



Occurrence and Distribution of Microplastics from Nepal's Second Largest Lake

Rajeshwori Malla-Pradhan¹ · Bijay Lal Pradhan¹ ·
Khamphe Phoungthong² · Tista Prasai Joshi¹

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Abstract Due to its harmful impact on biota, microplastic pollution is the top priority research in many countries. However, there is hardly any research on microplastic pollution in Nepal's freshwater. Therefore, the present research was accomplished in Phewa Lake to evaluate the occurrence and distribution of microplastic contamination in shoreline sediments. The average abundance of microplastic varied from 55 to 122.5 items/kg dry weight (dw). The highest value appeared on densely populated eastern side of the lake and the western region reported the lowest concentration of microplastic. With regard to the shape, fibers dominated the sediments of Phewa Lake accounting for 62.03%. The dominant color was transparent (23.53%) followed by blue (21.39%). The size

category 0.2–1 mm recorded the highest abundance of microplastic. Similarly, Fourier transform infrared spectroscopy (FTIR) reveal the dominant polymer type as polypropylene (PP) and polyethylene (PE). The outcome of this result adds a step toward filling the existing knowledge gap and providing a database on microplastic pollution in Nepal's freshwater.

Keywords Microplastic · Sediments · Phewa Lake · FTIR

1 Introduction

Production of synthetic plastic shoots up exponentially reaching 367 million tons (in 2020) which was just 1.5 million tons when plastic production began back in the 1950s (PlasticsEurope, 2021). The continuous rise in plastic production and lack of proper handling of plastic debris has triggered a drastic acceleration of plastic dumped into our waterways (Li et al., 2018). Plastic debris in the ocean is thought to have cost about 22 billion euros (Beaumont et al., 2019). Plastic trash is the persistent environmental contaminant of growing concern (Horton et al., 2017) which photodegrades into smaller fragments term microplastic (Thompson et al., 2004). In 2008, the National Oceanic and Atmospheric Administration (NOAA) described plastic particles that are smaller than 5 mm as microplastic (Arthur et al., 2009). Microplastics are categorized as primary and

R. Malla-Pradhan · T. P. Joshi (✉)
Environment Research Laboratory, Faculty of Science,
Nepal Academy of Science and Technology, Lalitpur,
Nepal
e-mail: tistaprasai@gmail.com

R. Malla-Pradhan · K. Phoungthong
Faculty of Environmental Management, Prince of Songkla
University, Songkhla 90112, Thailand

R. Malla-Pradhan
Department of Environmental Science, Tri-
Chandra Multiple Campus, Tribhuvan University,
Ghantaghar, Kathmandu, Nepal

B. L. Pradhan (✉)
Amrit Campus, Tribhuvan University, Kathmandu, Nepal
e-mail: bijaya.pradhan@ac.tu.edu.np

secondary microplastics in accordance with their origin. Primary microplastics are directly or indirectly discharged into the environment which are small size plastic particles whereas, secondary microplastics are produced because of the progressive disintegration of bigger plastic particles lying around us (Andrady & Neal, 2009; Browne et al., 2007; Cole et al., 2011). Microplastics globally pollute the environment because macroplastics/microplastics are continuously introduced into water bodies through numerical pathways like the washing of clothes which may release up to 1900 fibers per textile (Browne et al., 2011), using facial and body care items (Fendall & Sewell, 2009; Napper et al., 2015), agricultural activities like using plastic mulch and tunnels (Kasirajan & Ngouajio, 2012; Steinmetz et al., 2016), industrial process using small plastic bits as abrasives, spillage of plastic pellets, and powders (Thompson et al., 2009), and open dumping (Bhattacharya, 2016). Moreover, the widespread of microplastics in urban sewage and wastewater treatment plants is the main source of microplastics near urban lakes. A recent review article by Ramasamy et al. (2022) mentioned that sludge and effluent discharged from wastewater treatment plants are a substantial sources of microplastics as municipal wastewater treatment plants can release up to 160 million microplastics into the environment each day. Likewise, the use of disposable face masks during COVID-19 has emerged as an important add-on — the source of microplastic fibers to the surrounding environment (Aragaw, 2020). Thus, adding a new environmental challenge to cope with the growing plastic pollution which can be minimized by finding suitable eco-friendly alternatives and effective waste management strategies (Fadare & Okoffo, 2020). Microplastics occur in diverse shapes such as pellets, fragments, and fibers due to their various sources (Klein et al., 2015).

