

Microplastics in the Surface Sediment of the main Red River Estuary

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Received 7 August 2022; Received in revised form 17 August 2022; Accepted 5 September 2022

ABSTRACT

Microplastics (< 5mm) are one emerging pollutant in the environment. These are the threats and challenges facing the global environment, economy, and society, especially in hotspot regions such as Asia. This paper presents the microplastic characteristics found in the surface sediment of the main Red River estuary (the Ba Lat) during four separate monitoring runs in 2020. The microplastic amount in the sediment samples varied from 800 items per kg of dried weight (dw) to 3,817 items.kg⁻¹ dw, averaging 2,188±1,499 items.kg⁻¹ dw. Fiber and fragment microplastics were discovered to be primary shapes, of which fibers dominated (94%). Microplastic fiber sizes were found mainly in the < 500 µm (69%) range. The most primarily observed colors of microplastics were blue (36%), white (21%), and red (11%). There were five recognized polymer types (polypropylene (PP), polyethylene (PE), polyurethane (PU), polyamide (PA), and polystyrene (PS) in the sediment samples, with PE and PP predominating. Seasonal fluctuations in microplastic concentrations at the Ba Lat site, a significant aquaculture zone, may indicate the contribution of multiple sources. Our research demonstrated the necessity of microplastic observation in organisms, particularly in the aquaculture zones in Vietnam. Our findings further underline the importance of managing and minimizing the amount of plastic garbage that enters the ecosystem.

Keywords: Ba Lat estuary, microplastics, Red River, surface riverine sediment, Vietnam.

1. Introduction

The world plastics industry has grown rapidly, and the global production reached 368.10⁶ tons.yr⁻¹ in 2019 (excluding fibers)

(Plastics Europe, 2020). The plastic manufacturing industry tends to shift to Asia, and currently, plastic is the third most popular artificial substance after steel and concrete (Phuong et al., 2022). However, the treatment of plastic waste has not been effective, leading

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to a huge amount of plastic waste being discarded and polluting the environment. Plastic waste can be divided into microplastics under physical, chemical, and biological effects. Tiny plastic pieces (< 5 mm) are defined as “microplastic” (Arthur et al., 2009; GESAMP, 2019), which pollute the environment in which they exist because of their durability and slow decomposition. Plastic pollution, including microplastics, is one of the threats and challenges facing the global environment, economy, and society. Microplastics are found in many different environments, including water, sediment, soil, air, and organisms, especially in hotspot regions such as Asia (Phuong et al., 2022). Microplastics can impact aquatic organisms and then human health through the food chain. In Vietnam, microplastics have recently become a topic of discussion regarding their presence in water and sediment. Microplastics have been found in the Saigon River (Lahens et al., 2018; Trinh et al., 2021), in the Day River, a tributary of the Red River (Doan et al., 2021a; Duong et al., 2022), in the sediment of Hanoi’s aquaculture ponds (Le et al., 2022), and some sites of other rivers, lakes and coastal zones (Strady et al., 2021).

The natural hydrological and biogeochemical processes in many hydro-systems worldwide have been directly or indirectly affected by different human activities in the basin. The Red River is representative of Southeast Asia, subject to significant human and natural influences. Extending over 12,751 km², the Red River Delta, where the average population density is more than 1000 inhabitants.km⁻² is a key economic region of North Vietnam. In this area, socio-economic development activities (industrial and agricultural production development, urbanization, and population growth) are increasingly becoming the main

causes of environmental pollution (MONRE, 2019). Ba Lat, the main Red River estuary, plays an essential role in waterway traffic, agriculture irrigation, aquaculture water supply, and flood drainage for both Nam Dinh and Thai Binh provinces (Hoa et al., 2020). The riverine sediment and the water column are the habitats of many aquatic organisms and benthic animals. Thus the water and sediment quality are essential because they can directly affect organisms and their habitats. The quality of the water and sediment of the Red River, notably at the Ba Lat site, has been investigated in some prior studies (Nguyen et al., 2016; Hoa et al., 2020; Le et al., 2022b). However, microplastic pollution has not been observed.

This paper reports the findings of the microplastic characteristics in the sediment of the main Red River estuary, the Ba Lat, in 2020. The outcomes could be added to a database of microplastic pollution in ecosystems. They may provide a scientific basis for improvement in the management and conservation of aquatic ecosystems in Vietnam.

2. Sampling site and methodology

2.1. Sampling site

The Red River basin has a surface area of 156,451 km² (Le et al., 2018). The Red River originates from the Yunnan province, running through some provinces of Vietnam before flowing into Tonkin Bay through the four estuaries: Ba Lat, Tra Ly, Lach Giang, and Day. The Ba Lat estuary is the main estuary of the Red River and belongs to two provinces, Thai Binh and Nam Dinh (Fig. 1). The average annual water flow through the Ba Lat estuary is about 544 m³.s⁻¹ (Table 1), with a higher value in the rainy season (841 m³.s⁻¹) than in the dry one (247 m³.s⁻¹) (VASI, 2011).



Figure 1. The Ba Lat estuary of the Red River and the sampling site

Table 1. Some information of the Ba Lat estuary (VASI, 2011; Cao and Nguyen, 2009)

Ba Lat's estuary area, km ²	Population density, inhabitants.km ⁻²	River discharge, m ³ .s ⁻¹	Mean water depth, m	
			In rainy season	In dry season
26,396	>1000	544	2.1	1.4

This area experiences two seasons: the rainy one (May October); and the dry one (November-next April). The average annual rainfall and tidal amplitude were approximately 1700-1800 mm.yr⁻¹ and 1.6-1.7 m, respectively (GSO, 2020; Nguyen et al., 2020).

2.2. Methodology

Four samplings were organized in 2020 (November and December, the dry season; and August and September, the rainy season) at the Ba Lat estuary (20°18'07.6"N, 106°32'25.4"E) of the Red River (Fig. 1). A Van Veen grab sampler was used to take three separate sediment sub-samples (about 0-30cm

from the river's banks and middle stream). Then the sub-samples were thoroughly mixed to ensure a representative sample was obtained for analysis. Sediment samples were preserved in aluminum foil bags for microplastic analysis and polyethylene bags for analysis of other variables (pH, metals, organic carbon, and nutrients). All samples were delivered to the laboratory on the day they were collected.

