Hue University Journal of Science: Natural Science
Vol. 134, No. 1S-1, 83–95, 2025 (Special Issue: IFGTM 2025)

pISSN 1859-1388
eISSN 2615-9678

Risk levels of microplastic pollution in surface water and sediments at Ba Be Lake

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(*Received: 24 June 2025; Revised: 29 July 2025; Accepted: 29 July 2025*)

Abstract. Microplastics, plastic particles smaller than 5 mm, have become a serious issue in lake water environments, negatively affecting ecosystems and water quality. This study on microplastic pollution levels in the surface water and sediments of Ba Be Lake provides essential insights into the pollution status in this area. The results reveal that microplastic concentrations in surface water range from 2.1 ± 0.4 to 14.2 ± 8.9 particles/m^3, and sediment contains from 29.5 ± 25.1 to 552.1 ± 760.6 particles/kg of dry weight. This indicates that microplastics tend to accumulate in sediment rather than remain suspended in the water column, resulting in a markedly higher abundance in benthic environments. Fibre-shaped microplastics dominate, and smaller particles account for the majority, indicating a diverse origin and easy dispersion in the environment. Fourier-transform infrared microscopy analysis helped to identify common types of microplastics in surface water and sediments, including urea-formaldehyde condensate, cellophane, polypropylene, and polyacrylamide. High-density microplastics tend to settle more into sediments, which may affect their transport and accumulation in the environment. The risk index of the detected polymers shows that the polymer hazard index scores for surface water and sediment in Ba Be Lake are 1024.2 and 1814.6, respectively, both classified under pollution level V (extremely hazardous). This indicates a significant threat to human health and ecosystems. These findings enhance the understanding of microplastic pollution in Ba Be Lake and support environmental managers in developing practical solutions to control and mitigate pollution in the area.

Keywords: microplastics, Ba Be Lake, polymer hazard index, surface water, sediment

1 Introduction

Plastics are materials developed with a wide range of diverse properties, from durability and flexibility to heat resistance and ease of processing, helping to meet the varied needs of human use. Thanks to these advantages, plastics are found in all fields, from daily life to industry, healthcare, and technology. Additionally, plastics have a low production cost, which helps reduce industry expenses, making product prices more competitive and accessible to consumers. As a result, the demand for plastics in both production and consumption continues to increase, driving strong growth in global plastic production [1].

Microplastics are plastic particles smaller than 5 mm, representing a persistent form of environmental pollution that is increasingly widespread in freshwater ecosystems, particularly in lakes [2]. They can originate from rainwater, surface runoff, and human activities; through the degradation of larger plastic waste due to environmental factors such as temperature, wind, and waves; from synthetic fibres, or directly from manufactured plastic particles [3].

The plastics industry continuously develops and innovates, introducing new plastic products, ranging from recycled plastics to bioplastics, contributing to meeting the increasingly high demands for sustainability and environmental protection [1]. According to a report published by Plastics Europe, in 2023, global plastic production reached 413.8 million tons, an increase of 13.4 million tons compared with 2022 [4].

During their presence in the environment, microplastics can accumulate harmful substances, such as aluminum, arsenic, lead, chromium, and other heavy metals, on their surfaces [5]. These metals may cause cancer, cardiovascular diseases, birth defects, and genetic impacts on future generations [5]. Because of their small size, microplastics are easily mistaken for food sources by aquatic organisms, leading to ingestion and the movement through different trophic levels in the food chain, transferring toxic substances and affecting both ecosystems and human health [5].

Freshwater lakes play a crucial role in sustaining ecosystems and human well-being, especially when climate change continues to intensify worldwide. Microplastics have already been detected in surface water and sediment in natural lakes, potentially affecting key environmental functions such as supporting biodiversity, providing freshwater resources, and regulating climate [6].

Chen analysed factors contributing to microplastic pollution in lakes from 42 research papers on the subject, revealing significant differences in microplastic abundance across various lakes. Their distribution patterns are influenced by geographical location, sampling methods, and extraction techniques [7]. Microplastic size varies distinctly between water and sediment, with a notably higher proportion of small microplastics (<1 mm) in sediment (72%) compared with water (46%). Environmental risk assessments indicate that microplastic pollution levels in most lakes worldwide are low, although pollution risks in lake water are higher than in sediments [7].

In China, Jiang and colleagues investigated Dongting West Lake and Dongting South Lake and found that microplastic concentrations in surface water ranged from 616.7 to 2216.7 particles/m^3 and from 716.7 to 2316.7 particles/m^3, respectively. The microplastic levels in sediment varied from 320 to 480 particles/m^3 in the former and from 200 to 1150 particles/m^3 in the latter.