Microplastics are of growing concern because of their extensive distribution (Cole et al., 2013; Klein et al., 2015) and eco-toxicological risk to the aquatic ecosystems and human health (Akdogan & Guven, 2019). Tiny microplastics may be consumed by an array of aquatic species (Cole & Galloway, 2015; Lee et al., 2013) which in turn may transfer to the uppermost tropic level through the food chain (Setälä et al., 2014). They can cause detrimental effects on survival, overall growth, and development and decrease metabolic activities and reproductive health of aquatic

organisms (Galloway et al., 2017; Lu et al., 2016; Sussarellu et al., 2016). Moreover, due to the hydrophobic nature of microplastic, it exhibits an enhanced capacity to adsorb heavy metals and organic and inorganic substances and transfer their toxicity to aquatic life (Deng et al., 2018; Kim et al., 2017; Lin et al., 2020; Zhao et al., 2020).

Although many comprehensive studies on marine habitat are conducted, less research has concentrated on the freshwater ecosystem, which are possible sources and channels for the transport of microplastic into the marine habitat (Migwi et al., 2020). Although in recent years, there is a rise in microplastic pollution studies in worldwide lakes (Dusaucy et al., 2021), Nepal is at an early phase where only a limited research on microplastic has been done (Malla-Pradhan et al., 2022). Therefore, in order to address poorly quantified levels of microplastic pollution in the freshwater environment of Nepal, it is necessary to study the lakes to find the level of pollution from microplastics.

In Pokhara Valley, the largest freshwater lake is Phewa. In recent years, natural and anthropogenic activities are resulting in the shrinkage of Phewa Lake, and in the next 110–347 years, it is expected to lose 80% of its storage capacity (Watson et al., 2019). The risk of contaminant release increases as the sediment discharge period is prolonged by changes in the water level of the Poyang Lake Basin in China (Zhao et al., 2010). Therefore, the objective of this research was to examine the abundance and characteristics of microplastic pollution in the shoreline sediment of Phewa Lake. Thus, this study can increase the database about microplastic pollution for better monitoring of freshwater resources in Nepal.

2 Materials and Methods

2.1 Study Area and Sample Collection

Phewa Lake lies in the Kaski district of Gandaki province which is the main tourist attraction of Pokhara Valley. It is fed by Harpan Khola (stream) which is the inlet to the lake and outlet water is controlled by a dam (Shrestha & Janauer, 2001). The lake occupies a catchment area of 122.53 km² and a total surface area of 5.762 km². The highest observed lake depth is 21.4 m with a mean depth of 8.5 ± 5.3 m (Watson

et al., 2019). The lake serves as a commercial site for cage fish culture for the local fisher community and a recreation center for tourists.