In the laboratory, the representative sample was triplicate analyzed, and the results shown here were the average values. The representative samples were dried in an oven at 40°C. The following step was passing 30 grams of the dried sample through a 1 mm

sieve to eliminate the chunks too big to pass. The sieved sample was then placed in a 500 ml glass bottle, where it was heated in a 30% H₂O₂ solution for 3 hours at 40°C on a heating plate (Strady et al., 2021). After that, a saturated NaCl solution was used to separate microplastics in sediment samples (Thompson et al., 2004), and an overflow technique was implemented (Hidalgo-Ruz et al., 2012). The glassware filtration unit was then used to filter the microplastic-laden overflow solution via Whatman GF/A filters (pore diameters of 1.6 µm).

Petri dishes were used to store filter papers until they could be examined with an Olympus microscope (model SZX16, Japan) with 690x maximum magnification, connected to a camera and computer. Microplastics' characteristics (concentration, shape, and color) were measured on OLYMPUS Stream image analysis software with a maximum zoom ratio of 16:4:1.

The suspect microplastic items from each sample were taken out and added to a vial. Add pure ethanol to the vial, followed by sonification for 3 min, and then pour them into a 50 mL beaker. Rinse the vial 3 times with pure alcohol until no item is visible on the vial's bottom or walls. Filter the solution through a 0.1 µm Anodisc filter (25 mm in diameter), and tightly cover the beaker until it is dry at room temperature.

Then, the polymer type of the sediment sample on the Anodisc filter was determined by an FT-IR microscope (Thermo iN10-MX, Waltham, MA, USA) equipped with the software OMNICPICTA 1.8 (about 600,000 spectrums per one filter). Microplastics were analyzed using an imaging detector in automatic mode. The measurement was carried out with a resolution of 8 cm⁻¹ while operating in transmission mode in the 4000-1200 cm⁻¹. The spectrum was

analyzed by the software siMPle, version beta 1.1, with the spectrum reference of MP_Library_Extended_Grouped_1_5.

Approximately 20% of the total items suspected of microplastics were randomly analyzed.

Our previous study presented the analysis methods for different sediment sample variables (Le et al., 2022b).

2.3. Statistical methods

Student t-tests were used for all statistical and analytical results to confirm the variation in microplastic amounts between the rainy and dry seasons. Calculated probabilities (*p*) were judged statistically significant at the *p* value of 0.05.

The Pearson correlation and Principal Component Analyses (PCA) were used based on the statistical package SPSS for Windows, version 20, and XLSTAT ver. 2019.2.2.59614 to determine the correlation between microplastic amounts and different environmental variables.

3. Results and Discussion

3.1. Evaluation of microplastic amounts in the Ba Lat sediment

Microplastic amounts in the Ba Lat sediment varied from 800 items.kg⁻¹ dw (in August 2020, the rainy season) to 3,817 items.kg⁻¹ dw (in December 2020, the dry season), averaging 2,188±1,499 items.kg⁻¹ dw for all four sampling campaigns (Fig. 2). A slightly higher value of microplastic concentration in the dry season (averaging 2,425±1,968 items.kg⁻¹ dw) than in the rainy one (1,950±1,626 items.kg⁻¹ dw) was observed (Fig. 2). Still, the statistical results did not show a significant seasonal difference (*p* > 0.05).

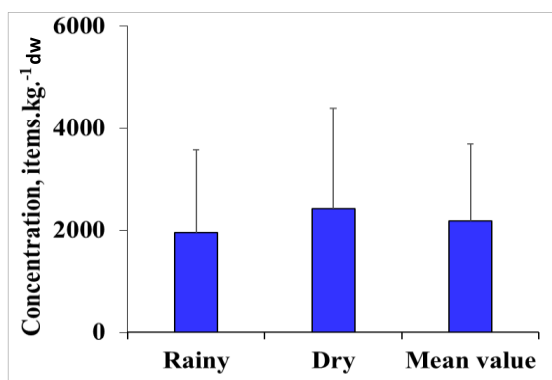


Figure 2. Microplastic concentrations in the Ba Lat estuary's sediment during four sampling campaigns in 2020

3.2. Typical features of microplastics in the Ba Lat sediment

3.2.1. Microplastic form and dimensions

The results of microscope observation indicated that microplastics in the Ba Lat sediment samples were mainly fiber and fragment shapes (Fig. 3). The fiber form has the highest frequency (94%), whereas fragment one was insignificant (6%) in four observation times in both wet and dry seasons. Seasonally, 90% of the fibers and 10% of the fragments were found during the wet season, whereas 97% of the fibers and 3% of the fragments were detected in the dry one (Fig. 4a).

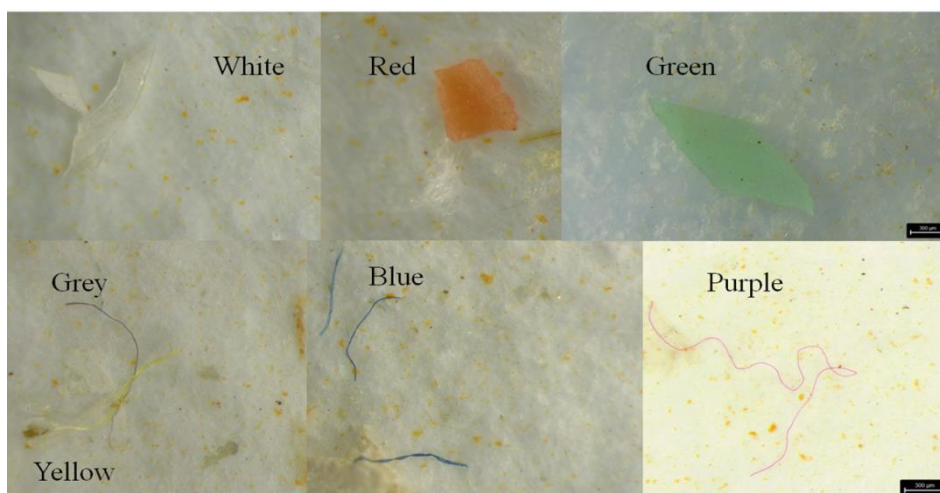


Figure 3. Some photos of microplastics in the Ba Lat estuary's sediment

Microplastic sizes were found mainly in the range of $< 500 \mu\text{m}$ (69%) for fibers and mostly in the range of $1,378\text{-}38,5691 \mu\text{m}^2$ for fragments. Regarding seasonal variation, in

the rainy season, fiber microplastics with the sizes of $500\text{-}1000 \mu\text{m}$ dominated, whereas those with small sizes ($<500 \mu\text{m}$) appeared mainly in the dry one (Fig. 4b).