A study on microplastics in the surface water environment of lakes in Hanoi, focusing on three major lakes—West Lake, Yen So Lake, and Bay Mau Lake—revealed that microplastics are widely and unevenly distributed across all the three lakes. The highest microplastic density was observed in West Lake, situated in the most densely populated area, where tourism and aquaculture activities are prevalent (8). The study also examined the status and characteristics of microplastic pollution in seven urban lakes in Da Nang, Vietnam. This study was conducted in two seasons—the dry and the rainy seasons—to assess seasonal variation. The results show that microplastic concentrations in surface water ranged from 293.3 ± 23.1 to 6510.0 ± 380.4 particles/m^3 in the dry season and from 366.7 ± 23.1 to 1143.3 ± 110.2 particles/m^3 in the rainy season, which are considered to be within the average range of global lake microplastic pollution. An ecological risk assessment based on the Pollution Load Index (PLI) and the Potential Ecological Risk Index (PERI) indicated that, except for Hoa Nghi Lake, which exhibited high risk during the dry season, most of the surveyed lakes had low ecological risk levels [9].

Ba Be Lake is one of Vietnam's largest freshwater lakes and was designated as a Ramsar site in 2011, playing a vital role in the regional

pISSN 1859-1388
eISSN 2615-9678

freshwater ecosystem and environmental conservation. With an area of 500 hectares and situated at an elevation of 145 metres, Ba Be Lake forms a rich ecosystem that maintains water quality, regulates climate, and provides habitat for numerous rare plant and animal species [10, 11]. The lake performs essential environmental functions such as water storage, soil conservation, and disaster mitigation while supporting biodiversity and offering ecological services to local communities.

Protecting Ba Be Lake is not only essential for conserving a valuable natural ecosystem but also represents a strategic effort towards sustainable development and addressing global environmental challenges. This study was conducted to assess the density, types, shapes, and sizes of microplastics in both surface water and sediment in Ba Be Lake, thereby evaluating the potential ecological risks associated with their presence. To the best of our knowledge, no previous studies have investigated microplastic pollution in Ba Be Lake, making this research the first to provide baseline data for this important freshwater ecosystem.

2 Materials and methods

2.1 Study sites and sampling

Ba Be Lake, located in Ba Be District, Bac Kan Province (Northeastern Vietnam), is the largest natural freshwater lake in the country. Geologically, it lies within a karst limestone region formed during the Permian-Carboniferous period (approximately 250–300 million years ago), characterised by cliffs, caves, and subsurface drainage systems. The lake comprises three interconnected sections—Pe Lam, Pe Lu, and Pe Leng—with a total length of approximately 8 km and a surface area of around 500 hectares.

Climatically, the area falls within the humid subtropical monsoon zone, receiving an average annual rainfall of 1,500 to 2,000 mm, mostly concentrated in the rainy season from May to October. The mean annual temperature ranges from 21 to 23 °C. These climatic and hydrological conditions significantly influence the transport, dispersion, and accumulation of pollutants within the lake ecosystem.

Ba Be Lake plays a crucial role in supplying freshwater to local communities, supporting aquaculture, promoting ecotourism, and maintaining regional biodiversity, including several rare and endemic aquatic species. However, the lake has experienced increasing anthropogenic pressures such as domestic wastewater discharge, agricultural runoff, and unregulated tourism activities from surrounding catchments and local settlements.

In this study, five sampling sites were strategically selected to represent key zones of the lake, including open-water areas, inlet and outlet regions, and nearshore zones adjacent to residential areas. Site selection was based on a combination of land-use analysis, field accessibility, and the expected gradient of anthropogenic influence, aiming to capture spatial variability in microplastic contamination and identify potential pollution sources.

A total of 30 environmental samples, including both surface water and bottom sediment, were collected in October 2024, corresponding to the end of the rainy season. Specifically, 15 surface water samples and 15 bottom sediment samples were obtained. This timing was chosen to reflect the potential accumulation of pollutants following peak surface runoff and to provide insights into seasonal patterns of microplastic distribution within the lake. The sampling locations are illustrated in Fig. 1.