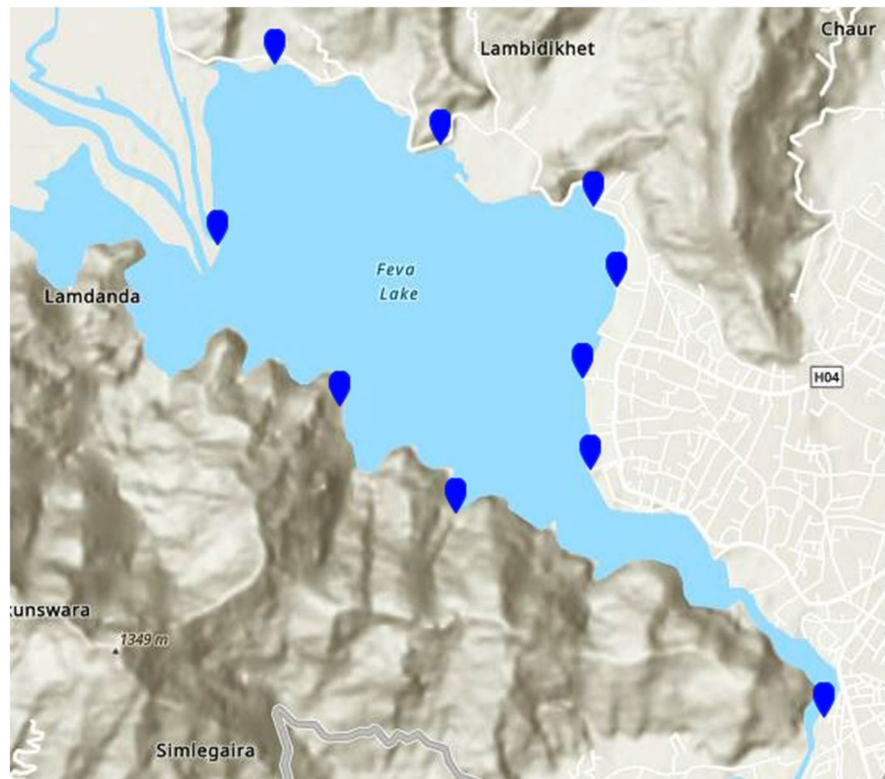
The sampling was accomplished in July 2021 to determine the existence of microplastics in shoreline sediments from 10 locations. These sampling locations were divided into six different stations such as L1 (western region, water inlet of lake), L 2–3 (northern region), L 4–7 (eastern region), L8 (south eastern region), and L 9–10 (southern region) (Fig. 1). At each location, the uppermost 2 cm of the shoreline sediment from 25 cm × 25 cm quadrat was collected (Fischer et al., 2016) using a steel spoon. Three samples about 5 m away from each other were collected from each site; pooled together and two replicated were taken which were then stored in an aluminum foil container until further analysis.

2.2 Extraction of Microplastics from Sediment Samples

In the laboratory, sediment sample preparation for extraction was done with reference to previous

studies (Blettler et al., 2017; Sruthy & Ramasamy, 2017). A modified NOAA methodology was used for the extraction of microplastics (Masura et al., 2015). A beaker with hundred grams of sediment sample was taken along with 400 mL of saturated sodium chloride (NaCl, Sisco, Research Laboratories Pvt. Ltd., India) mixture ($d=1.2 \text{ g/mL}$). Then, this combined solution was stirred and left undisturbed for about 5 min. After the settling of the sediment, it was carefully moved to a clean beaker without disturbing the settled sediments. The segregation process was accomplished thrice for individual samples (Zhao et al., 2018). After the isolation process, 20 mL each of 30% hydrogen peroxide (H_2O_2 , Qualikems®, India) and 0.05 M ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, Merck Limited, India) solution was mixed with the sample to degrade the biological substances and allow to stand for few minutes and then boiled at $50 \text{ }^\circ\text{C}$ on a hot plate. To attain density separation, the sample was left undisturbed for about 24 h. Finally, the sample was passed through a 1 mm sieve and the filtrate was passed via Whatman GF/C (47 mm dia.). The filter paper was covered, air dried for 24 h,

Fig. 1 Sampling points at Phewa Lake



and visually identified under a stereomicroscope (SZ2-ILST, Olympus, Japan) at 40× magnification. Microplastics were counted and noted based on their morphological characteristic. The chemical composition of suspected visible microplastic particles (size 1–5 mm) was examined using FTIR (IRAffinity-1S, SHIMADZU, serial number A221352) at 500 to 4000 cm^{-1} wavelength.

2.3 Quality Assurance/Quality Control (QA/QC)

To avoid potential contamination during sampling to laboratory analysis, nitrile gloves and laboratory cotton coats were used. Sampling tools and glassware were pre-washed using ultra-pure water. It was then covered with aluminum foil until used. To avoid contamination, filters were immediately kept in a petri dish and covered until further examination. Air blanks were conducted to check for potential contamination. A total of 0.2 microplastics per filter paper were observed under a stereo microscope. As a negligible amount of fibers was detected, background contamination was neglected (Baldwin et al., 2020).

