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# Characterization and removal of microplastics in the Guheshwori Wastewater Treatment Plant, Nepal

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## HIGHLIGHTS

- This study is among a few reports on microplastics removal at a wastewater treatment plant in South Asia.
- We collected and conducted 300 tests for year-round samples from four stages of wastewater treatment.
- The Guheshwori wastewater plant successfully removed 72.5 % microplastics from the wastewater.

## GRAPHICAL ABSTRACT


## ARTICLE INFO

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## ABSTRACT

Contamination of river water systems by microplastic particles (MPPs) is one of the emerging global environmental concerns with potentially widespread ecological, socioeconomic, and health implications. A wastewater treatment plant (WWTP) processes and treats wastewater to remove pollutants and release safe water into the environment. There has been limited research on the characterization of microplastics and their removal in WWTP in South Asia. In this work, we report on the characterization of microplastics in wastewater and sludge samples ($n = 300$) from Guheshwori WWTP located on the bank of the Bagmati River in Kathmandu city, Nepal representing inlet, secondary aeration tank (SAT), outlet, and sludge from November 2021 to November 2022. On average, we detected 31.2 ± 17.3 MPPs/L, 11.2 ± 9.4 MPPs/L, 8.5 ± 5.6 MPPs/L, and 6.6 ± 4.8 MPPs/g in the samples collected from inlet, SAT, outlet, and sludge, respectively. Commonly found MPPs were in the form of fiber, fragments, foam, and pellets. Largely, MPPs were red, yellow, white, blue, and black. Among the 44 μm – 150 μm, 150 μm – 500 μm and 500 μm – 5 mm categories of size fractions, the most dominant fractions were 500 μm – 150 μm in inlet, SAT, and sludge, and 150 μm – 44 μm in the outlet sampling unit. The Guheshwori WWTP was able to remove 72.5 % of MPPs on average, that mostly occurred in the inlet. The effluent released into the river and the sludge still contained a significant number of MPPs.

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## 1. Introduction

Plastics are a part of everyday life and have become indistinguishable from daily activities. They are meant to meet the needs of end manufactured goods such as in packaging, building, construction, electronic devices, agriculture, medical facilities, and transport sectors to name a few. Production of plastics has continued to increase since their discovery. For example, it was only two million tons per year in 1950 and the quantity reached 381 million tons in 2015 (Geyer et al., 2017). Plastic materials are primarily produced from fossil fuels like petroleum, natural gas, or coal, and consist of different polymer types including polypropylene (PP), polyethylene (PE), polystyrene (PS), polyvinylchloride (PVC), polyethylene terephthalate (PET), and polyamides (PA) (Geyer et al., 2017).

The plastic materials ultimately end up in the environment. They have a very slow decomposition rate which allows them to remain in the environment for hundreds of years (Barnes et al., 2009). It is projected that at least 8 million tons of plastic waste end up in the global oceans each year and by 2050 the weight of marine plastic will exceed that of fish (Wang et al., 2020).

Microplastics (MPs) are plastic particles with a size $<5$ mm in diameter (or length). MPs are released from raw materials and personal care products. They are also produced as fragmentation products of larger plastic particles (Gigault et al., 2018). Sources of MPs include domestic materials, paint flakes, debris from tires, and industrial manufacturing (Nizzetto et al., 2016). Microplastic particles (MPPs) are distributed widely in the aquatic, terrestrial and marine environment as well as in the air. They have become a major global issue and have the potential to cause risk and harm to the ecosystem and human health (Wang et al., 2020).