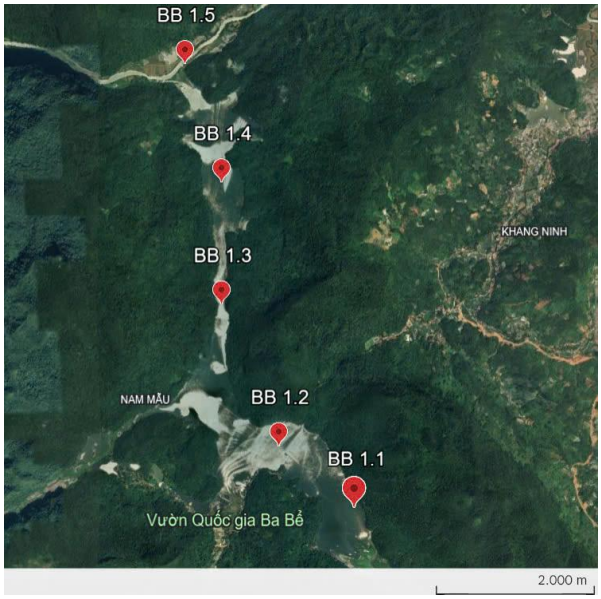

Fig. 1. Sampling locations in Ba Be Lake

Table 1. Sampling locations in Ba Be Lake

Location	Longitude	Latitude
BB 1.1	1.22.398889	2.105.631389
BB 1.2	3.22.405833	4.105.622222
BB 1.3	5.22.421667	6.105.615278
BB 1.4	7.22.435278	8.105.615278
BB 1.5	9.22.4439	10.105.6122

A total of 15 surface water samples were collected from Ba Be Lake by using a Manta net (Hydro-Bios, Germany), as shown in Fig. 2a. The net was placed horizontally at the water surface, and the towing time was recorded to calculate the water volume filtered. The samples were collected three times consecutively, preserved in 500 mL glass bottles, and labelled with time, location, and environmental conditions such as water temperature, salinity, and flow rate [12, 13].

The other 15 sediment samples were collected by using a Wildco grab sampler (USA) (Fig. 2b). At each location, the samples were collected three times consecutively to ensure accuracy and representation, preserved in 1000 mL glass bottles (Duran, Germany), and labelled with location and sampling time. They were kept at 4 °C in insulated containers and transported to the laboratory for further refrigerated storage and analysis of microplastic characteristics.

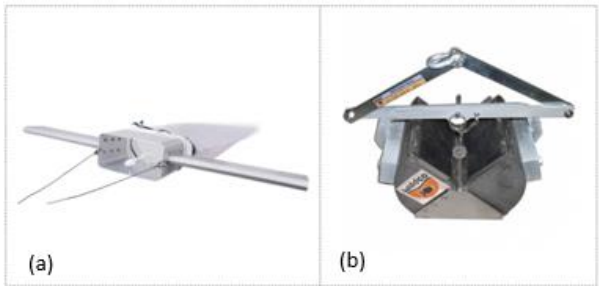

Fig. 2. Sampling tools for microplastics in sediment and surface water: (a) Manta trawl with 300 µm mesh size; (b) Grab sampler for sediment microplastics

2.2 Microplastics extraction and identification

The chemicals and materials used in this study were of analytical grade and applied without further purification. H_2O_2 (30%), $FeSO_4{\cdot}7H_2O$ (≥99%), and NaCl (≥99%) were all purchased from Merck (Germany). Sartorius filter papers (0.45 µm pore size, 47 mm diameter) were used for filtration. The extraction followed the method developed by Masura et al., as published by NOAA [14], in which the density separation with NaCl and organic matter digestion using Fenton's reagent were used. The water samples were sieved with a 5 mm mesh to remove large debris. Then, 20 mL of 0.05 M Fe^{2+} and 20 mL of 30% H_2O_2 were added and heated at 60 °C for 6 hours to degrade organic matter. If necessary, the solution was replenished until fully digested. Next, the separation with saturated NaCl was applied, followed by vacuum filtration with Sartorius 0.45 µm cellulose acetate filters. The samples were scanned with a Micro-FTIR Nicolet iN10 MX microscope (Thermo Fisher Scientific, USA) under contamination-free lab conditions to analyse polymer components in the microplastics. In this study, the microplastic particles isolated from surface water and sediment samples were analysed by using micro-Fourier-Transform Infrared Spectroscopy (µ-FTIR) in the ATR reflectance mode. The analysis was conducted on a

pISSN 1859-1388
eISSN 2615-9678

Nicolet iN10 MX Infrared Imaging Microscope (Thermo Fisher Scientific, USA) equipped with a highly sensitive liquid nitrogen-cooled Mercury Cadmium Telluride (MCT) detector to ensure low noise and high spectral resolution. After filtration and drying, selected particles from each sample were carefully transferred onto gold-coated microscope slides with clean tweezers and a fine needle under a stereomicroscope. The slides were then mounted on a motorised sample stage for precise scanning. The MCT detector was precooled with liquid nitrogen for at least 20 minutes before data acquisition to ensure optimal sensitivity. Spectral scanning was performed with an aperture size of 150 × 150 μm, and each spectrum was acquired by averaging 16 scans per pixel, with a total scan time of approximately 3 seconds per point. Depending on the number and distribution of microplastic-like particles, each sample area was scanned for 5 to 10 minutes. Microplastics were identified on the basis of their infrared spectra and morphology by using the integrated software of the Nicolet iN10 MX system. The software provided output parameters, including polymer type, match percentage, particle size (length and width), area coverage, corresponding infrared spectra, and optical images. Polymer identification was performed by comparing the acquired spectra with a built-in reference database.

