

Occurrence Characteristics and Control Countermeasures of Microplastics in Surface Water of the Yellow River Basin

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How to cite this paper: Han, T.X., Xu, Y.X. and Xu, L.Q. (2026) Occurrence Characteristics and Control Countermeasures of Microplastics in Surface Water of the Yellow River Basin. *Open Journal of Applied Sciences*, 16, 3807-3823.

<https://doi.org/10.4236/ojapps.2026.1610210>

Received: August 19, 2026

Accepted: October 12, 2026

Published: October 15, 2026

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Abstract

As an emerging pollutant, microplastics have attracted widespread global attention in recent years. To explore the occurrence characteristics of microplastics in surface water of the Yellow River Basin and the progress of relevant countermeasures, this study conducted a comprehensive analysis based on 129 sampling sites across 11 river reaches. The results show that fibers and fragments are the dominant microplastic shapes in the compiled dataset. Microplastics are mostly colored, white or transparent, with PET, PP, PE and PS as major polymer types. Particles smaller than 1000 μm dominate at most sites in included studies, yet differences in particle-size classifications across publications limit their basin-wide applicability. Potential sources of microplastics include agricultural activities, domestic discharge, industrial emissions, fishery-related inputs, tourism-related inputs and atmospheric transport. Current countermeasures are mainly advanced in three aspects: source substitution, degradation technology and recycling. However, these technologies still need to be translated into efficient, economical and sustainable practical applications. This study can provide scientific references for microplastic pollution control and management in the Yellow River Basin.

Keywords

Microplastics, Yellow River Basin, Occurrence Characteristics, Control Technologies

1. Introduction

Microplastics (MPs), a new class of pollutants, are vividly described as “PM2.5 in

the ocean” [1]. They have aroused great concern worldwide in recent years. Since the mid-20th century, the emergence of synthetic polymers has greatly increased global plastic production [2]. In 1972, Carpenter *et al.* first reported plastic particles of 2.5–5 mm in marine environments [3]. In 2004, Thompson *et al.* defined plastic items smaller than 5000 μm as microplastics [4], including fibers, fragments, pellets and films. Microplastics have been widely detected around the world, such as the Los Angeles River [5], Ciwalingke River [6], Ergene River [7], Antuã River [8], Amazon River [9] and Indus River [10] abroad; domestically, they have been found in the Yangtze River [11], Pearl River [12], Dongting Lake [13], Haihe River [14], Songhua River [15] and other watersheds. Microplastics are even detected in remote regions including the Mariana Trench—the deepest trench on Earth [16], the Himalayas—the roof of the world [17], as well as the Arctic and Antarctic [18]. Based on model estimation, Lebreton *et al.* suggested that 1.15×10^6 and 2.41×10^6 tons of microplastics enter the ocean via rivers every year [19]. As persistent organic pollutants [20], microplastics feature small particle size, strong hydrophobicity and large specific surface area, which makes them ideal carriers for numerous hydrophobic organic contaminants and heavy metal ions [21]. According to their origins, microplastics are classified into primary microplastics and secondary microplastics [22]. In terms of ecological hazards, microplastics readily adsorb toxic substances such as organic pollutants and heavy metals in river water [23] [24]. They can be ingested in large quantities by aquatic organisms, causing gastrointestinal tract damage. Moreover, microplastics can transfer and bioaccumulate along food webs and may exert direct or indirect risks to human health [25]–[27]. Many studies have confirmed high microplastic abundance in Chinese rivers, and the eco-environmental risks induced by microplastic pollution cannot be ignored [28]. As the Mother River of the Chinese nation, the Yellow River covers densely populated urban agglomerations, so its water quality safety is of great significance. However, comprehensive research targeting the whole Yellow River Basin remains scarce. This paper reviews microplastic pollution and corresponding countermeasures in the Yellow River Basin from the perspectives of source identification, occurrence status and available control technologies, aiming to provide scientific support for microplastic pollution research and management within this basin.

2. Study Area and Data Sources

2.1. Overview of the Study Area

The Yellow River is the sixth longest river in the world and the second longest river in China. It originates from the Bayan Har Mountains on the Qinghai-Xizang Plateau, with a total length of 5464 km and a drainage area of approximately $7.95 \times 10^5 \text{ km}^2$. Flowing from west to east, it passes through Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan and Shandong Provinces/Autonomous Regions before emptying into the Bohai Sea. Its major tributaries include the Huangshui River, Taohe River, Zuli River, Qingshui River, Dahei River,