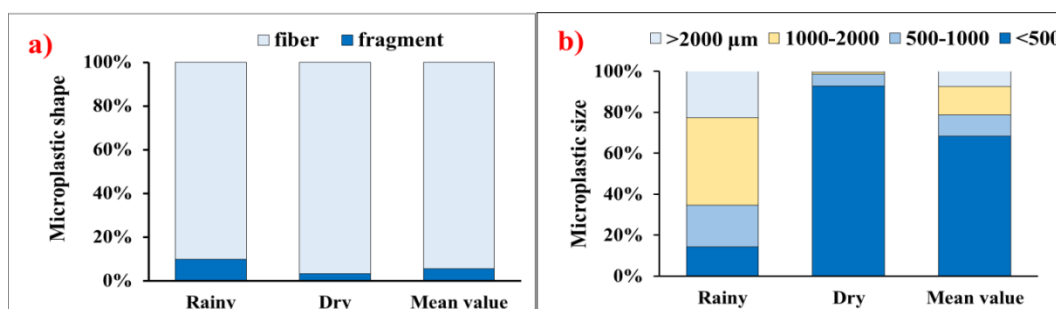
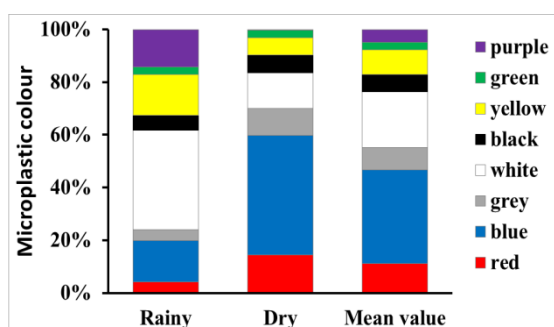


Figure 4. Distribution of microplastic form and dimension in the Ba Lat estuary's sediment

3.2.2. Color of microplastics

The microplastic colors observed at the Ba Lat site during the four sampling campaigns were white, blue, red, yellow, gray, purple, black, and green. The primary colors were blue (36%), white (21%), and red (11%). The least encountered color was green (3%) (Fig. 5).



←Figure 5. Distribution of microplastic color in the Ba Lat estuary's sediment

Seasonal variation was observed for microplastic colors in this study. In the rainy season, white (37%) was predominant, and blue and yellow colors equally accounted for 16%. In the dry season, blue color was the primary color, accounting for 45%, and red color was for 15% (Fig. 5).

3.2.3. Chemical nature of microplastics

The μ FTIR analysis showed the presence of numerous common plastics, including PE, PS, PA, and PU (Fig. 6). Among the different plastics found, PE accounted for 44%, PP for 43%, PS for 7%, and PA and PU equally accounted for 3%.

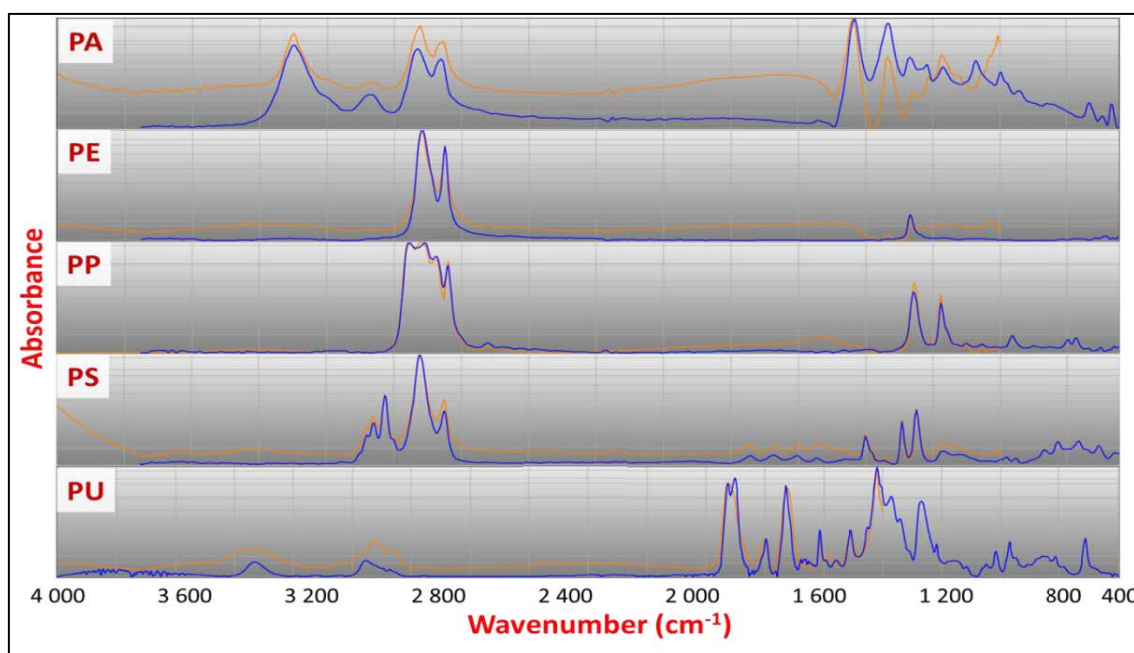


Figure 6. μ FTIR spectrums of PA, PE, PP, PS and PU (reference in blue and measure in orange)

3.3. Discussion of microplastic contamination in the Ba Lat estuary's surface sediment

3.3.1. Discussion of microplastic contamination level

Microplastics pose a significant environmental concern, as has been

demonstrated by numerous studies examining their presence in the hydro-systems of many countries. Table 2 lists the relative amounts of microplastics found in the sediment of the Ba Lat estuary and other rivers worldwide. The finding showed that the microplastic amounts in the Ba Lat sediment averaged $2,188 \pm 1,499$

items.kg⁻¹ dw, was far greater than that of the Nakdong river, Korea (Eo et al., 2019), but lower than that of some rivers in China, such as the Wen-Rui Tang (Wang et al., 2018), the Liangfeng (Xia et al., 2021) (Table 2). Some previous studies (Dris et al., 2015; Phuong et al., 2022) revealed that the difference in microplastic concentrations in different hydro-systems probably depends on study sites, meteorological-hydrological characteristics, microplastic sources, and the sampling and analysis methods used for microplastics. For example, microplastics in the riverine sediment of the To Lich, one of the Red River Delta's urban tributaries, reached a high value of 55,950±10,111 items.kg⁻¹ as a result of Hanoi city's untreated sewage (which amounted to roughly 960,000 m³ every day) (Duong et al., 2022).