For sediment samples, the preparation process followed the method of Scheurer and Bigalke [15]. The samples were dried at 55–60 °C for 48 to 72 hours, then homogenised and accurately weighed (50 g). Organic matter was removed by treating the samples with 30% hydrogen peroxide (H_2O_2) at 60 °C. Microplastics were separated by using a saturated sodium chloride (NaCl) solution with a density of approximately 1.2 g/mL and allowed to settle for 24–48 hours. The supernatant, containing microplastics, was vacuum filtered through 0.45 μm cellulose acetate membranes and stored in Petri dishes at ambient temperature prior to analysis with a Micro-FTIR spectrometer (Nicolet iN10 MX) [15].

Fig. 3. Micro-FTIR Microscope – Nicolet iN10 MX (Thermo Fisher Scientific, USA)

2.3 Quality control measures

Prior to initiating the analytical procedure, all the laboratory equipment was rinsed with 70% ethanol to eliminate potential contaminants. Throughout sample processing, the analysts wore cotton laboratory coats and nitrile gloves to minimise the risk of contamination. Only glass or metal instruments and containers were employed for both sampling and analysis. All the procedures were conducted in a closed, controlled laboratory environment to prevent airborne particle intrusion. Additionally, all the chemical reagents and distilled water were pre-filtered using GF/A glass fibre filters.

To assess the extent of airborne microplastic contamination during analysis, a GF/A filter was placed in an open Petri dish and exposed to ambient laboratory conditions concurrently with sample processing.

To evaluate the recovery efficiency of the microplastic extraction and analysis protocol, recovery tests were performed by spiking three sediment samples (approximately 50 g each) collected from the study site with a total of 20 polypropylene (PP) (10 particles) and polystyrene (PS) (10 particles) microplastic particles (~1 mm in

size; Sigma-Aldrich, USA). To evaluate the recovery efficiency of microplastics in water samples, a spiking experiment was conducted by adding 20 microplastic particles (including 10 PP and 10 PS particles) into three different field-collected water samples. These samples were subjected to the same processing and analytical procedures as the unspiked samples. The spiked samples were then processed following the standard analytical procedure described in this study.

The microplastic recovery rate (R) was calculated using the following equation

$$R = N_i/N(\%)$$

where R is the calculated microplastic recovery rate (%); N_i is the quantity of standard microplastics recovered after analysis; N is the number of standard microplastic particles added to the analysed sample.

The calculated recovery rates were 92.0 ± 3.1% for PP and 89.0 ± 2.5% for PS in surface sediment. For surface water samples, the recovery rates were slightly higher, with 96.5 ± 2.2% for PP and 95.3 ± 1.9% for PS, likely because of the lower matrix complexity and easier separation of microplastic particles in aqueous samples. These results indicate high efficiency and reliability of the applied method and are consistent with findings reported by Wu et al. (2020), which also demonstrated effective microplastic recovery using similar techniques.

2.4 Microplastics risk assessment

a. The density of microplastics in water was determined by using the following formula

$$C_w = \frac{n}{V} \text{ (particles/m}^3\text{)}$$

where C_w is the microplastic concentration in water; n is the number of microplastic particles counted in the sample; V is the sample volume (m^3).

b. The concentration of microplastics in sediment was determined using the following formula

$$C_s = \frac{n}{m} \text{(particles/kg)}$$

where C_s is the microplastic concentration in sediment; n is the number of microplastic particles counted; m is the dry sediment mass (kg)

c. Chemical composition risks in microplastics

The potential risk (polymer hazard index – PHI) of microplastics in Ba Be Lake is evaluated on the basis of the concentration and hazard scores of the chemical components of microplastics. The toxicity of the different types of microplastics is studied and scored to assess their ecological impact. The polymer hazard index for the microplastic types in this study is calculated according to the formula presented by Xu et al. as follows:

$$PHI = \sum_{n=1}^{n} P_n \times S_n \qquad [16]$$

where P_n is the proportion of each polymer in the sample; S_n is the hazard score of the corresponding polymer in the microplastics [17].

Table 2. PHI classification for both water and sediment environment

PHI	Pollution Level	
0–1	I	Low
1–10	II	Medium
10–100	III	High
100–1000	IV	Dangerous
>1000	V	Extremely hazardous

pISSN 1859-1388
eISSN 2615-9678

2.5 Data analysis

The microplastic data were analysed by using descriptive statistics, calculating density (particles per m³ of water or per kg of sediment). Excel was used to analyse the distribution and trends. Statistical methods such as ANOVA and the Kruskal-Wallis test were applied to compare microplastic densities between sampling areas, supporting environmental management and pollution reduction proposals.

