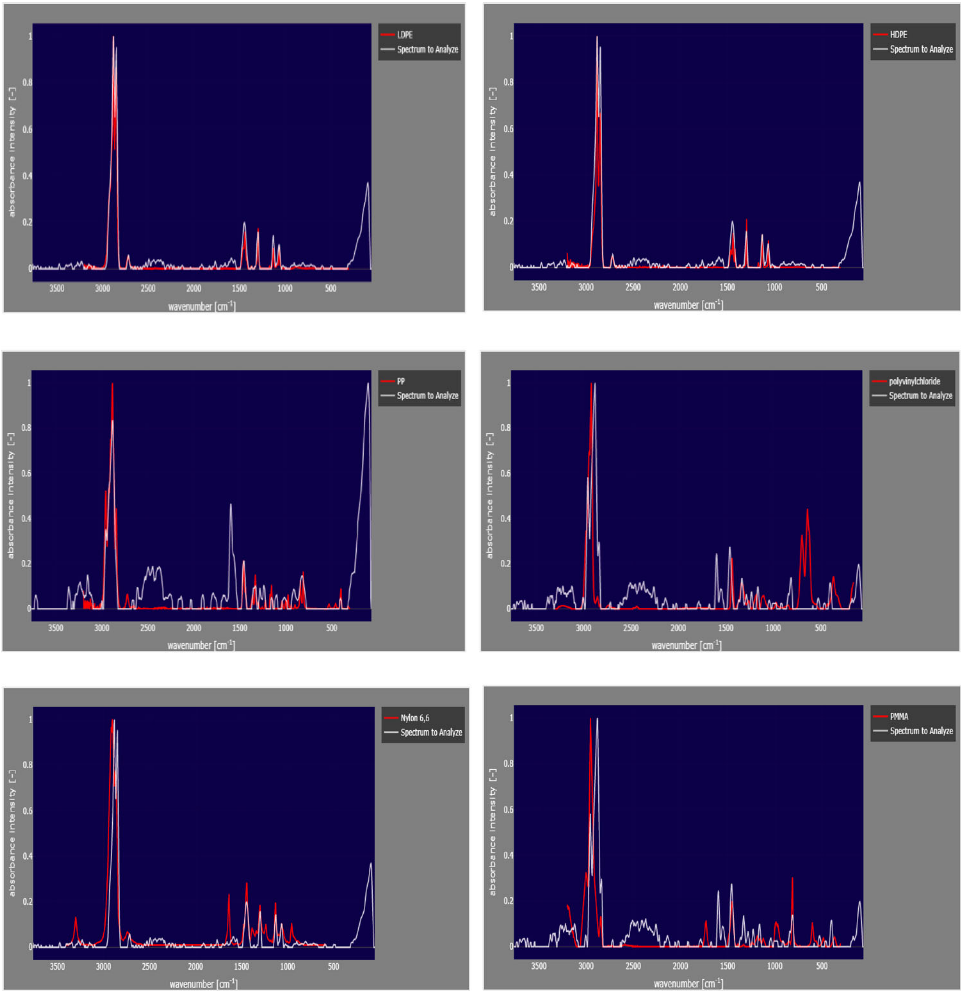

Figure 9. Different polymer groups identified: Low-Density Poly Ethylene (LDPE), High-Density Poly Ethylene (HDPE), Poly Propylene (PP), Poly Vinyl Chloride (PVC), and Polymethyl Methacrylate (PMMA).

from the fragmentation of pipes, cooking oil bottles, etc. The PMMA is the transparent and rigid plastic type which mainly used to substitute glass products.