A municipal wastewater treatment plant (WWTP) or sewage treatment plant cleans dirty water from domestic, industrial, and commercial wastewater, along with surface water effluents. The effluent from WWTP may be released directly into the ocean or into freshwater ecosystems, such as rivers, from which it can be routed to the marine environment, depending on the geography of a location (McCormick et al., 2014). Understanding the characteristics of MPs in the WWTP and their transformation during the treatment process are still ongoing research topics. MPs are complex materials with different chemical compositions, morphology, and color and they are found in complex sample matrices. A standardized protocol for sample collection, sample preparation, and MPs characterization is not available (Gatidou et al., 2019a) which has limited the accurate assessment of these analytes. Very few studies have quantified MPs in WWTPs in comparison to the studies of MPs in other sample matrices. Recent research reports, primarily from Europe, United States, and China suggest that advanced treatment methods in the WWTP can help remove MPs (Carr et al., 2016; Mintenig et al., 2017). The effectiveness of MPs removal in WWTPs is expected to vary depending on the treatment technique and the physical and chemical properties of the polymer (Bond et al., 2018). MPs that are removed during sewage treatment may remain in sludge which is frequently processed and applied to the land for agricultural uses (Rillig, 2012). Some studies showed that MPs removal rates in WWTP are high, typically over 95 %, but even if most MPs are removed with sludge the remaining fraction still represents a large amount of MPs (Lv et al., 2019). Moreover, the sludge produced in WWTP is frequently reused in agriculture as soil amendment because of its high nutrient content (Gherghel et al., 2019). Such studies are lacking in South Asia.

South Asia is projected to witness an urban population of about 250 million by 2030, making it one of the fastest-growing emerging markets and developing economies (Ellis and Roberts, 2016). This rapid urbanization is expected to exacerbate water (river) pollution (Strokal et al., 2021), as the share of wastewater treatment in this region stands at only 22 %, leading to a significant portion of wastewater flowing into the rivers (Liao et al., 2021). Several studies in South Asia have analyzed MPs in river water samples, including the Koshi River system in Nepal (Yang et al., 2021), the Ganges River system in India (Neelavannan and Sen, 2023; Singh et al., 2021), and the Buriganga, Karnafully, and Karnaphuli rivers in Bangladesh (Fatema et al., 2023; Islam et al., 2022), as well as the Ravi and Swat rivers in Pakistan (Aslam et al., 2022; Bilal et al., 2023). These studies have revealed microplastic particle concentrations ranging from a few hundred to thousands of particles per cubic meter of water. However, there has been relatively limited research on MPs in WWTPs in South Asia. Therefore, it is important to study the fate of MPs in the wastewater treatment facilities in this region to comprehend their occurrence in wastewater and their removal processes. Such study will provide foundational data to address the research gap for policymakers and facilitate better wastewater management in the region. In our study, we focused on a WWTP in Kathmandu, the capital of Nepal.

Nepal is a developing country in South Asia with a population of 29 million, out of which 66.17 % reside in urban municipalities. Kathmandu city has the highest population density of 5169 people per square kilometer in Nepal. The Kathmandu Valley, which constitutes Kathmandu, Lalitpur, and Bhaktapur districts, has a population of 3.26 million. According to the 2021 population and housing census, only 57 % of households have access to tap or piped drinking water in Nepal. Almost 95.5 % of households use one or the other type of toilet facility (National Population and Housing Census 2021 (National Report), 2023). Since the wastewater treatment is poor, untreated sewage is discharged directly into the local rivers and streams in Kathmandu. Kathmandu city has only one functional municipal WWTP – the Guheshwori WWTP (ADB, 2023). The Guheshwori WWTP has been operational since 2001 and following recent expansion, the facility currently operates at an installed capacity of 32.4 MLD. It is an activated sludge plant incorporating a biological reactor, a settling tank, and a recycle stream. The facility offers pre-treatment of wastewater, but it lacks primary clarification tanks, opting instead for oxidation ditches. (ADB, 2023)The Guheshwori WWTP has not been studied for its ability to remove MPs. We collected wastewater and sludge samples from the Guheshwori WWTP in Kathmandu for a period of one year and studied the MPs removal efficiency at different points of treatment using literature-reported methods of sample collection and sample processing utilizing density separation and pretreatment methods. We also characterized the MPs using microscopy and Fourier-transform infrared spectroscopy and reported on the effectiveness of WWTP in Kathmandu in removing MPs. Finally, the MPs removal efficiency of the Guheshwori WWTP was compared with relevant studies.