3 Results and discussion

3.1 Concentration of microplastics

The analysis results presented in Fig. 4 show that microplastics were present in all the surface water samples at the surveyed sites in Ba Be Lake. The concentration of microplastics in surface water ranged from 2.1 ± 0.4 to 14.2 ± 8.9 particles/m³ (n = 15), with an average value of 6.2 ± 3.7 particles/m³. This level is significantly higher than that in some other inland water bodies in Vietnam, such as Tri An Lake (1.5 particles/m³) [18] and the Bach Dang estuary (3.4 particles/m³) [19]. In the Central region, Quynh Anh et al. recorded that the density of microplastics in the surface water of lakes in Da Nang was significantly higher than in Ba Be, with an average value of 2,145.2 ± 322.6 particles/m³ in the dry season and 643.8 ± 87.5 particles/m³ in the rainy season [9]. Compared with major lakes around the world, Ba Be Lake has a higher microplastic density than Lake Victoria in Africa (2.2 particles/m³) [20] but still much lower than Lake Luruaco — a water body in the lower Magdalena River basin (Colombia), where concentrations of up to 250 particles/m³ were recorded during the rainy season. Similarly, Ba Be Lake also shows significantly lower pollution levels than Lake Taihu (China), where microplastic concentrations range from 3.4 to 25.8 particles/L, equivalent to approximately 3,400 to 25,800 particles/m³ [21]. This stark difference is largely attributed to the geographical characteristics and the degree of human impact on each lake. Ba Be Lake is a natural freshwater lake located in the core zone of a national protected area, with a relatively pristine ecosystem and minimal influence from urbanisation or industrial activities. In contrast, the lakes in Da Nang and Taihu are situated in rapidly developing urban areas with high population density and regular exposure to domestic wastewater and plastic waste from daily human activities. Statistical analysis, including one-way ANOVA and Kruskal-Wallis tests, indicated no statistically significant differences in microplastic concentrations among the sampling locations for either surface water or sediment samples ($p > 0.05$). Although elevated concentrations were observed at certain sites (e.g., BB 1.5 for water and BB 1.3 for sediment), the differences were not significant at the group level.

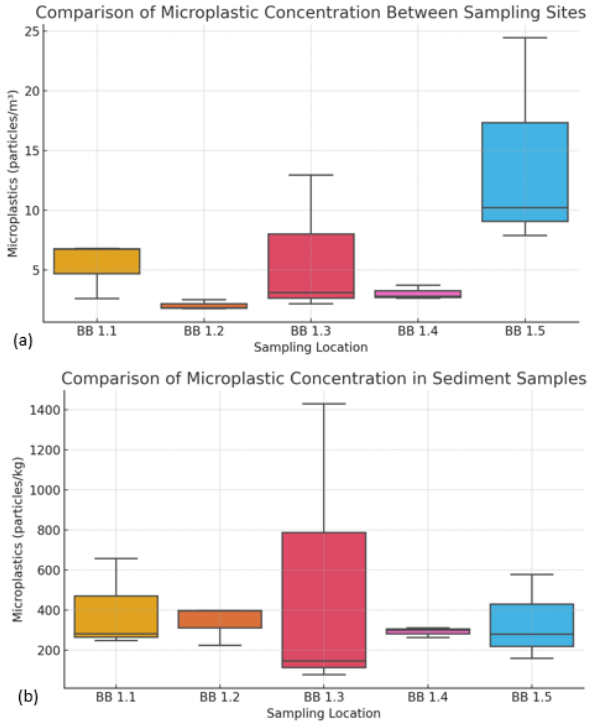

Fig. 4. Microplastic concentrations: (a) in surface water; (b) in sediment at sampling sites in Ba Be Lake

Notably, among the sampling sites in Ba Be Lake, site BB 1.5 recorded the highest microplastic concentration, reaching up to 24.4 particles/m^3. The primary reason is believed to be its location at the headwaters, where inflows carry microplastics from upstream residential areas, particularly the Khang Ninh region. Additionally, the slow flow characteristics of this area contribute to increased accumulation of microplastics, whereas the mid-lake areas have better water circulation and dilution conditions, resulting in significantly lower microplastic concentrations.