Regarding microplastic form, fiber microplastics dominated in the Ba Lat

sediment. Fiber microplastics were also the predominant form in some sediments and river waters of Vietnam, including the To Lich - Nhue River and the Day River (Doan et al., 2021a; Duong et al., 2022), or in some other regions (Strady et al., 2021). In many rivers in the world, fiber microplastics appeared with great frequency in the sediment of some rivers such as the Ciwalengke, Indonesia (Alam et al., 2019), the Pearl (Lin et al., 2018), the Wei (Ding et al., 2019) and the Changjiang, China (Peng et al., 2017), and the Ottawa, Canada (Vermaire et al., 2017) (Table 2).

Concerning microplastic chemical nature, various polymers, including PP, PE, PS, PU, and PA, of which PE and PP accounted for 87%, were found in the sediment samples of the Ba Lat estuary. Different polymers were also detected in riverine sediments worldwide, depending on the microplastic sources (Table 2).

Table 2. Microplastics in sediments of some rivers in the World

Location	Microplastic concentration (items.kg ⁻¹ dw)	Dominated shape	Chemical nature	Sources of pollution	References
River Kelvin in Glasgow, Scotland, UK	161-432	Pellet, fiber, fragment	PP, PE	Domestic wastewater	(Blair et al., 2019)
River Thames, England	185±42 to 660±77	Fragment (91%)	PP, PE	Urban wastewater	(Horton et al., 2017)
Danube Romania to the Black Sea	159.2	Fiber, fragment, pellets	PET, PP, PS	Industrial and urban wastewater	(Pojar et al., 2021)
Ottawa River, Canada	220	Fiber	-	Domestic wastewater	(Vermaire et al., 2017)
Andean rivers, Ecuador	14.3-186.5	Fiber, film, fragment	-	Urban wastewater and agricultural activities	(Donoso et al., 2020)
Netravathi river, India	96	Fragment (44.4%)	PE, PET, PP	Domestic wastewater, pilgrims	(Amrutha et al., 2020)
Ciwalengke river, Indonesia	58.5±32.8	Fiber	PE, PA	Domestic wastewater, industrial activities	(Alam et al., 2019)
Nakdong river, Korea	1,970±62	Fragment (84%)	PP, PE	Domestic wastewater	(Eo et al., 2019)
Fuhe River, Baiyangdian Wetland, Northern China	17-36	fragment, fiber, film, pellet	PE, PP	Waste generated by people, factories, domestic wastewater	(Zhou et al., 2021)
Chao Phraya River, Thailand	91±13	Fragment, fiber	PP, PE, PS	Activities of residents and tourists	(Ta and Babel, 2020)
Shanghai River, China	802±594	Pellet (88.9%)	PP	Urban wastewater, industrial waste	(Peng et al., 2018)
Changjiang River, China	121±9 (20-340)	Fiber (93%)	Rayon, PE, PMMA	Clothes washing wastewater	(Peng et al., 2017)
Wen-Rui Tang, China	32,947±15,342	Fragment (45.9%) and foam (29.5%)	PE, PP, PS, PES	Industrial activities, domestic wastewater	(Wang et al., 2018)
Wei River, China	360-1,320	Fiber (42.25% - 53.20%)	PE, PVC, PS	Agricultural activities, domestic wastewater	(Ding et al., 2019)
Pearl river, China	80-9,597	Fiber	PE, PP	Urban wastewater, domestic waste	(Lin et al., 2018)
Liangfeng River, China	6,950-149,350	Fiber, fragment, film	PE	Domestic wastewater of seven universities, transportation activities	(Xia et al., 2021)
Kavery river, India	386.1±84.5	Fragment, fiber, foam	PA, PP, PVC, PS, PET	Industrial activities, domestic wastewater	(Maheswaran et al., 2022)
To Lich - Nhue, Vietnam	1,450-55,950	Fiber, fragment	PET, PVC	Domestic, industrial wastewater	(Duong et al., 2022)
Day River, Vietnam	1,450±494	Fiber, fragment	PET, PVC	Domestic, industrial wastewater	(Duong et al., 2022)
Ba Lat estuary, Red River, Vietnam	800-3,817	Fiber, fragment	PP, PE, PS, PA, PU	Domestic, industrial wastewater, agricultural runoff	This study

3.3.2. Factors impacted microplastic accumulation

3.3.2.1. Environment factors

Some variables (pH, nutrients, organic

carbon, and metals) of the sediment samples collected at the Ba Lat site in 2019 were analyzed and presented in our previous study (Le et al., 2022b). In this study, correlations between microplastic concentrations and other

Ba Lat sediment variables were checked by both Pearson and PCA analysis.

The Pearson analysis showed that within different variables observed, microplastic concentrations were positively correlated

with organic carbon and total nitrogen ($R^2 \sim 0.6$, $p < 0.05$), whereas they were negatively correlated with some variables such as Cd, Hg, and Cr (Table 3).