Huangfuchuan River, Wuding River, Fenhe River, Weihe River, Yiluo River, Qinhe River and Dawen River. Statistical data show that the average annual runoff of the Yellow River exceeds 50 billion m³. It supplies water for 17% of China's cultivated land, 12% of the national population and more than 50 large and medium-sized cities [29]. The mainstream of the Yellow River is divided into upper, middle and lower reaches. The upper reach stretches from the river source to Hekou Town in Tuoketuo County, Inner Mongolia Autonomous Region (3471.6 km, drainage area 4.28×10^5 km²). The middle reach runs from Hekou Town to Taohuayu in Zhengzhou City, Henan Province (1206.4 km, drainage area 3.44×10^5 km²). The lower reach extends from Taohuayu to the river estuary (786 km, drainage area 2.30×10^4 km²). The Yellow River flows through numerous cities. Urban sewage and agricultural return flow from surrounding farmlands may enter the river directly or indirectly. Improper disposal of woven fertilizer bags and agricultural mulching films also constitutes potential sources of microplastic pollution [30].

2.2. Data Source and Processing

Literature retrieval was performed in Web of Science and CNKI using subject terms “Yellow River”, “tributaries of the Yellow River”, “microplastics”, “surface water”. The retrieval was completed on April 30, 2026. The initial literature search yielded 37 publications. After de-duplication and screening, 22 publications were excluded, and 15 publications were finally included for analysis in this study. Considering the limited number of available studies on microplastics in the Yellow River Basin, screening was carried out only for sampling period, sampling methods, microplastic extraction and identification approaches to obtain sufficient data. The inclusion criterion was that measurable original data of microplastic abundance, particle size, shape, color or polymer type should be available. To avoid duplicate datasets from the same river reach or study area, the most recent literature with the most complete dataset was preferentially selected when multiple sources reported data for the same region. Key data, including microplastic abundance, size, shape, color and polymer type, were obtained by direct text extraction or digitalization of figures from published literature using Origin 2024. Finally, an MPs dataset covering 129 sampling sites distributed across 11 river reaches of the Yellow River Basin was compiled. Data were sorted in the sequence from upstream to estuary: Liujiaxia Reservoir: 6 sampling sites (A1 - A6) [31]; Lanzhou Reach of the Yellow River mainstream: 8 sampling sites (B1 - B8) [32]; Huangshui River: 9 sampling sites (C1 - C9) [33]; Wuliangshuai Lake: 12 sampling sites (D1 - D12) [34] [35]; Hetao Irrigation District: 12 sampling sites (E1 - E12) [36]; Weihe River: 32 sampling sites (F1 - F32) [37]-[39]; Shanxi Reach of the Yellow River mainstream: 5 sampling sites (G1 - G5) [40]; Wuding River: 12 sampling sites (H1 - H12) [41]; Zhengzhou Reach of the Yellow River mainstream: 14 sampling sites (I1 - I14) [28] [42]; Sishui River (Xingyang Reach): 9 sampling sites (J1 - J9) [43]; Estuary of the Yellow River: 10 sampling sites (K1 - K10) [22]. The detailed loca-

tions are shown in **Figure 1**.

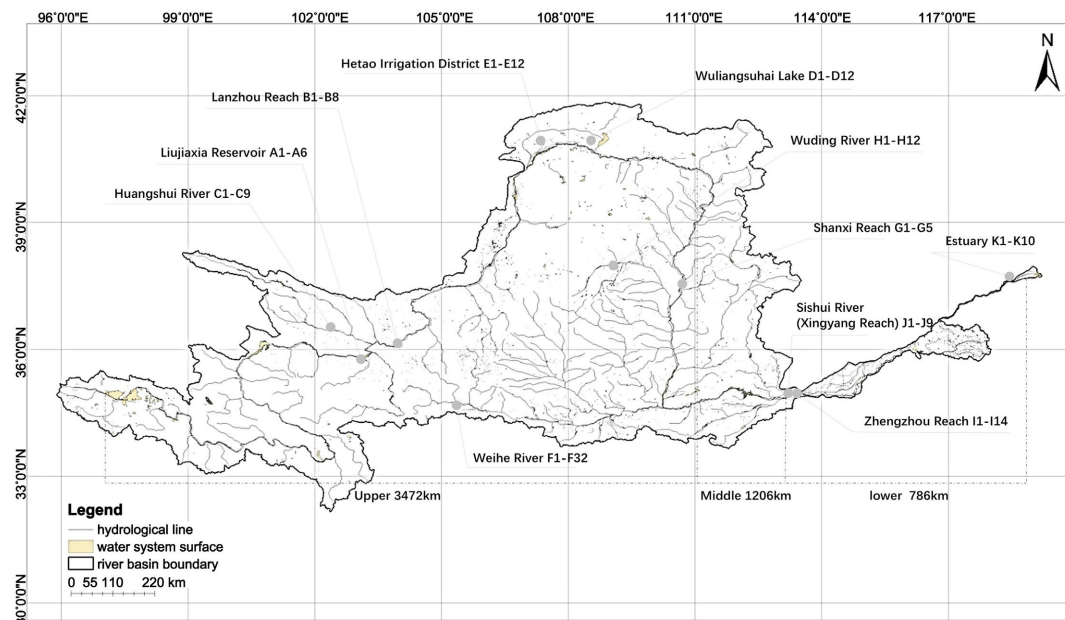


Figure 1. Schematic diagram of MPs sampling sites in the Yellow River Basin.