Similar to water samples, all the sediment samples contained microplastics. The microplastic concentrations in sediments ranged from 291.46 ± 25.1 to 552.1 ± 760.6 particles/kg, with a mean value of 384 ± 265.8 particles/kg. The highest concentration was observed at sampling site BB 1.3, located in the central region of the lake, with a value of 552.1 ± 760.6 particles/kg. This elevated concentration is primarily attributed to the site's topographical depression and weak hydrodynamic conditions, which favour the deposition and accumulation of microplastic particles from the water column onto the lakebed. Furthermore, the BB 1.3 site functions as a natural sedimentation zone, receiving inflows that transport microplastics from upstream locations such as BB 1.5 and BB 1.4. The low flow velocity and minimal physical disturbance in this area enhance the persistence of microplastics in the sediment, resulting in higher accumulation compared with other sites within the lake. In comparison with other lakes globally, Ba Be Lake exhibits a relatively high level of microplastic accumulation in sediments. For instance, lakes in Northern Italy have been reported to contain an average concentration of only 14.4 ± 13.3 particles/kg [22]; while Lake Superior (USA) has recorded approximately 65 particles/kg [23]; and Lake Huron, Ontario (Canada), has a reported concentration of around 290 particles/kg [24]. These findings suggest that the natural environment, geomorphology, and hydrodynamic conditions of Ba Be Lake may contribute significantly to the localised accumulation of microplastics in its central region.

3.2 Size and shape of microplastics

The shape proportion of microplastics found in water and sediment from Ba Be Lake is illustrated in Fig. 5. Similar to findings in various estuarine environments, fibrous microplastics were the most prevalent shape, accounting for the largest proportion in both the environments. We used the length-to-width ratio to determine the shape of microplastic particles, following the approach described by Manh et al. [25]. Specifically, fibres made up 71% of the total microplastics in both water samples (Fig. 5a) and sediment samples (Fig. 5b). The second most common type was fragment-shaped microplastics, comprising 28% in water samples and 29% in sediments. Notably, pellet-shaped microplastics were present at a very low proportion—1% in water samples—and were not detected in sediments. These results are largely consistent with Vietnamese studies. For example, Nguyen Hoai Nhu Y et al. identified fibrous microplastics as the dominant shape, accounting for 86.5% of the total particles across all the samples [26]. Le et al. also reported that fibrous and fragment-shaped microplastics were the primary forms detected, with fibres being predominant, accounting for 94% of the total microplastics [27]. Additionally, Wang et al. indicated that fibres and fragments were the dominant microplastic shapes in the surface water of the Chao Jiang estuary, China [28].

These results indicate a clear dominance of fibrous microplastics in the Ba Be Lake environment. This kind of microplastics may originate from domestic and tourism-related sources, activities that potentially release fibres

pISSN 1859-1388
eISSN 2615-9678

from textiles, fishing nets, or degraded plastic products. These similar distribution patterns observed between water and sediment samples also reflect a high settling potential of fibrous microplastics because of their lightweight nature, making them easily transported by water currents before settling on the lakebed.

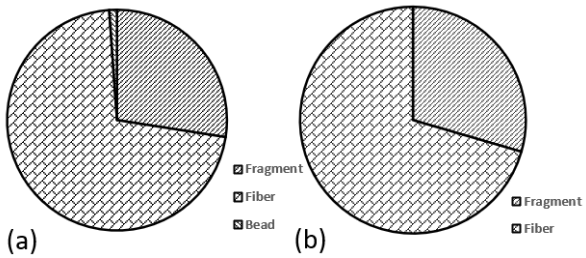

Fig. 5. Proportion of microplastic shapes: (a) in water; (b) in sediment

The analysis of microplastic size distribution at the surveyed sites in surface water and sediments of Ba Be Lake revealed predominant size classes ranging from 100–500 μm to 500–1000 μm, with a clear presence in both environments. In surface water (Fig. 6a), microplastics sized 100–500 μm were the most abundant, particularly prominent at sites BB 1.3 and BB 1.5, where this size class dominated the microplastic composition. Additionally, the size classes of 0–100 μm and 500–1000 μm were also present in significant proportions, reflecting the diversity of microplastic sizes in the water column. Microplastics sized 1000–5000 μm appeared at low levels and were relatively uncommon. Significant differences in microplastic concentrations were observed among size classes in both the water and sediment samples. One-way ANOVA and Kruskal–Wallis tests consistently revealed that smaller particles, particularly those in the 100–500 μm range, were significantly more abundant than those with larger sizes ($p < 0.05$), indicating a dominant contribution of finer microplastics in the aquatic system.

In sediments (Fig. 6b), a similar size distribution trend was observed with the 100–500 μm and 500–1000 μm size classes, accounting for the highest proportions at most sampling sites. Notably, sites BB 1.2, BB 1.3, and BB 1.5 exhibited a high density of microplastics within these size ranges. Although particles smaller than 100 μm were detected, they constituted a smaller fraction compared with the other size classes. The 1000–5000 μm size class appeared only in low proportions at some sites, indicating limited deposition of larger particles in the lake sediments.