Table 3. Pearson correlation between microplastics and other variables of sediment quality at Ba Lat estuary

Variables	P	K	Si	OC	N	pH	Pb	Zn	Cu	Cd	Fe	Cr	Mn	As	Hg	MPI
P	1															
K	-0.376	1														
Si	-0.443	-0.576	1													
OC	-0.132	-0.627	0.914	1												
N	0.000	-0.552	0.801	0.973*	1											
pH	0.662	0.388	-0.964*	-0.789	-0.649	1										
Pb	-0.293	0.682	-0.659	-0.902	-0.954*	0.448	1									
Zn	-0.538	-0.126	0.214	-0.182	-0.403	-0.372	0.497	1								
Cu	0.554	0.505	-0.734	-0.423	-0.204	0.802	0.082	-0.813	1							
Cd	-0.333	0.225	-0.316	-0.662	-0.816	0.132	0.848	0.857	-0.399	1						
Fe	0.877	0.096	-0.813	-0.545	-0.386	0.938	0.129	-0.528	0.796	-0.112	1					
Cr	0.997**	-0.386	-0.463	-0.175	-0.054	0.675	-0.243	-0.473	0.519	-0.262	0.880	1				
Mn	0.000	0.716	-0.875	-0.990*	-0.970*	0.721	0.940	0.211	0.394	0.677	0.444	0.040	1			
As	-0.328	0.964*	-0.687	-0.796	-0.753	0.485	0.849	0.057	0.432	0.455	0.166	-0.318	0.869	1		
Hg	-0.333	0.225	-0.316	-0.662	-0.816	0.132	0.848	0.857	-0.399	1.000**	-0.112	-0.262	0.677	0.455	1	
MPI	-0.513	0.284	0.493	0.568	0.626	-0.526	-0.412	-0.411	0.061	-0.617	-0.524	-0.578	-0.465	0.032	-0.617	1

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed)

16 environmental variables in four sediment samples collected during wet and dry seasons were considered using a Principal Component Analysis (PCA) (Fig. 7). According to the PCA's results, the first two axes explained 84.3% of the variation, although the two cases couldn't be more different. The metals (As, Mn, Pb, Cd, Zn, and Hg) and Si of samples collected during the wet months were concentrated in the upper portion of the PCA plot, while those collected during the drier months were located in, the lower region, where organic carbon, microplastics, and total nitrogen were more prevalent. The PCA may also suggest that organic carbon controls how and where microplastics are found in the Ba Lat estuary's sediment over time and space.

A previous study revealed that microplastic concentrations in hydro-systems

were affected by seasonal changes, especially rainfall (Xia et al., 2021). In the rainy season, microplastics can be transported from the soil into the water, leading to significantly higher microplastic concentrations than in the dry season (Schmidt et al., 2018). Another study has shown the significant role of rainwater runoff in transporting microplastics to waterbodies (Cheung et al., 2019). In our research, in contrast, we found a slightly higher concentration of microplastics in the dry season (2,425 items.kg⁻¹ dw) than in the rainy one (1,950 items.kg⁻¹ dw). However, the statistical results from the student's test did not show an apparent seasonal variation of microplastic concentrations. That may suggest that microplastics from complex sources (both point and non-point sources) from the upstream Red River basin could end up in the sediment of the Ba Lat estuary.

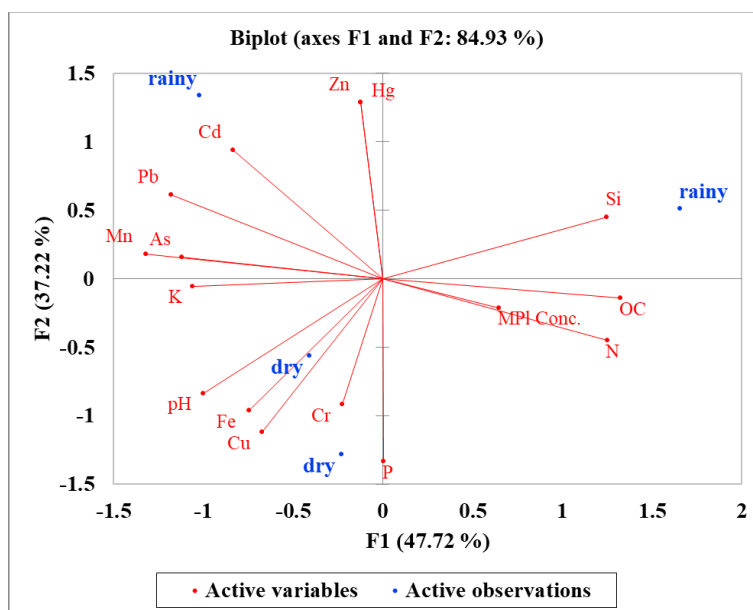


Figure 7. PCA of four sediment samples at the site Ba Lat in 2020.

All variations of sediment quality were expressed as the mean concentrations

3.3.2.2. Different sources of microplastics

Domestic waste

About 40 million people lived in the Red River watershed in 2019 (Wei et al., 2019). Many provinces and cities along the Red River discharge residential wastewater, but only around 30% of it is treated before being released into the hydro-system, as reported by the Vietnam Ministry of Natural Resources and Environment (MONRE, 2019). Domestic wastewater in urban areas, as is known, contains microplastics primarily from clothes washing or the use of cosmetic and beauty items (facial scrubs, shower gel, toothpaste, and so on). Furthermore, it could be noted that a great deal of solid plastic garbage from daily use is dumped into the environment, notably in the Delta. They are partially collected and transported to the landfill before being almost wholly burned or buried. During the retention time in the landfill, plastic waste may be degraded into microplastics and transferred into the hydro-system.

Solid waste and wastewater from industrial and craft village production

The Red River system may have pick up a lot of plastic and microplastics from near industrial zones. An estimated wastewater of $155,055 \text{ m}^3 \cdot \text{day}^{-1}$ is discharged into the hydrosystem by the industrial parks (chemical fertilizer, food processing, paper manufacturing, battery manufacturing, tanning, and textiles), which are present in numerous provinces and municipalities that make up the Red River Delta region (Nguyen et al., 2015; MONRE, 2009). As known most production companies already have wastewater treatment systems but cannot completely remove microplastics. Besides, plastics were used to make packaging and containers, especially single-use plastic products, and then discharged into the environment.

Craft villages, including silk weaving and fabric dyeing, and plastic recycling along the banks of the Red River system are also considered a significant microplastic source of the riverine environment when the wastewater

and solid waste do not have an effective treatment system. In addition, some craft villages are located in the middle of residential areas, making it difficult for the treatment process.

Agricultural land

Microplastic pollution in hydro-systems has been linked to the usage of chemical fertilizers and pesticides in agricultural areas and the breakdown of agricultural equipment (Lv et al., 2019; Battulga et al., 2020; Lestari et al., 2020). Agriculture in the Red River Delta is focused mainly on rice and vegetables. Indeed, many empty bags and containers used to store chemical fertilizers and pesticides were discarded in the agricultural land. In addition, organic fertilizers made from sludge may contain microplastics, as reported for other agricultural regions (Zhang et al., 2020).