## 2. Materials and methods

### 2.1. Materials and chemicals

The chemicals including $ZnCl_2$, NaCl, Nile red (NR), $H_2SO_4$, $FeSO_4.7H_2O$, and acetone were purchased from HiMedia, India, and were used without further purification. Glass microfiber filters were purchased from VWR, UK. We used distilled water to prepare solutions and reagents. The distilled water was further filtered using glass microfiber of pore size 1.2 μm to remove any particles.

### 2.2. Sample collection

We collected samples from Guheshwori WWTP located in the northern part of Kathmandu Valley (see map in Fig. 1). This WWTP receives 3.2 million liters of sewage daily, which is about 25 % of sewage of Kathmandu Valley, generated by the households, industries, and other institutions of nearby localities including Gokarna, Chabahil, Bouddha, and Jorpati area (Thapa et al., 2019). We collected samples from 11 a.m. to 12 p.m. every two weeks from November 2021 to November 2022 allowing 25 sampling campaigns collecting 100 samples in triplicate ($n = 300$). The liquid samples (3 L each) were collected in steel buckets from three locations - influent, secondary aeration tank

(SAT), and effluent. Sludge samples, each weighing 10 g, were collected in glass bottles from the digestion cake of the plant. The volume of wastewater samples has shown considerable variation, ranging from a few milliliters to liters for influents, and from half liters to thousands of liters for effluents, as discussed in a recent paper (Gatidou et al., 2019b). This significant discrepancy likely arises from the absence of standardized and widely accepted sampling and analytical procedures for studying MPs. Regarding the recommended sample volume, the literature currently lacks any available recommendations. Typically, influents contain high levels of organic matter, making it difficult to sieve large volumes of samples. Conversely, effluents generally have lower organic content, making it feasible to filter larger volumes. Additionally, the influent has more MPs, and treated wastewater is expected to contain fewer MPs, making it prudent to sample and handle higher volumes, especially when aiming to identify larger particles (Gatidou et al., 2019b). We chose to collect 3 L for all types of liquid samples following a method adopted by Ziajahromi et al. (2017) after making sure the volume was enough to process and detect MPs. The quantity of solid sludge samples used for MPs analysis has been documented to vary considerably in the literature, with reported ranges from as low as 1 g to as high as 1000 g (Edo et al., 2020; Magni et al., 2019; Murphy et al., 2016; Rafiq and Xu, 2023). We collected 10 g sludge samples following a methodology by Hurley et al. (2018) that had been validated for extracting MPs from complex organic-rich environmental matrices, including sludge. Moreover, our preliminary testing indicated that the sample amount event for effluent and sludge was sufficient for processing and detecting MPs; hence, we opted to employ this methodology.

### 2.3. Sample preparation

The wastewater samples were sieved on site using stainless-steel sieves of 5000 μm, 500 μm, 150 μm, and 44 μm in size. The sieves were stacked in decreasing order of mesh size from top to recover different size particles. After sieving the wastewater samples into different sieve stacks, the microplastic particles (MPPs) left in the sieves were rinsed with distilled water, transferred into the 500 mL glass bottles, and transported into the laboratory for further analysis. The wastewater samples were then digested using 20 mL of Fenton's reagent and 30 % $H_2O_2$ in a 1:1 ratio to remove the organic matter. Then, the samples were heated to 70 °C on a hotplate for 30 min. The heating was repeated by adding more Fenton's reagent and $H_2O_2$ until organic matter was removed completely (Thaiba et al., 2023).

After the digestion of organic matter, $ZnCl_2$ was added to the mixture, and the solution was transferred to the density separator. The sample beaker was rinsed with filtered distilled water and the funnel attached to the density separator was covered with aluminum foil to protect it from contamination. The solution was allowed to settle down overnight and the supernatant solution was taken in the beaker, and the settled solid was discarded. The density separator was rinsed with filtered distilled water several times to transfer all materials to the beaker. Next, the sample was vacuum filtered using the Buchner funnel and collected in the glass microfiber of pore size 1.2 μm (Thaiba et al., 2023).