2.4 Data Analysis

The unit of microplastic abundance in all shoreline sediment samples was expressed as the number of items/kg dry weight (dw). Mean and standard deviation (S.D.) values were calculated for each section of the sampling site. The normality of data was checked using the Kolmogorov–Smirnov test. Similarly, to measure the significant difference in the abundance of microplastics at various locations, the Kruskal–Wallis test was performed as normality was not followed.

3 Results and Discussion

3.1 Microplastics in Sediment Samples

All the shoreline sediment samples collected from Phewa Lake were detected to be contaminated with microplastics. The average abundance of microplastics ranged from 55 to 122.5 items/kg dry weight (dw) (Table 1) with the highest abundance observed in the eastern region (L 4–7). This region is one of the main tourist hubs which has a high human impact. Population density and various human activities have

Table 1 Average and standard deviation of microplastics abundance in different locations

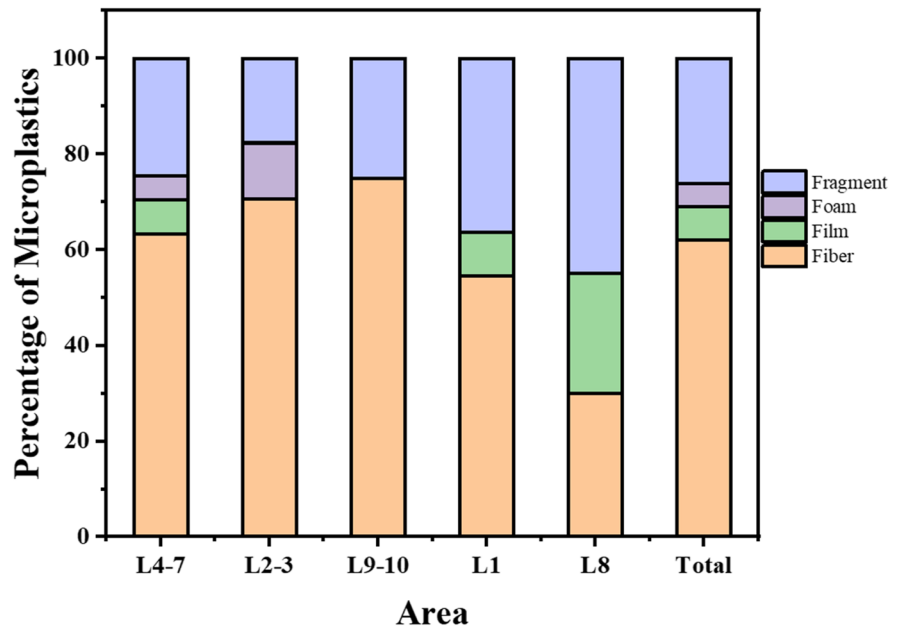
Area	Mean	SD
L 4–7 (eastern region)	122.5	58.74
L 2–3 (northern region)	85	41.23
L 9–10 (southern region)	60	21.6
L1 (western region)	55	7.07
L8 (south eastern region)	100	14.14
Total	93.5	48.91

a close connection with microplastic abundance (Jian et al., 2020; Wang et al., 2017). Similarly, site L8 is also found to have a high abundance of microplastics (100 items/kg dw). The obstructing structure like the dam (Di & Wang, 2018), the long narrow topography at this section of the lake (Yuan et al., 2019), and the drainage of domestic wastewater and runoff by Phikre Khola (stream) near this site may be the factors for higher microplastic abundance in the lake at this region (Malla-Pradhan et al., 2022). Another probable source of microplastics at the outlet (Site L8) during the rainy season may be runoff from urban ditches. As urban ditches are heavily contaminated with microplastics which receives municipal sewage from surrounding residential neighborhood, governmental buildings, restaurants, and tourism (Mhired Gela & Aragaw, 2022). Likewise, the lowest mean abundance of microplastics occurred in the western region (L1) which is the inlet of water to Lake Phewa, followed by the southern section of the lake (L9–L10) (Table 1). Both these region have less human impact. Although the mean abundance at different sections of the lake showed variations, there is no significant difference in the abundance of microplastics in a different sections of Phewa Lake as indicated by the Kruskal–Wallis H test ($H\text{-value}=6.244$, $p\text{-value}=0.182$). This may be because of the flushing mechanism caused by the rainfall (Fan et al., 2019; Han et al., 2020).