Comparing the obtained results with already published data (Table 8), revealed similarities as well as differences. Microplastics obtained from the Goulburn River (Australia) were in the range of 0.40 ± 0.27 items L^{-1} [60]; with polymer types viz., PA, PP, PE, PES, and Rayon. About 0.48 – 21.52 items L^{-1} were recovered from the Yangtze River Delta in China, where the prominent types identified were PES, PP, PE, and PS [31]. A study on freshwater ponds reported 3.52 – 32.05 particles m^{-3} [61]. Meanwhile, water samples from Rize province, Turkey reported microplastic abundance of 1 – 13 items L^{-1}; PES, PET, PP and PMMA were the polymers obtained [42]. Content of MPs in Tamsui River (Taiwan) and its different tributaries displayed MPs in the range of 10.1 ± 5.1 – 70.5 ± 30.6 particles m^{-3} [43]. Similarly, in a recent study from three Norwegian

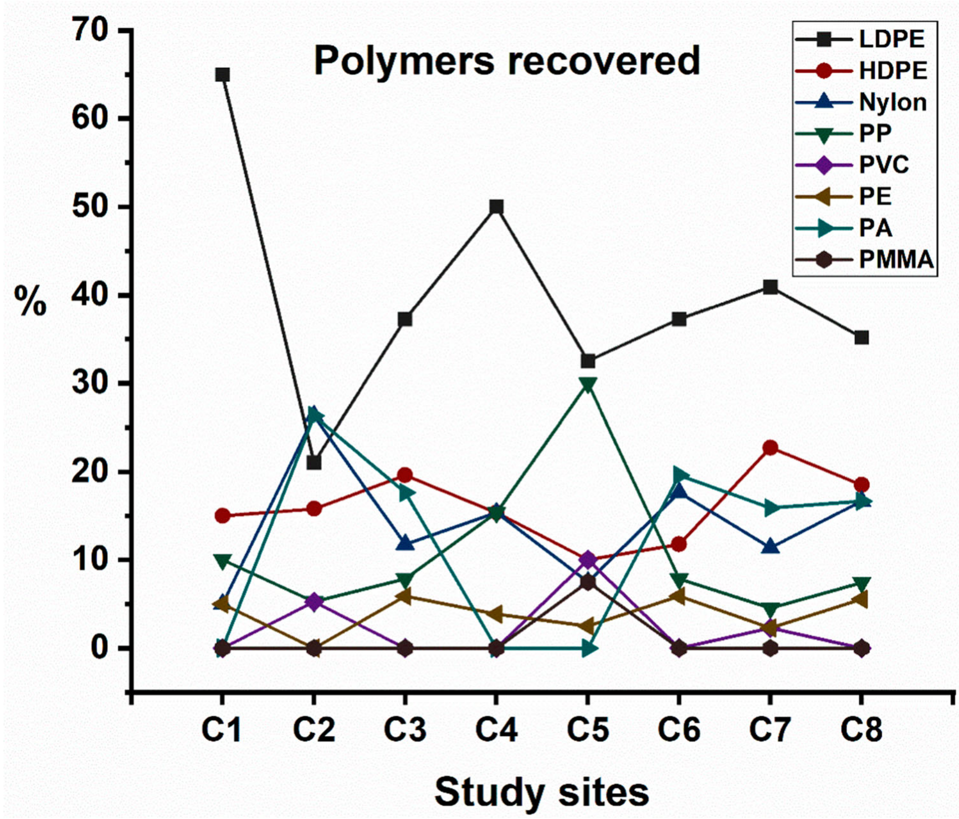

Figure 10. Polymer compounds recovered in different study sites.

rivers recovered about 2.8 ± 1.2 – 64.4 ± 76.2 MPs particles m^{-3} were from water samples of Keelung River, 6.7 ± 2.4 – 83.7 ± 70.8 MPs m^{-3} from Dahan River and 2.5 ± 1.8 – 11.7 ± 5.8 MP particles m^{-3} from Xindian River [43]. Likewise, the average abundance of MPs from another three rivers of Norway (Hobol, Gryta, Akerselva) followed the trend: 138 particles m^{-3}, 140 particles m^{-3}, and 1067 particles m^{-3} respectively [28]; in good agreement with our results and the obtained polymer compounds include LDPE, HDPE, PP, PVC, PA and PET. Cross-examination of the data with respect to microplastic abundance clarify that Chalakudy river has been much more contaminated than the Goulburn River (Australia), Yangtze River (China), Rize province (Turkey), Keelung River, Dahan River, Xindian River; but lower contamination compared