On the other hand, according to another study (Lv et al., 2019), film and foam microplastics have been found in extremely high levels in the water and sediment of places near significant farming or agricultural planting areas. Our investigation found that fibers and fragments were the most prevalent microplastic forms, indicating that agricultural operations have a lower influence on the environment than domestic and industrial waste.

Possible effect of microplastic pollution in the Ba Lat sediment

Many benthic organisms inhabit sediments. Microplastics are found abundantly in riverine sediments, considered reservoirs or sinks for microplastics (Hurley et al., 2018). It is challenging to decompose microplastics in the natural environment. Organisms can eat and ingest fine particles such as microplastics into their bodies, causing many health problems and indirectly affecting humans through the food chain (Silva et al., 2022; Van Cauwenberghe et al., 2015). In addition, in the production of plastic

products, some additives are used, and the surface of microplastics is also a place to accumulate many toxic substances. Thus, they can cause illness or death to organisms.

In Vietnamese natural aquaculture ponds, microplastics were prevalent in bivalves. Doan et al. (2021b) reported microplastic amounts from 1.0-2.4 items.g⁻¹ in the green mussel in the three locations in North, Center, and South Vietnam (Nam Dinh province, Hue city, and Binh Dinh province). In contrast, Nam et al. (2019) found a value of 2.60 items.individual⁻¹ in *Perna Viridis* in Thanh Hoa province. Other studies revealed the microplastic concentrations in clam (*Meretrix Lyrata* Sowerby) (13.79±1.06 items.individual⁻¹) in the Mekong Delta River (Gia Hang et al., 2021) or the Red River clam (ranging from 0.25±0.16 to 0.67±2.98 items.individual⁻¹) (Hue et al., 2021).

The Ba Lat estuary is an essential North Vietnam aquacultural zone. Thus, microplastics in the Ba Lat sediment (2,188±1,499 items.kg⁻¹ dw) may affect aquacultural products. Our research highlights the need to observe microplastics for creatures, particularly in the Red River's prime aquaculture ground, and to limit the quantity of plastic waste released into the environment.

4. Conclusions

According to the data collected throughout four sampling campaigns in 2020, microplastic concentrations in the Ba Lat estuary's surface sediment were from 800 items.kg⁻¹ dw (August, wet season) to 3,817 items.kg⁻¹ dw (December, dry season), averaging 2,188±1,499 items.kg⁻¹ dw. It was discovered that microplastics fell into two main shape categories: fibers (94%) and fragments (6%). Microplastic sizes were found mainly in the range of < 500 µm (69%) for fibers, and mostly in the range of

1,378-38,5691 m² for fragments. Different microplastic colors were observed, of which blue (36%), white (21%), and red (11%) were the most abundant. In terms of polymer type composition, five types (PP, PE, PU, PA, and PS) were recognized, of which PE and PP were predominant.

Our results revealed an unclear seasonal variation of microplastic concentrations that may suggest complex microplastic sources at the Ba Lat site. Population growth and industrialization may strongly impact microplastic characteristics in the Ba Lat estuary's sediment, an important aquaculture zone. Our research highlighted the importance of monitoring organisms contaminated with microplastics, especially in the Red River aquaculture zone and Vietnam. Our findings further emphasized the importance of controlling plastic garbage discharged into the ecosystem.

Acknowledgments

The research fundings from the Graduate University of Science and Technology (Grant number: GUST.STS.ĐT 2020-MT01).

Credit authorship contribution statement

Le ND: Methodology, Sampling, analysis, Funding acquisition, writing for the draft. Hoang TTH: Sampling and analysis, data analysis, writing for the draft; Duong TT: Methodology, writing for the draft; Phuong NN: Formal analysis, writing for the draft; Le PT: writing for the draft; Nguyen TD: methodology; Formal analysis; writing for the draft; Phung TXB: data analysis; Le TMH: Sampling and analysis. Le TPQ: Methodology, sampling, analysis and writing for the draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Alam F.C., Sembiring E., Muntalif B.S, Suendo V., 2019. Microplastic distribution in surface water and sediment river around slum and industrial area (case study: Ciwalengke River, Majalayadistrict, Indonesia). *Chemosphere*, 224, 637-645.
- Amrutha K., Warriar A.K., 2020. The first report on the source-to-sink characterization of microplastic pollution from a riverine environment in tropical India. *Science of the Total Environment*, 739, 140377.
- Arthur C., Baker J., Bamford H., 2009. In Proceedings of the international research workshop on the occurrence, effects and fate of microplastic marine debris. NOAA Technical Memorandum NOS-OR & R-30.NOAA, 530. Silver Spring, September 9-11, 2008.
- Battulga B., Kawahigashi M., Oyuntsetseg B., 2020. Behavior and distribution of polystyrene foams on the shore of Tuul River in Mongolia. *Environ. Pollut*, 260, 113979.
- Blair R.M., Waldron S., Phoenix V.R., Gauchotte-Lindsay, 2019. Microscopy and elemental analysis characterisation of microplastics in sediment of a freshwater urban river in Scotland, UK. *Environmental Science and Pollution Research*, 26(12), 12491-12504.
- Cao T.T.T., Nguyen M.T., 2009. Assessment the accumulation of pollutants in the Cam Bach Dang estuary and Ba Lat river mouth area. Proceedings of Marine Natural resources and Environment, VAST's conference, 16, 143-150 (in Vietnamese).
- Cheung P.K., Hung P.L., Fok L., 2019. River microplastic contamination and dynamics upon a rainfall event in Hong Kong, China. *Environmental Processes*, 6(1), 253-264.
- Ding L., Mao R.F., Guo X., Yang X., Zhang Q., Yang C., 2019. Microplastics in surface waters and sediments of the Wei River, in the northwest of China. *Science of the Total Environment*, 667, 427-434.
- Doan T.O., Duong T.T., Nguyen T.N.H, Hoang T.Q., Le T.P.Q, Duong H.P., Le P.T., Bui H.T., 2021a. Preliminary results on microplastics in surface water from the downstream of the Day River.