To mitigate the impacts of methodological differences on microplastic abundance comparisons, key information including sampling season, hydrological conditions, sampling volume, particle-size range, pretreatment procedures and polymer identification methods was extracted from each included study, as detailed in **Table 1**. It should be noted that these studies adopted different sampling approaches (e.g., Manta trawl, stainless-steel bucket sampling), pretreatment protocols (e.g., digestion treatment and types of flotation solution), and lower particle-size detection limits varying from 0.22 μm to 300 μm . These factors can directly influence detected microplastic abundance. Accordingly, abundance comparisons were only carried out among methodologically comparable datasets. Horizontal comparisons were performed for studies with similar sampling approaches (*i.e.*, direct surface-water collection or trawling), pretreatment protocols (*i.e.*, H_2O_2 digestion combined with NaCl density flotation), and particle-size ranges that overlapped or could be converted into unified intervals. For studies with major methodological discrepancies, their abundance data were not used for direct comparison and only served as qualitative references.

It should be noted that the overall average abundance of the Yellow River Basin was calculated as the arithmetic mean of the abundance values reported in each study for each river reach, without weighting by the number of sampling sites, sample replicates, or spatial area of the reaches. The standard deviation was derived from the abundance data of all reaches, reflecting the degree of dispersion among observations from different studies. Constrained by the variability in sampling conditions across studies, this statistical result represents only a summary of the present dataset and should not be equated with the actual pollution level of the entire

Yellow River Basin. For polymer composition statistics, PET, PP, PE, and PS were listed as the major polymer types and displayed separately, while other polymers detected in each reach (including PC, PEG, Rayon, PA, PVC, etc.) were grouped into the “others” category. Proportion calculations were performed only for records with clearly reported polymer composition data (*i.e.*, polymer types with corresponding counts or percentages). Records without polymer composition information were excluded from polymer-related analyses, and no interpolation or data imputation was applied; however, their abundance, morphology, and color data were still included in the corresponding statistical analyses.

Table 1. Information on microplastic sampling and analytical methods of each included study.

Name	Sampling Time	Hydrological Condition	Sample Volume	Size Range	Pretreatment Method	Polymer Identification Method	References
Liujiaxia Reservoir	June & August 2022	Wet season	Manta trawl	>300 µm	ZnCl ₂ + NaCl flotation, H ₂ O ₂ digestion	FTIR, Micro-confocal Laser Raman Spectroscopy	[31]
Lanzhou Section	Aug-22	Wet season	500 mL	<1 mm (dominant)	No digestion, NaCl + CaCl ₂ flotation	Micro-Raman Spectroscopy	[32]
Huangshui River	Aug-20	Wet season	4 L	0.45 - 5000 µm	H ₂ O ₂ digestion	Fourier Transform Infrared Spectroscopy (FTIR)	[33]
Ulansuhai Lake	Aug-23	Wet season	20 L	>48 µm	H ₂ O ₂ digestion	FTIR, SEM-EDS, Micro-FTIR	[34] [35]
Hetao Irrigation District	Aug-19	Wet season	20 L	>48 µm	H ₂ O ₂ digestion, NaCl flotation	FTIR	[36]
Wei River	May-21	Wet season	25 L	>75 µm, >50 µm	H ₂ O ₂ digestion, NaCl flotation	ATR-FTIR, SEM, Micro-confocal Raman Spectroscopy	[37]-[39]
Shanxi Section, Yellow River	Dec-21	Dry season	3 L	Membrane pore size 0.45 µm	NaCl flotation, H ₂ O ₂ digestion	FTIR	[40]
Wuding River	Aug-21	Wet season	20 L	>0.22 µm	H ₂ O ₂ digestion	Micro-Laser Raman Spectroscopy	[41]
Zhengzhou Section, Yellow River	Sep-22	Wet season	5 L	50 - 5000 µm, >10 µm	H ₂ O ₂ digestion, NaCl flotation	Micro-FTIR	[28] [42]
Sishui River (Xingyang Section)	Aug-22	Wet season	2.5 L	50 - 5000 µm	H ₂ O ₂ digestion, NaCl flotation	Laser Direct Infrared (LDIR) Imaging	[43]
Yellow River Estuary	Jul-18	Wet season	5 L	>50 µm	H ₂ O ₂ digestion, NaCl flotation	ATR-FTIR, Micro-FTIR	[22]