Table 7. Percentage of polymers recovered from various study sites

Study Sites	LDPE (%)	HDPE (%)	Nylon (%)	PP (%)	PVC (%)	PE (%)	PA (%)	PMMA (%)
C_1	65	15	5	10	0	5	0	0
C_2	21.05	15.79	26.32	5.26	5.26	0	26.32	0
C_3	37.25	19.61	11.76	7.84	0	5.88	17.65	0
C_4	50	15.38	15.38	15.38	0	3.85	0	0
C_5	32.5	10	7.5	30	10	2.5	0	7.5
C_6	37.25	11.76	17.65	7.84	0	5.88	19.61	0
C_7	40.91	22.73	11.36	4.55	2.27	2.27	15.91	0
C_8	35.18	18.52	16.67	7.41	0	5.55	16.67	0

Table 8. Average/range of microplastic abundance reported from the different aquatic environments.

Sl No.	Location	Range/average of microplastic abundance	Sample type	Polymer type	References
1	Greater Melbourne Area, Goulburn River (Australia)	0.40 ± 0.27 items L^{-1}	Water	PA, PP, PE, PES, Rayon	[60]
2	Yangtze River Delta, China	0.48 – 21.52 items L^{-1}	Water	PES,PP, PE, PS	[31]
3	Yangtze River Delta, China	35.76 – 3185 items/kg	Sediment	PES,PP, PE, PS	[31]
4	Hungarian freshwater (ponds)	3.52 – 32.05 particles m^{-3}	Water	PP,PE,PTFE, PS, PAC, PES	[61]
5	Rize province, Turkey	1 – 13 items L^{-1}	Water	PES, PET, PP, PMMA	[42]
6	Rize province, Turkey	64.17 – 472.1 items kg^{-1}	Sediment	PE, PES, PP, PVC, PS	[42]
7	Tamsui River	10.1 ± 5.1 – 70.5 ± 30.6 MP particles m^{-3}	Water	Not determined	[43]
8	Keelung River	2.8 ± 1.2 – 64.4 ± 76.2 MP particles m^{-3}	Water	Not determined	[43]
9	Dahan river	6.7 ± 2.4 – 83.7 ± 70.8 MP particles m^{-3}	Water	Not determined	[43]
10	Xindian River	2.5 ± 1.8 – 11.7 ± 5.8 MP particles m^{-3}	Water	Not determined	[43]
11	Hobol, Gryta, Akerselva (Norway)	138 particles m^{-3} 140 particles m^{-3} 1067 particles m^{-3}	Water	PE, PP, PS, PA, PUR	[28]
12	**Chalakudy river**	**15.13 ± 4.13 – 170 ± 17.75 particles L^{-1}**	**Water**	**LDPE, HDPE, PP, PVC, PA, PET**	**Present Study**

to the other riverine systems (Hobol, Gryta, Akerselva – Norway). The spatial variability in microplastic distribution and abundance was due to geographical features, urbanisation, and other anthropogenic activities. Overall analysis revealed gradual build-up of microplastics and the possibility for enhancement of contamination in the Chalakudy river system.

Conclusion

Microplastics were detected at all sampling sites of River Chalakudy. The study infers abundance of microplastic particles (range 15.13 ± 4.13 – 170 ± 17.75 particles L^{-1} of water) with a recovery rate of 108.33 mg particles L^{-1} of water. Among the eight sites, a higher abundance of microplastics with small-sized micro debris was observed at site C_3. Particles with a size <20 μm were dominant in the study area. Reduction in particle size leads to enhanced transportation through water and hence pose a risk of deposition. The particles of smaller sizes may get ingested by the aquatic organisms along with their food. Fragments were the dominant shape (47.06%) recovered in the study, and the irregularly shaped MPs may cause internal damage to the organisms like fish. The microscopic analysis revealed coloured MPs; brown/mud and black-coloured particles exhibited the major share. The coloured MPs also mimic the food of aquatic organisms. Raman spectral study confirms that almost all types of plastics were noticed in the study with dominance of LDPE.