The differences in size distribution between surface water and sediments reflect distinct transport and deposition mechanisms of microplastics. Smaller particles tend to remain suspended and dispersed within the water column, whereas larger particles are more prone to settling and accumulating in the lakebed sediment. These findings highlight the significant presence of microplastic pollution in both the environments of Ba Be Lake, especially concentrated within the medium size range.

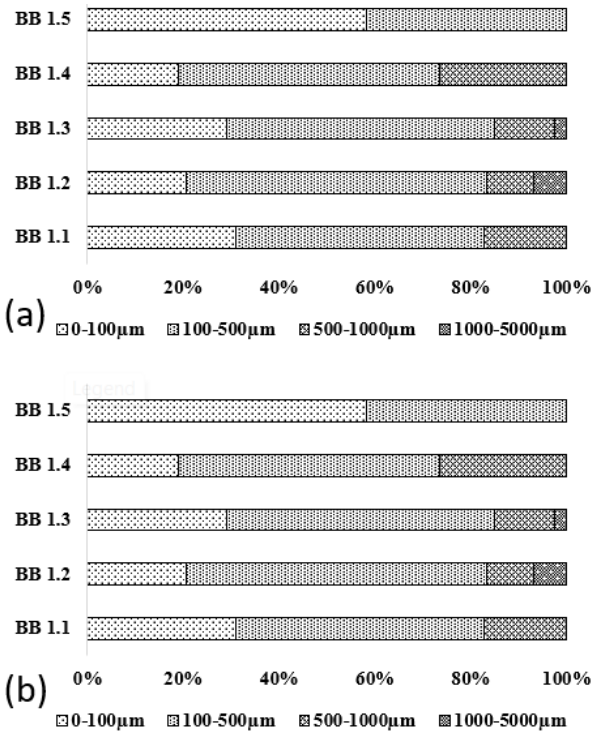

Fig. 6. Size distribution of microplastics: (a) in water; (b) in sediment

3.3 Polymer composition of microplastics

The FTIR analysis reveals a diverse polymer composition of microplastics in the surface water of Ba Be Lake, with 16 polymer types identified. Urea-formaldehyde condensate accounted for the highest proportion (29%), indicating sources related to plywood, furniture, or adhesives. Ethylene vinyl alcohol (EVOH EVAL) film (19%) and phenol resin (15%) were the next most common polymers, associated with food packaging and electronic materials. Cellophane and melamine-urea-formaldehyde resin each comprised 9%, suggesting influences from household waste and tourism activities. The remaining 11 polymer types collectively represented 19%, reflecting a variety of emission sources.

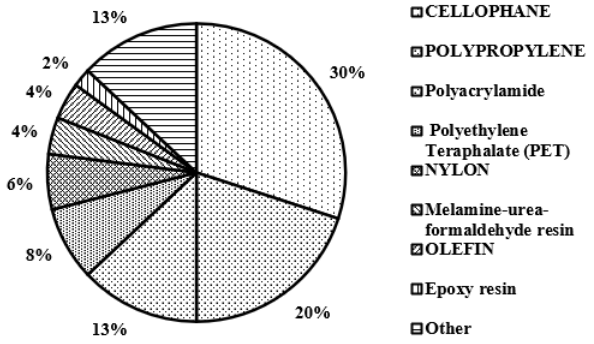

Fig. 7. Polymer composition of microplastics in surface water of Ba Be Lake

The polymer composition analysis of sediments from Ba Be Lake reveals a complex plastic pollution profile, with at least 17 different polymer types identified. Cellophane emerged as the dominant component, accounting for 30%, indicating significant influence from household waste and packaging materials. This was followed by polypropylene (20%), reflecting inputs from consumer product waste. Notably, polyacrylamide, commonly used in wastewater treatment and agriculture, made a 13% share. Additionally, common plastics such as PET (8%) and nylon (6%) were detected. The presence of industrial polymers like epoxy resin (2%) and durable materials such as Teflon and fluorocarbon-PFA suggested the accumulation of industrial waste. Overall, this diverse polymer composition indicates that sediment pollution in Ba Be Lake originates from multiple sources, ranging from daily domestic activities to agriculture and industry, raising concerns about long-term impacts on the ecosystem.