3. Current Status of Microplastic Pollution in the Yellow River Basin

3.1. Abundance Characteristics of MPs in Surface Water of the Yellow River Basin

The abundance characteristics of microplastics in surface water of the Yellow

River Basin are illustrated in **Figure 2**. The average MPs abundance was $79851.89 \pm 151,660$ items/m³. Affected by differences in sampling conditions, hydrological background and regional human activities across source studies, the microplastic abundance in surface water across different reaches of the Yellow River exhibits significant spatial heterogeneity with large inter-reach fluctuations. Relatively high abundance was observed at some downstream sites, yet no consistent increasing longitudinal trend from upstream to downstream exists for the whole basin. Noticeable fluctuations in microplastic abundance were observed across sampling sites. Microplastic abundance of approximately 0.58 items/m³ was detected in Liujiaxia Reservoir, which may be potentially associated with the water-quality management measures implemented for the reservoir. A microplastic abundance of around 497,000 items/m³ was recorded at the Yellow River Estuary. A relatively high microplastic abundance value was obtained for the Shanxi reach of the Yellow River main-stem. Located at the border of Shanxi and Shaanxi provinces, this area faces complex water-environment management challenges and intense human-activity disturbances, which may influence microplastic occurrence. Relatively high microplastic abundance was also documented in the Lanzhou reach. It has been speculated that the special topographic and geomorphological conditions of this reach may facilitate the transport of soil-borne microplastics into aquatic environments via rainfall runoff [44]. Considerable microplastic concentrations were also detected at some upstream tributary sites in the inland