The filter paper was dried in an oven at 50 °C for 5 min. Then the particles in the membrane glass filter were stained with 500 μL of NR dye solution (10 μg/mL in acetone) that was added thoroughly to the surface of the dried filter paper. The dried filter paper was covered with a watch glass, left in the dark for 30 min, and carefully examined under the stereomicroscope (Amscope, USA) to observe MPPs (Masura et al., 2015; Raju et al., 2020).

In the case of sludge, 10 g of sample was mixed with 20 mL of $ZnCl_2$ salt solution in a beaker and stirred for 5 min to separate particles that stuck together. Then, the mixture was kept overnight to settle down the solid matrix. The supernatant solution was centrifuged the next day at

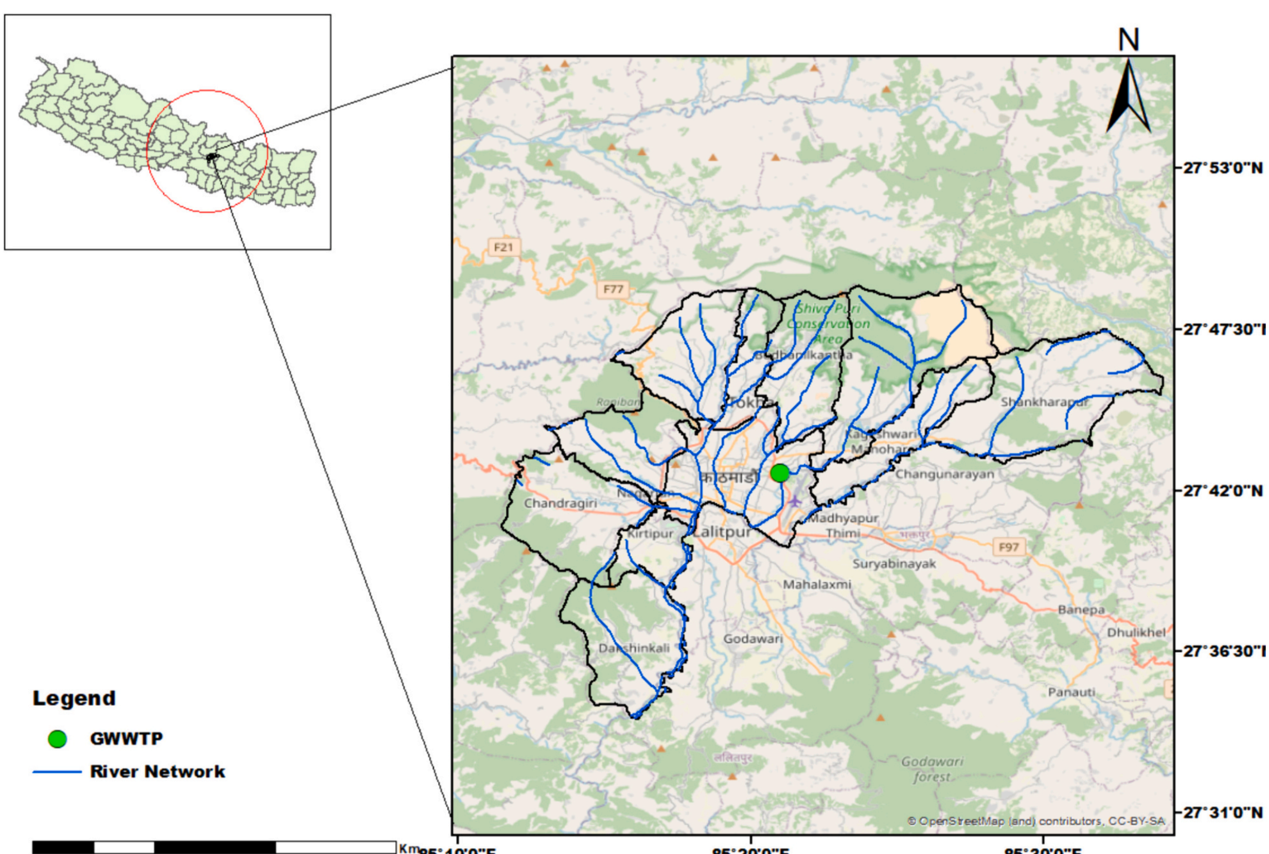


**Fig. 1.** Map showing Guheshwori WWTP and river network in Kathmandu.

3500 rpm for 5 min (Gatidou et al., 2019a) and was passed through a stainless-steel sieve stack comprising 5 mm, 500 µm, 150 µm, and 44 µm to recover the size of the particles. The materials retained in the stack were rinsed with filtered distilled water and transferred into a 500 mL glass beaker. Then, 20 mL $H_2O_2$ was added to the beaker to remove organic matter. This was followed by the addition of 20 mL of Fenton's reagent to fasten the decomposition of organic matter. The mixture was heated at 70 °C with more $H_2O_2$ to get rid of all organic matter. Then, the sample was vacuum filtered, dried in an oven for 5 min at 50 °C and stained with 500 µL NR solution (10 µg/mL in acetone) (Thaiba et al., 2023).

### 2.4. Microplastics characterization and quantification

We collected the infrared (IR) spectra in the range of 4000–600 $cm^{-1}$ in an attenuated total reflection mode using a Fourier transform infrared spectrometer (AT-FTIR) (Thermo Scientific Nicolet iS50, USA) at Fayetteville State University, NC, USA. The spectra were measured at the spectral resolution of 4 $cm^{-1}$. Each reported spectrum has an average of 128 optical scans. FTIR spectra of 14 particles, labeled as P1 to P14, were sent out for analysis. Particles P1 to P5 were collected from non-sludge samples and particles P6 to P14 were picked out from sludge samples.