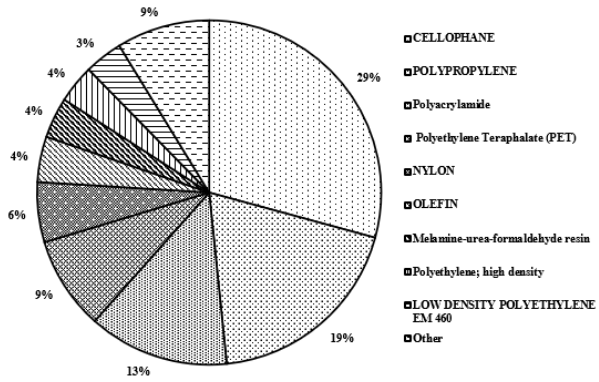

Fig. 8. Polymer composition of microplastics in the sediments of Ba Be Lake

3.4 Polymer hazard index

The calculation indicated that the total polymer hazard index (PHI) of microplastics in the surface water of Ba Be Lake was 1024.2, and the total PHI in sediments was notably higher at 1814.6. This suggests a greater potential ecological risk from microplastics in sediments compared with surface water, likely because of their prolonged retention and accumulation in the benthic environment. In surface water, polymers with high PHI values included phenol resin (224.9), polyacrylamide (220.5), and urea-formaldehyde condensate (214.7), and they exhibit significant ecological toxicity and biological hazard potential. In sediments, polyacrylamide (1644.8) was the primary contributor to the overall risk, accounting for the largest share, and likely reflects its high occurrence frequency and considerable ecological toxicity. Overall, polymers with elevated PHI values should be prioritised in environmental monitoring and

pISSN 1859-1388
eISSN 2615-9678

management strategies, particularly in areas with high sediment accumulation, where they pose long-term risks to benthic organisms and aquatic food webs.

Table 3. Comparison of PHI values in selected studies

Location		PHI		Ref.
		Score	Level	
India	Sediments of Kodaikanal Lake	>1000	V	[29]
Bangladesh	Surface water of Mohamaya Lake	936 to 73857	III to V	[30]
	Sediments of Mohamaya Lake	684 to 11606	III to V	[30]
	Surface water of Kaptai Lake	999.29	IV	[31]
Vietnam	Surface water of Ba Be Lake	1024.20	V	This study
	Sediments of Ba Be Lake	1814.65	V	This study
	Surface water from Red River to the Gulf of Tonkin	1207.20	V	[32]
	Sediments from Red River to the Gulf of Tonkin	792.40	IV	[32]

The PHI values of microplastics at the surveyed sites show a significant variation, reflecting uneven levels of pollution and environmental risk across different regions. Among them, Ba Be Lake (Vietnam) recorded elevated PHI values, with 1024.2 in surface water and notably 1814.6 in sediments, both classified as risk level V (extremely hazardous), indicating a substantial potential impact on benthic organisms and aquatic ecosystems. Compared with other lakes, such as Mohamaya Lake (Bangladesh), where PHI ranges from 936 to 73,857 in surface water and from 684 to 116,061 in sediments (levels III to V), or Kaptai Lake (Bangladesh) with a surface water PHI of 999.29 (level IV), Ba Be Lake exhibits remarkably high sediment PHI. Overall, these results suggest that microplastics tend to accumulate more in sediments than in surface water, underscoring the urgent need to enhance monitoring and management of microplastics in the freshwater ecosystems. Particularly in Vietnam, PHI assessments in freshwater lakes remain very limited. Therefore, expanding similar studies to other lakes is necessary to acquire a more comprehensive database to support environmental protection and aquatic biodiversity conservation regarding increasing microplastic pollution.

4 Conclusion

This study at Ba Be Lake revealed the widespread presence of microplastics in both surface water and sediments. In surface water, the microplastic concentrations ranged from approximately 2.1 ± 0.4 to 14.2 ± 8.9 particles/m^3, with an average concentration of 6.2 ± 3.7 particles/m^3. In sediments, the concentrations varied from 291.46 ± 25.15 to 552.1 ± 760.6 particles/kg, with an average value of 384.02 ± 265.8 particles/kg. The highest density was recorded at site BB 1.3 (552.1 ± 760.6 particles/kg). Morphologically, fibrous microplastics dominated in both the environments. Microplastic sizes were mainly concentrated in the medium range (100–1000 μm). Polymer composition analysis indicated diverse pollution sources, with urea-formaldehyde condensate prevailing in surface water, while cellophane, polypropylene, and polyacrylamide were predominant in

sediments. Notably, ecological risk assessment based on the PHI index highlighted a higher potential risk from microplastics in sediments compared with surface water, with polyacrylamide identified as the main contributor to ecological risk. Overall, these findings demonstrate a significant and complex microplastic pollution level at Ba Be Lake, requiring attention and effective management measures to protect this important freshwater ecosystem.

Acknowledgements. The authors thank the Vietnam Academy of Science and Technology for funding this study through the grant with a code number of TĐĐGVN.01/24-26.

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