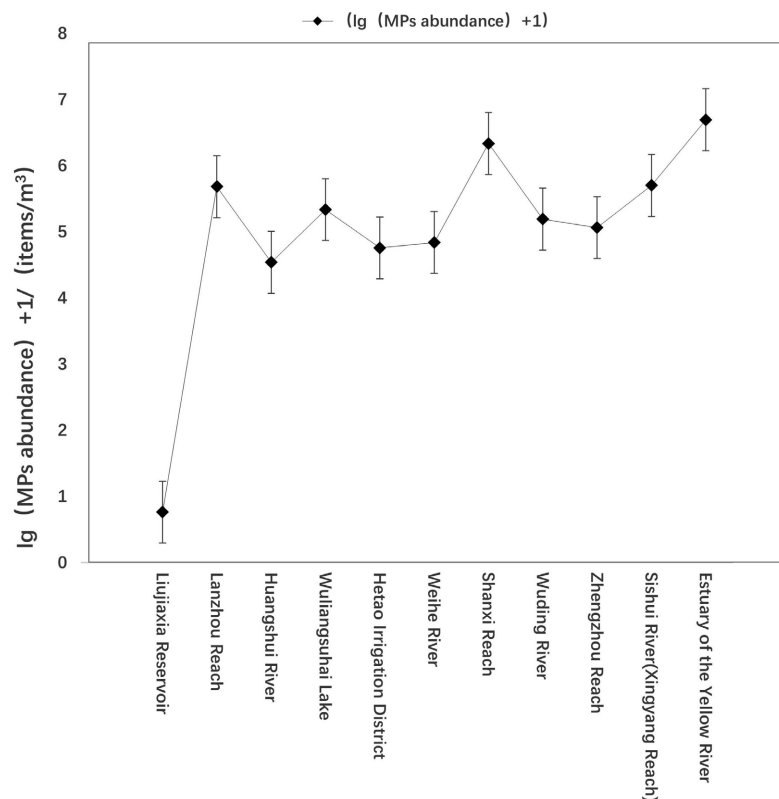


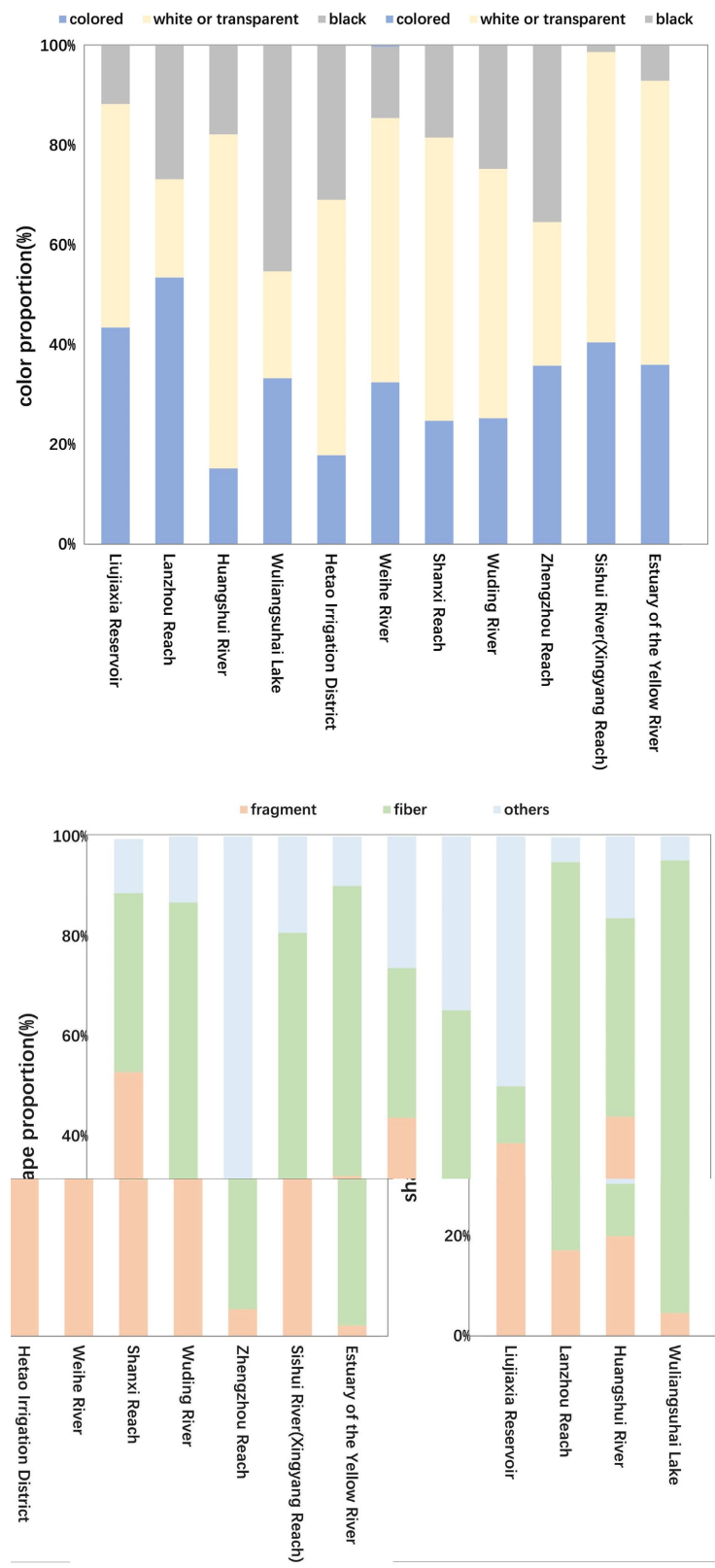
Figure 2. Average MPs abundance in surface water of different river reaches in the Yellow River Basin.

northwest region, suggesting that microplastic pollution in the upper Yellow River and its tributaries deserves attention.

3.2. Compositional Characteristics of MPs in Surface Water of the Yellow River Basin

Figure 3 reveals the compositional profiles of microplastics at each sampling site. In terms of color, colored, white and transparent microplastics dominated, while black microplastics accounted for a low proportion. Located in North China, most water bodies in the middle-lower Yellow River Basin lie within plain regions with intensive agricultural activities. Agricultural mulching films and plastic greenhouses are widely used in cold winter seasons. Large quantities of plastic residues from farming can be weathered and fragmented into film-shaped microplastics entering aquatic systems [33]. White and transparent microplastics may derive from long-term weathering discoloration or fragmentation of agricultural mulch films. Colored microplastics are likely associated with daily consumption of colored plastic commodities and fiber shedding during textile washing [45]. In respect of shape, fibers and fragments were predominant, followed by other types such as films, pellets and foams. According to Hernandez *et al.*, fibrous microplastics originate not only from primary microplastics in cosmetics and facial cleansers, but also from secondary microplastics generated by further weathering and degradation of large-size plastics, including fragments and films [46]. Furthermore, fishing gear, atmospheric deposition and surface runoff constitute potential sources of plastic fibers [47]. Notably, in the Huangshui River Basin, fibers only took up 10%, whereas films and pellets accounted for 69%. The Huangshui River is situated in Qinghai Province with low-density population yet important agricultural zones; mulching films and greenhouse plastics readily weather into film-like microplastics [33]. Microplastics in the Wuding River were dominated by fragments and other categories, which may stem from breakage of large rigid plastic debris under strong hydraulic scouring [41]. For particle size distribution, particles smaller than 1000 μm dominated at most sampling sites from included studies, while particles larger than 1000 μm accounted for a relatively low proportion. Nevertheless, due to inconsistent particle-size classification schemes among publications, this observation cannot be generalized as a unified particle-size pattern for the entire Yellow River Basin. Particularly, microplastics less than 500 μm dominated in the Sishui River (Xingyang Reach) and the Yellow River Estuary. Large-sized microplastics can be decomposed into finer particles via combined physical-chemical effects in the Yellow River. Owing to their chemical stability, these fine micro-particles are hardly degradable, which may lead to high proportions of microplastics < 1000 μm in river water [43]. This mechanism is consistent with Doyle's conclusion: a negative correlation exists between microplastic particle abundance and particle size, *i.e.*, smaller particles correspond to higher concentrations [48]. Previous studies also indicated that smaller microplastics possess stronger adsorption capacity toward co-existing pollutants and thereby impose greater environmental risks [49]. Based on the compiled datasets, fibers and fragments were the

predominant microplastic shapes, and colored, white and transparent particles were frequently observed across sampling sites.