### 2.5. Quality assurance and quality control

We tested two salt solutions for density separation: $ZnCl_2$ (1.72 g/$cm^3$) and NaCl (1.2 g/$cm^3$) and examined the impact of staining the microplastics with NR dye. We then carried out spike recovery experiments with artificially created plastic particles from the cap and body of water jar. The wastewater sample (100 mL) was spiked with 10 MPPs and followed the same sample preparation and characterization described above. The number of particles was counted and compared to the originally spiked number of particles to get the recovery. These experiments were performed in triplicates.

Precautions were taken during the sample collection, pretreatment, and identification steps to avoid external environmental contamination. The working area was cleaned with distilled water and detergent first, then with 50 % ethanol. The equipment was rinsed with distilled water before used. Glass containers were used instead of plastics to avoid contamination from external sources. We used cotton lab coats, cotton masks, and nitrile gloves. All the solutions used in the experiments were prepared in distilled water filtered through the glass microfiber of pore size 1.2 µm.

Field ($n = 3$) and lab blank ($n = 3$) tests were carried out along with samples following the same procedure of sample preparation and characterization. The blank samples contained 50 mL of filtered distilled water. The detected MPs have been reported in average value ± standard deviation and found to be 9 ± 1.

## 3. Results and discussion

We tested the recovery of MPs using a mixture of PE and PET MPPs to understand the effect of NR staining and salt type for gravity separation. The size of these particles ranged from 150 to 5000 µm. Experiments showed that staining with NR had more recovery of MPs (89.2 ± 12.2 %) than non-stained plastic particles (84.2 ± 11.4 %). The spike recovery experiments with wastewater showed that $ZnCl_2$ resulted in better recovery (89.2 ± 10.7 %) than NaCl (81.7 ± 11.7 %). In all combinations of experiments, PE polymer had better recovery (93.3 ± 5.5 %) than PET (79.5 ± 11.5 %) (see Fig. 2). Based on previous studies we adapted methods for the detection and identification of MPs in the WWTP during the treatment process. The recovery results show that the adapted method was able to separate and identify MPs in wastewater samples. The recovery data is similar to the previously reported results (reviewed in Thaiba et al., 2023). NR takes advantage of the lipophilicity of plastic material and improves the efficiency of detecting them (Maes et al., 2017).