The plastic particles were unequally distributed across the river and their concentrations may vary with the geographical location and features of sampling sites and the flow pattern of the river. Bulk quantities of plastic waste were observed near the bathing sites (Kadavu), and also from the fishing points. The occurrence of MPs in River Chalakudy is mainly due to the unscientific practices of waste disposal from domestic, municipal, industrial and tourism activities. The study provides baseline information on the occurrence, distribution, size, shape, colour, and polymer type of microplastic in the surface waters of River Chalakudy. The analysis indicated the fact that Chalakudy River is contaminated with microplastics and possibility for potential threats of plastic particles to organisms. Further studies pertaining to the occurrence of microplastics in sediment, aquatic biota, and their bioaccumulation in the food chain have to be carried out to evaluate the overall impact of microplastics on the riverine ecosystem.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Mr. ***S. K. Maneesh Kumar*** has been working as a research scholar (Register Number: 5656) in the School of Environmental Studies, at Cochin University of Science and Technology, Kochi, Kerala, India. Area of research includes identification and risk assessment of pollution due to microplastics in rivers, lakes, estuaries, oceans, and wetland ecosystems.

Ms. ***Aswathy R. Kartha*** successfully completed her post-graduation degree - MSc Environmental Science, from School of Environmental Studies, Cochin University of Science and Technology. Field of research includes identification and risk assessment of pollution due to microplastics in aquatic environment. Currently she has been pursuing Master's degree, at the Brandenburgische Technische Universitat Cottbus-Senftenberg, Germany.

Dr. ***S. Rajathy served*** as Professor (Retired) in the field of Environmental Toxicology, at School of Environmental Studies, Cochin University of Science and Technology, Kochi, Kerala, India. Her area of research includes toxicity studies in the aquatic and terrestrial environments, pesticide toxicity in soil and environmental biodiversity.

Dr. ***C. S. Ratheesh Kumar*** has been working as an assistant professor in Environmental Chemistry, at School of Environmental Studies, Cochin University of Science and Technology. His area of research includes geochemical studies of riverine, estuarine, and coastal aquatic environments.

Mrs. ***P. K. Chandni*** has been working as a Research Scholar (Register Number: 5053) in the School of Environmental Studies, at Cochin University of Science and Technology, Kochi, Kerala, India. Her field of study is soil pesticide pollution and ecotoxicology.

Mrs. ***P. V. Vidya*** has been working as a Research Scholar (Register Number: 5654) in the School of Environmental Studies, Cochin University of Science and Technology, Kochi, Kerala, India. Her field of study is biogeochemical studies of wetlands.

Mr. ***P. K. Madhuraj*** has been working as a research scholar (Register Number: 6262) in the School of Environmental Studies at Cochin University of Science and Technology, Kochi, Kerala, India. His field of study includes atmospheric microplastic pollution.

Dr. ***K. S. Sajith*** has been working as a Research Scholar (Register Number: 4662) in the School of Environmental Studies, at Cochin University of Science and Technology, Kochi, Kerala, India. His field of research expertise includes environmental management and remote sensing.

Ms. ***S. Anamika*** successfully completed her post-graduation degree - MSc Environmental Technology, from School of Environmental Studies, Cochin University of Science and Technology. Currently she has been serving as Project Fellow at Centre for Water Resource development, Kozhikode, Kerala, India. Focus on biodiversity of riverine estuarine and oceanic ecosystems.

Data availability statement

The datasets used and analysed during this article are available from the corresponding author on reasonable request.

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