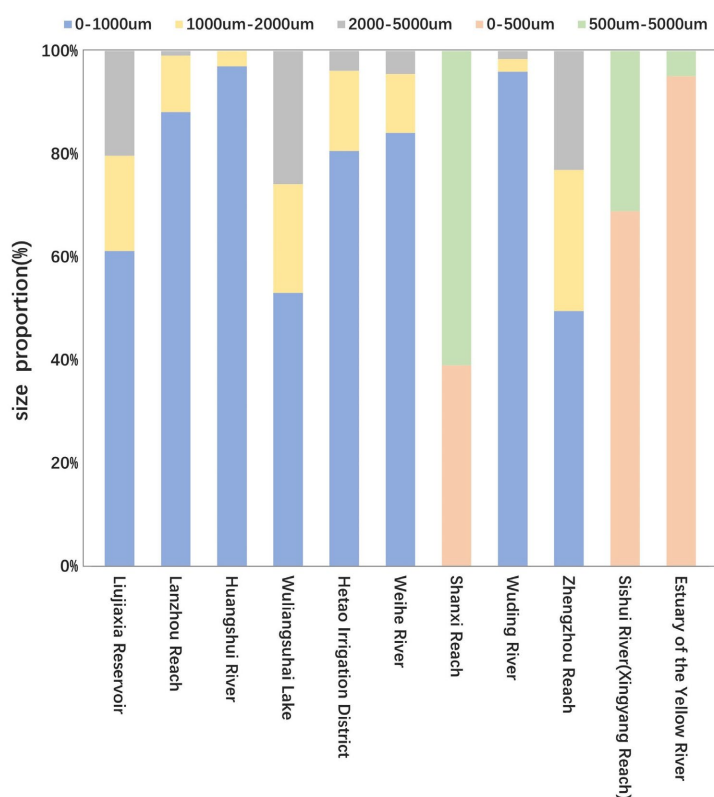


Figure 3. Compositional characteristics of MPs in surface water of different river reaches in the Yellow River Basin. Note: Particle-size bins adopted by original publications are inconsistent. The size results reflect characteristics within individual studies and cannot represent a unified basin-wide distribution pattern.

3.3. Polymer Types of MPs in Surface Water of the Yellow River Basin

For polymer composition, microplastics in the Yellow River Basin were mainly Polyethylene Terephthalate (PET), Polypropylene (PP), Polyethylene (PE) and Polystyrene (PS). Microplastic shapes are closely related to polymer types: fibrous microplastics are mostly composed of PE, which is widely applied in agricultural mulch films, industrial packaging films, pharmaceutical/food packaging, textiles including garments and blankets, mechanical components, daily commodities, construction materials, wire cable insulation layers and synthetic paper. Fragment-shaped microplastics are mostly PP, commonly manufactured into medical devices, automobile and bicycle spare parts, transportation pipelines and chemical containers, as well as food and pharmaceutical packages. Film-shaped and pellet-like microplastics are mainly PS [50]. High proportion of “other” microplastics was observed in the Lanzhou Reach of the Yellow River, among which Polycarbonate (PC) reached 17.14%. PC is frequently used for optical lenses, electronic housings and medical apparatus. It is worth noting that neither PET nor PP was detected in the Wuding River, and Polyethylene Glycol (PEG) became the dominant polymer type, accounting for 62.96%. PEG serves as matrix, softener and lubricant in cosmetics, pharmaceutical preparations and industrial production [41].

In the Zhengzhou Reach of the Yellow River, Rayon occupied the highest proportion among all microplastic polymer types according to Li Hetong *et al.* [28]. No valid polymer composition data were available for the Shanxi Reach and the Yellow River Estuary. Nevertheless, studies by Niu Xuerui [22] and Lü Yuejun [40] suggested that PP, PE, PS and other materials constituted the major polymer components for these two sections.