- Vietnam Journal of Earth Sciences, 43(4), 485-495. <https://doi.org/10.15625/2615-9783/16504>.
- Doan T.O., Duong T.T., Nguyen T.N.H., Hoang T.Q., Vu T.N., Phuong N.N., Pham Q.T., Ngo T.X.T., Bui H.T., Le T.P.Q., 2021b. Efficiency assessment of microplastic extraction from green mussel *Perna viridis* Linnaeus. *Academia Journal of Biology*, 43(4), 5566. <https://doi.org/10.15625/2615-9023/16153>.
- Donoso J.M., Rios-Touma B., 2020. Microplastics in tropical Andean rivers: A perspective from a highly populated Ecuadorian basin without wastewater treatment. *Heliyon*, 6(7), e04302. <https://doi.org/10.1016/j.heliyon.2020.e04302>.
- Dris R., Gasperi J., Rocher V., Saad M., Renault N., Tassin B., 2015. Microplastic contamination in an urban area: A case study in Greater Paris. *Environ. Chem.*, 12, 592-599.
- Duong T.T., Le T.P.Q., Doan T.O., Nguyen N.H., Le N.D., Duong H.P., Le P.T., Trinh V.T., 2020. Preliminary assessment of microplastics pollution in surface water of the Nhuê River. 45th Conference of Vietnam Academy of Science and Technology on Environment and Energy, Hanoi, 4p.
- Duong T.T., Le P.T., Nguyen T.N., Hoang T.Q., Ngo H.M., Doan T.O., Le T.P., Bui H.T., Bui M.H., Trinh V.T, Nguyen T.L., 2022. Selection of a density separation solution to study microplastics in tropical riverine sediment. *Environmental Monitoring and Assessment.*, 194(2),1-7. <https://doi.org/10.1007/s10661-021-09664-0>.
- Eo S., Hong S.H., Song Y.K., Han G.M., Shim W.J., 2019. Spatiotemporal distribution and annual load of microplastics in the Nakdong River, South Korea. *Water Research*, 160, 228-237.
- GSO (General statistics office of Vietnam), 2020. General statistics office of Vietnam, retrieved from <https://gso.gov.vn/>.
- GESAMP, 2019. Guidelines or the monitoring and assessment of plastic litter and microplastics in the ocean. United Nations Environment Programme (UNEP), 138p.
- Gia Hang N.T., Do N., Nguyen M., Thanh T., Tran D., Le T., 2021. Microplastic pollution in clam (*Meretrix Lyrata* Sowerby, 1851) at Mekong Delta river, Vietnam. *Science and Technology Development Journal - Natural Sciences*, 5(3), 1443-1454. <https://doi.org/10.32508/stdjns.v5i3.949>.
- Hidalgo-Ruz V., Gutow L., Thompson R. C. and Thiel M., 2012. Microplastics in the marine environment: a review of the methods used for identification and quantification. *Environmental Science & Technology*, 46(6), 3060-3075.
- Hoa B.T., Huan N.X., Nam N.T., Ha L.T., 2020. Water quality of Ba Lat estuary. *Vietnam Journal of Marine Science and Technology*, 20(1), 51-59. <https://doi.org/10.15625/1859-3097/12892> (in Vietnamese).
- Horton A.A., Svendsen C., Williams R.J., Spurgeon D.J., Lahive E., 2017. Large microplastic particles in sediments of tributaries of the River Thames, UK - Abundance, sources and methods for effective quantification. *Mar. Pollut. Bull.*, 114, 218-226.
- Hue H.T.T., Dong L.K., Hien T.T., Nguyen T.N., Pradit S., 2021. Assessment of microplastics contamination in commercial clam in Viet Nam coast zone. *Applied Ecology and Environmental Research*, 19(6), 4977-4991. http://dx.doi.org/10.15666/aeer/1906_49774991.
- Hurley R., Woodward J., Rothwell J.J., 2018. Microplastic contamination of river beds significantly reduced by catchment-wide flooding. *Nat. Geosci.*, 11, 251-257. <https://doi.org/10.1038/s41561-018-0080-1>.
- Lahens L., Strady E., Kieu-Le T.C., Dris R., Boukerma K., Rinnert E., Gasperi J., Tassin B., 2018. Macroplastic and microplastic contamination assessment of a tropical river (Saigon River, Vietnam) transversed by a developing megacity. *Environ. Pollut.*, 236, 661-671.
- Le T.P.Q., Le N.D., Hoang T.T.H., Rochelle-Newall E., Nguyen T.A.H., Dinh L.M., Duong T.T., Pham T.M.H., Nguyen T.D., Phung T.X.B., Nguyen T.Q.T., Vu T.H., Le P.T., Phung V.P., 2022b. Surface sediment quality of the Red River (Vietnam): impacted by anthropogenic and natural factors. *International Journal of Environmental Science and Technology*. <https://doi.org/10.1007/s13762-022-03936-z>.
- Le N.D., Hoang T.T.H., Duong T.T., Lu X.X., Pham T.M.H., Phung T.X.B., Le T.M.H., Duong L.H., Nguyen T.D., Le T.P.Q., 2022. First observation of