3.2 Physical Characteristics of Microplastics

Microplastic observed under a stereomicroscope were sorted into four types: fibers, foams, fragments, and films. The percentage composition of microplastics by shape in all five sampling regions is shown in Fig. 2. Fibers were the most common types of microplastic observed in four different

Fig. 2 Area wise percentage distribution of microplastics according to shape



sampling regions of Phewa Lake (L1, L2–3, L4–7, and L9–10) followed by fragments. Whereas, in site L8, it was just the reversed (Fig. 2). Previous freshwater studies like Dongting Lake (Jiang et al., 2018), Taihu Lake (Su et al., 2016), Poyang Lake (Yuan et al., 2019), Red Hills Lake (Gopinath et al., 2020), Lake Ulanshuhai (Qin et al., 2020), and Lake Mead National Recreation Area (Baldwin et al., 2020) also reported fibers as the dominant type of microplastic. The greater abundance of fibers in Phewa Lake sediments can be linked to domestic waste input, cage fish culture and fishing, washing clothes at the bank of the lake, the use of ropes in boats, and cigarette butts lying on the shore. Previous research has pointed out that domestic waste originating from the washing machine is laden with fibers (Browne et al., 2013). Similarly, fishing activities may generate fibers/ lines due to the aging of fishnets and strings (Su et al., 2016; Xiong et al., 2018; Yuan et al., 2019). Fragments are initiated by the disintegration of plastic goods once it is discarded. Films were noted only in site L1, L4–7, and L8. It may be linked with plastic shopping bags (Nor & Obbard, 2014; Yin et al., 2019), plastic wrappers, and labels discarded by visitors and local residents which were seen lying on the shore of Phewa Lake during field observation. Similarly, the probable source of foam may be the disintegration

of thermocol boxes which are used in site L4–7 and site L2–3 of Phewa Lake for fish preservation and transportation.

As colored plastic items are widely used in daily life (Yuan et al., 2019), microplastics in sediments sample showed different colors across all sampling region (Fig. 3). In total, transparent were the most common color accounting for 23.53% though it was not observed in site L1 and site L8. Discoloration during environmental weathering, oxidation step in the microplastics extraction (Su et al., 2018), or the use of disposable plastic items may be the likely source of transparent microplastics (Xiong et al., 2018). Blue, white, red, and black microplastics were the other frequently encountered colors in the sediment of Phewa Lake. The capacity of predators to perceive their prey is greatly influenced by color (Adji et al., 2022). Previous studies have reported that fishes deliberately ingest colored microplastics as it resemble their natural food item (Nadal et al., 2016). For example, the planktivorous juvenile fish (palm ruff) selectively picked up black microplastics as it is similar to their food items (Ory et al., 2018).

Microplastics recovered from the sediments of Phewa Lake were classified into two groups based on size: 0.2–1 mm and 1–5 mm. Size class 0.2–1 mm dominated in all five sampling regions (Fig. 4). Likewise, in Phewa Lake, the pre-dominance of tiny-sized microplastics has