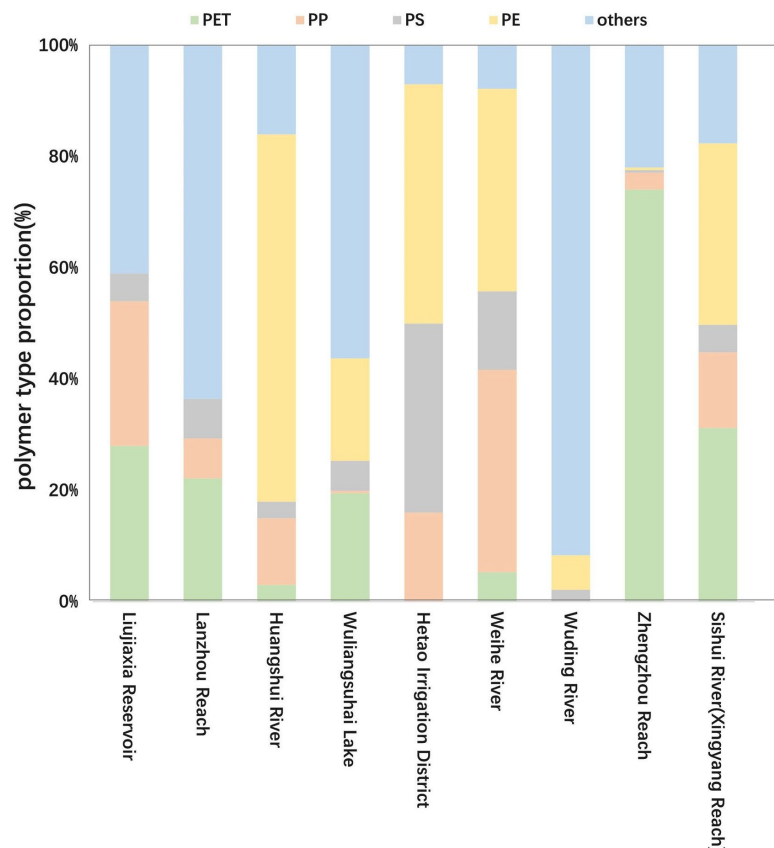


Figure 4. Polymer types of MPs in surface water of the Yellow River Basin.

4. Source Analysis of Microplastics in the Yellow River Basin

As shown in **Figure 4**, the microplastic composition of tributaries across the Yellow River Basin is complex, with diverse potential sources. In the drainage ditches of the Hetao Irrigation District in Inner Mongolia, transparent microplastics dominate, and PE accounts for more than 40% of total microplastics [36]. In the Huangshui River basin, microplastic abundance is positively correlated with cultivated land area, and PE and PP are the dominant polymer types [33]. Agricultural activities are intensive in this region, where agricultural mulch films, plastic greenhouses and fertilizer woven bags are widely used. It is therefore speculated that fragments and films generated from weathering of these plastic products constitute one potential source of microplastics in the Yellow River. Fibers account for up to 79% of microplastics in the Zhengzhou reach of the Yellow River, with rayon as the major polymer together with PET [28]. Fiber fractions also range from 60%

to 90% in the Yellow River Estuary [22] and the Lanzhou reach of the Yellow River [32]. These polymers are common raw materials for textiles and personal-care products, suggesting that domestic sewage and laundry wastewater from surrounding residents represent a potential pathway for microplastic input. Highly toxic plastic types such as PVC and ABS were detected in Liujiaxia Reservoir [31], an important aquaculture area where broken blue and green fishing nets are widely observed in surrounding zones. Similar findings have been reported for Wuliang-suhai Lake [35], and fishing-net debris may serve as an important source of colored fibers. Considerable microplastic levels were documented in studies covering the Zhengzhou reach [28] and Wuliang-suhai Lake [35]. Dense tourist scenic spots are distributed in these areas. Plastic wastes discarded by tourists, including broken disposable tableware, beverage bottles and packaging bags, can form fragments and films, which represent another potential source of microplastics. Studies on the Huangshui River [33] and Wuliang-suhai Lake [35] show that wind speed and ultraviolet intensity are significantly correlated with microplastic abundance, and wind in winter can transport atmospheric microplastics into water bodies. Located at the edge of desert, the upper reaches of the Wuding River are also frequently affected by wind forces. Hence, atmospheric deposition and wind transport are inferred as potential pathways for microplastics entering river systems.

5. Control Countermeasures for Microplastics in the Yellow River Basin

Given complex sources and high abundance of microplastics in the Yellow River Basin, current control strategies focus on three aspects as follows.

5.1. Source Substitution

With worsening microplastic pollution, developing new materials with favorable performance and degradability offers a solution for pollution mitigation at source. Wang *et al.* prepared bio-plastic films with excellent performance using PBAT, TPS and PPC, providing new insights for degradable material development [51]. Cai *et al.* proposed to replace plastic microbeads in daily-use cosmetics with inorganic particles so as to reduce primary microplastic consumption [52]. Duraj-Thatte *et al.* obtained a novel biodegradable aquaplastic directly purified from bacterial cultures, offering alternative options for plastic commodities [53].