- microplastics in surface sediment of some aquaculture ponds in Hanoi city, Vietnam. *Journal of Hazardous Materials Advances.*, 6, 100061. <https://doi.org/10.1016/j.hazadv.2022.100061>.
- Le T.P.Q., Le N.D., Dao V.N., Rochelle-Newall E., Nguyen T.M.H., Marchand C., Duong T.T., Phung T.X.B., 2018. Change in carbon flux (1960-2015) of the Red River (Vietnam). *Environ. Earth Sci.*, 77, 658. <https://doi.org/10.1007/s12665-018-7851-2>.
- Lestari P., Trihadiningrum Y., Wijaya B. A., Yunus K. A., Firdaus M., 2020. Distribution of microplastics in Surabaya River, Indonesia. *Sci. Total. Environ.*, 726, 138560.
- Lin L., Zuo L.Z., Peng J.P., Cai L.Q., Fok L., Yan Y., Li H.X., Xu X.R., 2018. Occurrence and distribution of microplastics in an urban river: A case study in the Pearl River along Guangzhou City, China. *Science of the Total Environment*, 644, 375-381.
- Lv W., Zhou W., Lu S., Huang W., Yuan Q., Tian M., Lv W., He D., 2019. Microplastic pollution in rice-fish co-culture system: a report of three farmland stations in Shanghai, China. *Sci. Total Environ.*, 652, 1209-1218.
- Maheswaran B., Karmegam N., Al-Ansari M., Subbaiya R., Al-Humaid L., Raj J.S., Govarthanam M., 2022. Assessment, characterization, and quantification of microplastics from river sediments. *Chemosphere*, 298, 134268.
- MONRE (Vietnam Ministry of Natural Resources and Environment), 2009. National report on Environment statement in 2009: Environment in industrial zones in Vietnam. Environmental Resources and Map of Vietnam, Hanoi.
- MONRE (Vietnam Ministry of Natural Resource and Environment), 2019. National report on Environment statement in 2018: Water Environment in river basins. Environmental Resources and Map of Vietnam, Hanoi.
- Nam P.N., Tuan P.Q., Thuy D.T., Quynh L.T.P., Amiard F., 2019. Contamination of microplastic in bivalve: first evaluation in Vietnam. *Vietnam Journal of Earth Sciences*, 41(3), 252-258. <https://doi.org/10.15625/0866-7187/41/3/13925>.
- Nguyen T.B.N., Le T.P.Q., Nguyen T.M.H., Nguyen B.T., Vu D.A., Duong T.T., Ho T.C., 2015. Preliminary results on some heavy metal contents in the Red River. *Vietnam Journal of Science and Technology*, 53(1), 64-76.
- Nguyen T.T.H., Zhang W., Li Z., Li J., Ge C., Liu J., Bai X., Feng H., Yu L., 2016. Assessment of heavy metal pollution in Red River surface sediments, Vietnam. *Marine Pollution Bulletin*, 113, 513-519. <https://doi.org/10.1016/j.marpolbul.2016.08.030>.
- Nguyen T.T.H., Vuong H.N., Zhang W.G., Lai V.C., Nguyen V.H., Le B.B., Nguyen P.T., Tran T.N., 2020. Distribution of heavy metals in the topsoil of agricultural land in Nam Dinh province, Vietnam. *Appl. Ecol. Env. Res.*, 18, 6793-6811. https://doi.org/10.15666/aer/1805_67936811.
- Peng G., Zhu B., Yang D., Su L., Shi H., Li D., 2017. Microplastics in sediments of the Changjiang estuary, China. *Environ. Pollut.*, 225, 283-290.
- Phuong N.N., Duong T.T., Le T.P.Q., Hoang T.K., Ngo H.M., Phuong N.A., Pham Q.T., Doan T.O., Ho T.C., Le N.D., Nguyen T.A.H., Strady E., Fauvelle V., Ourgaud M., Schmidt N., Sempere R., 2022. Microplastics in Asian freshwater ecosystems: Current knowledge and perspectives. *Science of the Total Environment*, 808, 151989, <https://doi.org/10.1016/j.scitotenv.2021.151989>.
- Plastics Europe, 2020. *Plastics: the Facts 2020: An Analysis of European plastics production, demand and waste data.* <https://plasticseurope.org/>.
- Pojar I., Stănică A., Stock F., Kochleus C., Schultz M., Bradley C., 2021. Sedimentary microplastic concentrations from the Romanian Danube River to the Black Sea. *Scientific reports*, 11(1), 1-9.
- Schmidt L.K., Bochow M., Imhof H.K., Oswald S.E., 2018. Multi-temporal surveys for microplastic particles enabled by a novel and fast application of SWIR imaging spectroscopy - study of an urban watercourse traversing the city of Berlin, Germany. *Environ. Pollut.*, 239, 579-589.
- Silva C.J., Machado A.L., Campos D., Rodrigues A.C., Silva A.L., Soares A.M., Pestana J.L., 2022. Microplastics in freshwater sediments: Effects on benthic invertebrate communities and ecosystem functioning assessed in artificial streams. *Science of The Total Environment*, Jan, 15, 804, 150118.
- Strady E., et al., 2021. Baseline assessment of microplastic concentrations in marine and freshwater environments of a developing Southeast Asian country, Viet Nam. *Mar. Pollut. Bull.*, 162, 111870.

- Ta A.T., Babel S., 2020. Microplastic contamination on the lower Chao Phraya: Abundance, characteristic and interaction with heavy metals. *Chemosphere*, 257, 127234.
- Trinh B.S., Dam V.N., Pham B.L., Pham H.C., 2021. A separation of plastic debris in Saigon river sediment using a microplastic sediment separator. *Science & Technology Development Journal-Science of The Earth & Environment*. Dec 27, 5(S11), S1137-46.
- Thompson R.C., Olsen Y., Mitchell R.P., Davis A., Rowland A.S.J., John A.W.G., McGonigle D., Russell A.E., 2004. Lost at Sea: where is all the plastic?. *Science*, 304(5672), 838.
- VASI (Vietnam Administration of Seas and Islands), 2011. Report of the Project "Impact assessment of contaminants load to Vietnamese marine environment", 116p (in Vietnamese).
- Van Cauwenberghe L., Devriese L., Galgani F., Robbins J., Janssen C. R., 2015. Microplastics in sediments: a review of techniques, occurrence and effects. *Marine Environmental Research*, 111, 5-17.
- Vermaire J.C., Pomeroy C., Herczegh S.M., Haggart O., Murphy M., 2017. Microplastic abundance and distribution in the open water and sediment of the Ottawa River, Canada, and its tributaries. *Facets*, 2, 301-314.
- Wang Z., Su B., Xu X., Di D., Huang H., Mei K., Dahlgren R.A., Zhang M., Shan X., 2018. Preferential accumulation of small (<300 μm) microplastics in the sediments of a coastal plain river network in eastern China. *Water research*, 144, 393-401.
- Wei X., Sauvage S., Le T.P.Q., Ouillon S., Orange D., Vinh V.D., Sanchez-Perez J-M., 2019. A modeling approach to diagnose the impacts of global changes on discharge and suspended sediment concentration within the Red River Basin. *Water*, 11, 958. <https://doi.org/10.3390/w11050958>.
- Xia F., Yao Q., Zhang J., Wang D., 2021. Effects of seasonal variation and resuspension on microplastics in river sediments. *Environmental Pollution*, 286, 117403. <https://doi.org/10.1016/j.envpol.2021.117403>.
- Zhang L., Xie Y., Liu J., Zhong S., Qian Y., Gao P., 2020. An overlooked entry pathway of microplastics into agricultural soils from application of sludge-based fertilizers. *Environmental Science & Technology*, 54(7), 4248-4255.
- Zhou Z., Zhang P., Zhang G., Wang S., Cai Y., H. Wang, 2021. Vertical microplastic distribution in sediments of Fuhe River estuary to Baiyangdian Wetland in Northern China. *Chemosphere*, 280, 130800.