Fig. 3 Area wise percentage distribution of microplastics according to color

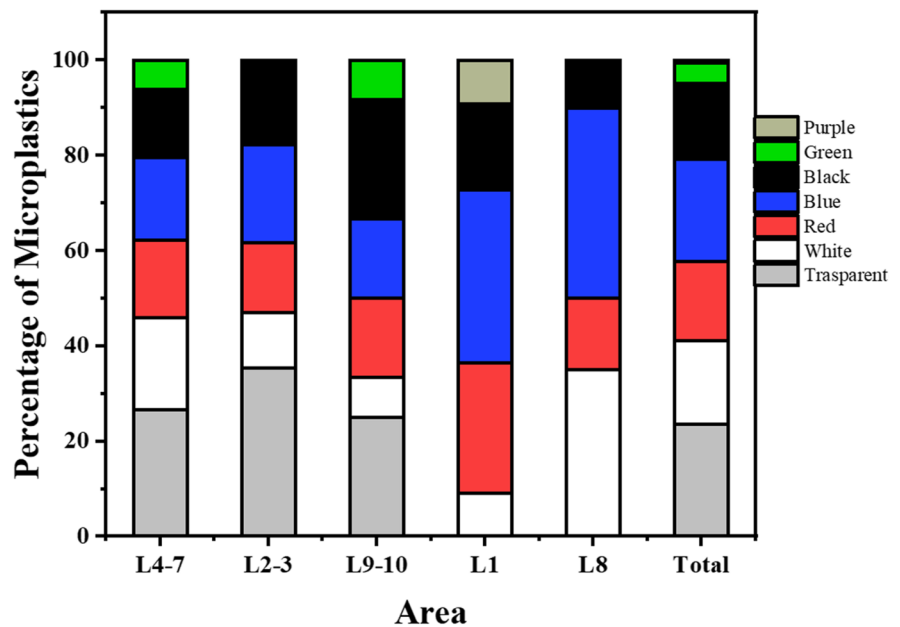
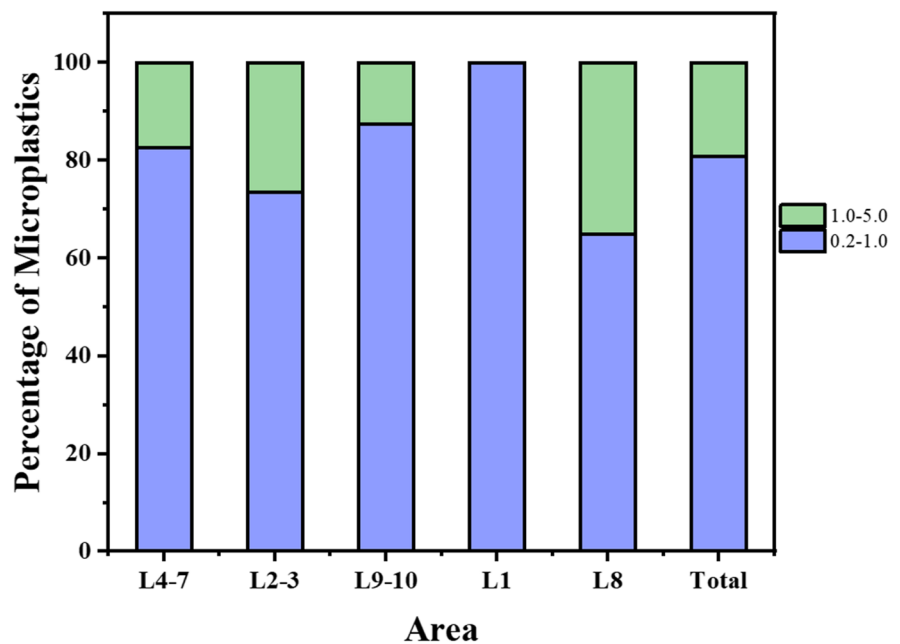


Fig. 4 Area wise percentage distribution of microplastic according to size



been detected in numerous freshwater studies on sediments (Liu et al., 2019; Su et al., 2016; Yuan et al., 2019). A higher percentage of small-size microplastics in the sediment of Phewa Lake increases the chance of ingestion by organisms (Cole et al., 2011). Moreover, aquatic biota may face a serious potential threats from small-sized microplastic as there is the possibility of adsorption

of harmful pollutants from the surrounding habitat owing to its greater surface area (Devriese et al., 2017).