5.2. Degradation Treatment

Most conventional plastics are recalcitrant toward degradation, resulting in long-term pollution and high management difficulty. Numerous domestic and international studies have explored degradation approaches for plastic pollution. Existing degradation technologies can be categorized into three types.

5.2.1. Physical Degradation Technologies

Traditional physical degradation relies on mechanical forces to break plastic debris without altering chemical composition; it is mostly applied for pre-treatment

of plastic waste. Common engineering separation approaches include coagulation, flocculation and ultrafiltration. Coagulation and flocculation aggregate microplastics via charge neutralization to realize sedimentation. Ultrafiltration intercepts microplastics with semi-permeable membranes and is widely adopted for drinking water purification [54].

5.2.2. Biodegradation Technologies

Biodegradation contains microbial degradation and animal-mediated degradation. Skariyachan *et al.* [55] proved that mixed bacterial consortia achieve higher microplastic degradation efficiency compared with single strains. Amobonye *et al.* [56] reported that earthworm larvae ingest environmental microplastics, which can be further degraded by endosymbiotic microorganisms inside earthworms. Gao *et al.* [57] isolated marine fungi possessing broad-spectrum plastic-degrading capacity that can efficiently degrade PE.

5.2.3. Chemical Degradation Technologies

Major chemical degradation approaches include oxidation, hydrolysis, alcoholysis and ammonolysis. Their core principle is to break chemical bonds within long polymer chains via specific chemical reactions such as oxidation and nucleophilic substitution, reduce molecular weight and modify chemical structures to achieve degradation. Advanced Oxidation Processes (AOPs) are emerging wastewater treatment technologies, which degrade persistent organic pollutants into carbon dioxide and water by generating Reactive Oxygen Species (ROS). Typical AOPs include UV photolysis, photocatalysis and plasma techniques [54]. For instance, under ultraviolet irradiation, Nabi *et al.* [58] adopted thin film TiO₂ photocatalyst to decompose PE and PS micro nano spheres.

Although laboratory-scale degradation studies have achieved certain progress, multiple engineering bottlenecks, including material stability, catalytic activity, economic cost and environmental risks, still need to be resolved before practical application. More resources should be invested to optimize degradation technologies for efficient, economical and sustainable microplastic remediation.

5.3. Recycling and Reutilization

Plastic recycling represents an effective countermeasure for microplastic pollution. Instead of simple physical recovery, systematic approaches are required to convert plastic waste into regenerative plastic products and block waste plastics from entering aquatic environments and generating secondary microplastics. Ahrens *et al.* [59] recovered bisphenol A and fiber materials from epoxy resin via transition metal catalysis. Xu *et al.* [60] converted PE and PP plastics into fatty acids for soap production, realizing upcycling of plastic waste into valuable commodities and opening new pathways for plastic recycling.

6. Conclusions

- 1) The average microplastic abundance in the Yellow River Basin was $79851.89 \pm$

151,660 items/m³, showing distinct spatial heterogeneity and substantial inter-reach fluctuations. Liujiaxia Reservoir in the upper reaches presented the lowest abundance (~0.58 items/m³), while the Yellow River Estuary in the lower reaches had the highest abundance (~497,000 items/m³).

2) Microplastics in the Yellow River Basin are predominantly fibers and fragments, mostly colored, white or transparent, with PET, PP, PE and PS as the major polymer types. Particles smaller than 1000 µm account for a high proportion within most individual included studies. Nevertheless, inconsistent particle-size classification among original publications prevents this feature from being generalized as a unified basin-wide pattern.

3) Plausible source pathways of microplastics in the Yellow River Basin include agricultural activities, domestic discharge, industrial emissions, fishery-related inputs, tourism-related inputs, and atmospheric transport. Inputs from agricultural and domestic waste may constitute relatively important contributions.

4) Microplastic pollution control advances from source substitution, degradation and recycling. Source mitigation focuses on developing degradable alternatives for conventional plastics; degradation approaches cover physical, biological and chemical technologies; recycling aims to convert plastic waste into new products and block environmental input. Nevertheless, technical systems still need further improvement for practical, efficient, economical and sustainable implementation.

Author Contributions

Conceptualization, Tianxiao Han and Yuxia Xu; methodology, Tianxiao Han; software, Tianxiao Han; validation, Tianxiao Han, Yuxia Xu, and Liqun Xu; formal analysis, Tianxiao Han; investigation, Tianxiao Han; resources, Tianxiao Han; data curation, Tianxiao Han; writing—original draft preparation, Tianxiao Han; writing—review and editing, Tianxiao Han; visualization, Tianxiao Han; supervision, Tianxiao Han; project administration, Tianxiao Han; funding acquisition, Tianxiao Han. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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