General details of microplastics in sediment samples like their abundance, size, and color are insufficient for a thorough investigation of their contamination source (Qin et al., 2020). So polymer identification can be a useful tool to track down the

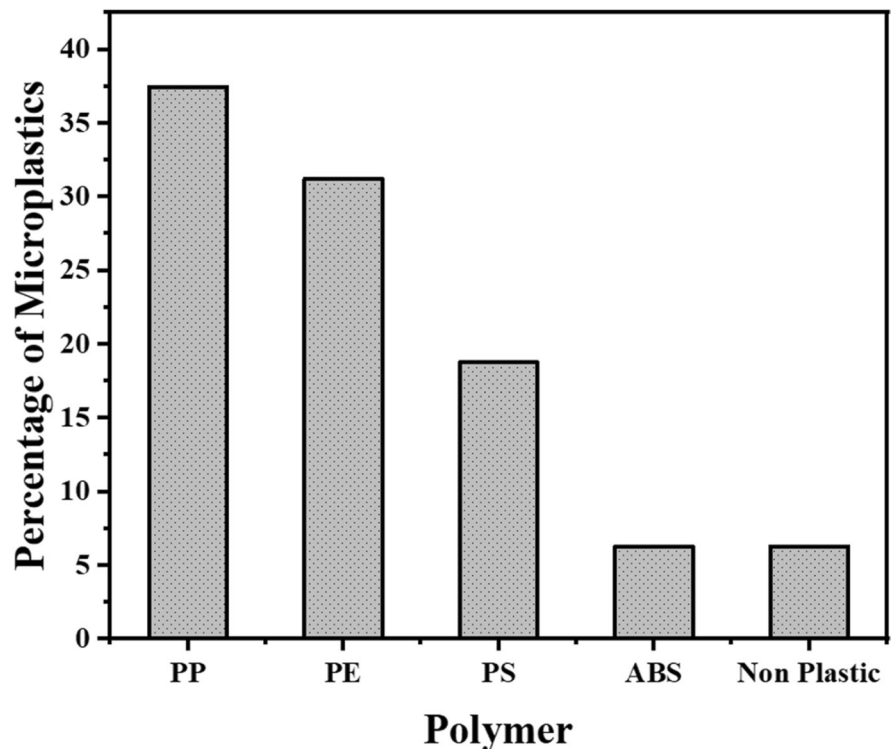
Table 2 Band assessment for FTIR spectra of PP and PE

Polymer	Absorption peaks (cm ⁻¹)		Assignment	References
Polypropylene (PP)	2954	CH ₃ stretch		(Asensio et al., 2009; Jung et al., 2018; Noda et al., 2007; Verleye et al., 2001)
	2916	CH ₂ stretch		
	2870	CH ₃ stretch		
	2839	CH ₂ stretch		
	1458	CH ₂ bend		
	1373	CH ₃ bend		
	1165	CH bend, CH ₃ rock, C–C stretch		
	996	CH bend, CH ₃ rock, CH ₃ bend		
	841	CH ₂ rock, C–CH ₃ stretch		
	809	CH ₂ rock, C–C stretch, C–CH stretch		
Polyethylene (PE)	2915	CH stretch		(Asensio et al., 2009; Jung et al., 2018; Noda et al., 2007; Verleye et al., 2001)
	2847	CH stretch		
	1466	CH ₂ bend		
	1078	C–C stretch		
	717	CH ₂ rock		

origin of plastic waste (Ballent et al., 2016). For polymer identification, FTIR is widely used (Hidalgo-Ruz et al., 2012) which was also applied in this study. The result of FTIR analysis showed a resemblance

with polypropylene (PP), polyethylene (PE), polystyrene (PS), and acrylonitrile butadiene styrene (ABS) because of the characteristic absorption peaks of the polymer as reported in several literatures. The two

Fig. 5 FTIR spectra curve of polyethylene and polypropylene



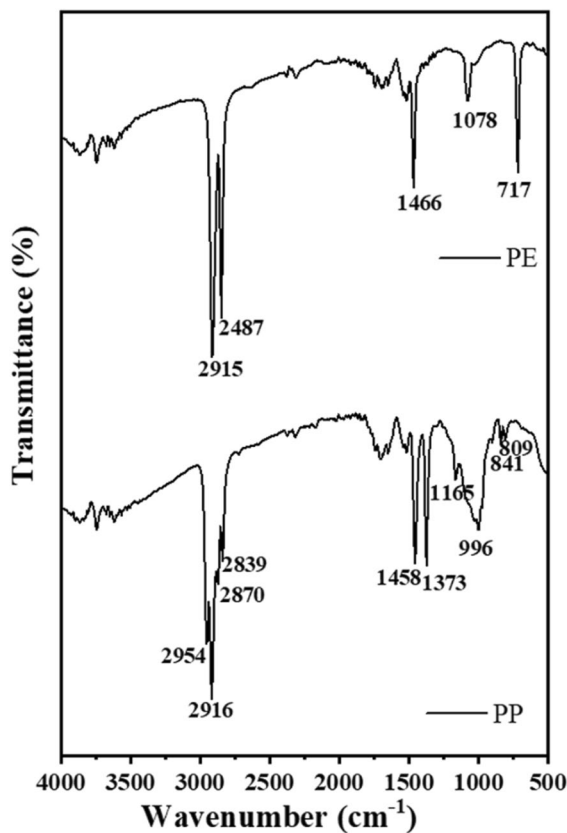


Fig. 6 Percentage distribution of microplastic according to polymer type

dominant types of polymer with FTIR spectrum and band assignment are given in Table 2 and Fig. 5. The PP (37.5%) and PE (31.2%) were the dominant polymer type found in the shoreline sediment of Phewa Lake (Fig. 6) which was also reported in other freshwater sediment studies like Poyang Lake, China (Yuan et al., 2019), Qinghai Lake, China (Xiong et al., 2018), and Nakdong River, South Korea (Eo et al., 2019). PE and PP have frequently used plastic materials in packaging industries, manufacturing of carrying bags and fishnets (PlasticsEurope, 2021), Hence, it is widely detected microplastics in sediments.

4 Possible Strategy Macro Debris Pollution Reduction in Phewa Lake

The result of this study indicates that the sediment of Phewa Lake is polluted with microplastics. Poor management system and weak implementation of pollution

control laws and regulations are in a way responsible for microplastic pollution in Phewa Lake. The local authorities should immediately establish an action plan to minimize the release of macro debris around the periphery of Phewa Lake in the first place. Only proper waste management will indirectly manage the release of microplastics into the surrounding environment (Aragaw, 2021b). The following are the possible strategies to combat macro debris pollution reduction in Phewa Lake:

- (1) Public awareness about the impact of macro plastic debris in the Phewa Lake ecosystem
- (2) Imposing a ban on single-use plastics around Phewa Lake
- (3) Littering the shore with a water bottle, cigarette butts, and wrappers (noodles, biscuits, chips etc.) should be strictly prohibited
- (4) Enforcement of polluters pay principle to macro debris (Aragaw, 2021a) in the vicinity of Phewa Lake

5 Conclusion

Microplastic pollution is a growing global issue that may have detrimental effects on the ecosystem but very limited studies on microplastic exist in Nepal. In this study, we evaluated the shoreline sediments of Phewa Lake for microplastic contamination at ten sampling sites during the rainy season. The result showed that in different sections of the lake, microplastic contamination level has no significant difference. Directly mixing of domestic wastewater at site L8, washing clothes at the periphery of the lake, mismanaging waste disposal by hotels and restaurants and recreational boating at the eastern region site (L4–7), and littering at the shore by the local people and tourists are the sources of microplastics entering into Phewa Lake. Runoff from urban ditches is another probable source of microplastics in Phewa Lake during the rainy season. This study can provide an important database of microplastic pollution in the sediments of Phewa Lake. As small-size microplastics are dominant in Phewa Lake, further studies are needed to access the risk of microplastic pollution on freshwater biota.

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Author Contribution Conceptualization, visualization, writing—original draft was done by Rajeshwori Malla-Pradhan. Supervision and writing—reviewing was done by Tista Prasai Joshi. Supervision and validation was done by Khamphe Phoungthong. Data curation and formal analysis were performed by Bijay Lal Pradhan. All authors read and approved the final manuscript.

Data Availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics Approval and Consent to Participate Not applicable.

Consent for Publication Not applicable.

Competing Interests The authors declare no competing interests.

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