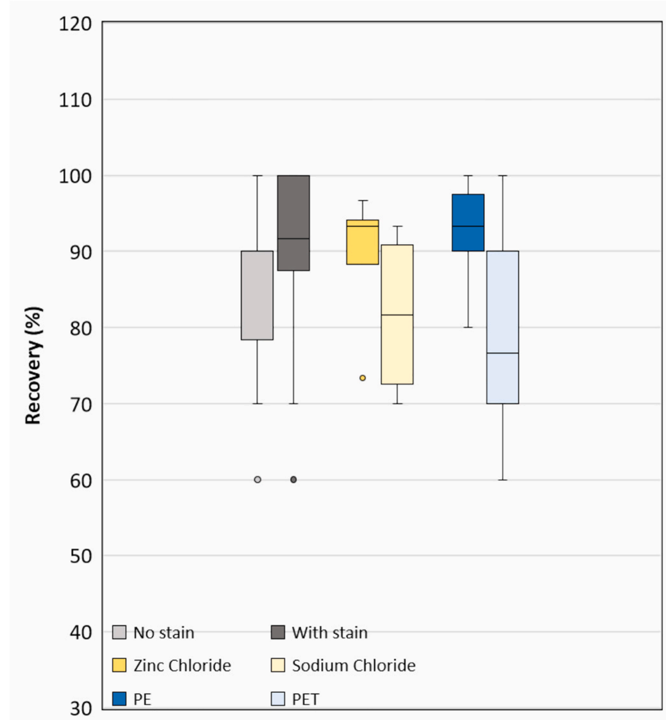


**Fig. 2.** Box plots showing recovery of custom-generated microplastics spiked in wastewater samples. The median line in the no-stain plot overlaps with the third quartile boundary of the boxplot.

### 3.1. Microplastics abundance in wastewater and sludge samples

The MPs were detected at each treatment stage of Guheshwori WWTP including inlet, SAT, outlet, and sludge from digestion cakes. The average number of MPs detected was 31.2 ± 17.3 MPPs/L in the inlet, 11.2 ± 9.4 MPPs/L in SAT, 8.5 ± 5.6 MPPs/L in the outlet, and 6.6 ± 4.8 MPPs/g in sludge samples (Fig. 3). This shows that the treatment facility was able to remove up to 72.5 % of the MPPs recorded in the inlet.

The number of MPs in untreated wastewater is affected by a combination of parameters, including the degree of urbanization, and industrial activities in the wastewater catchment area among others. The quantity of MPs released into the final treated effluent is heavily influenced by the characteristics and performance of the treatment facilities (Hartline et al., 2016). The average value of MPs found in the inlet (31.2 ± 17.3 MPPs/L) in our study was higher than reported in the UK (15.7 ± 5.2 MPs/L) (Murphy et al., 2016) and in northern Italy (2.5 ± 0.3 MPs/L) (Ngo et al., 2019) but lower than reported in Finland (57.6 ± 12.4 MPs/L) (Lares et al., 2018).

The sludge from the WWTP is used for fertilization and the effluent is released back into the river and it may be used for irrigation downstream, ultimately releasing the MPs from the treatment plants again into the environment (Buta et al., 2021). These findings support the argument of WWTPs in collecting MPs from human use and redistributing them to the natural environment, which has recently been observed in other WWTPs around the world (Prata, 2018). WWTPs generate large amounts of sludge because of the treatment processes. The concentration of MPs can be significant and pose a hazard to the environment due to the high concentration of MPs in sewage sludge (Lv et al., 2019). The sludge released from WWTPs is widely applied in the agricultural amendments. Treated sludge, when applied on land surfaces, has a positive effect on soil fertility and has economic benefits. Therefore, there is an increase in the attention to sludge utility.

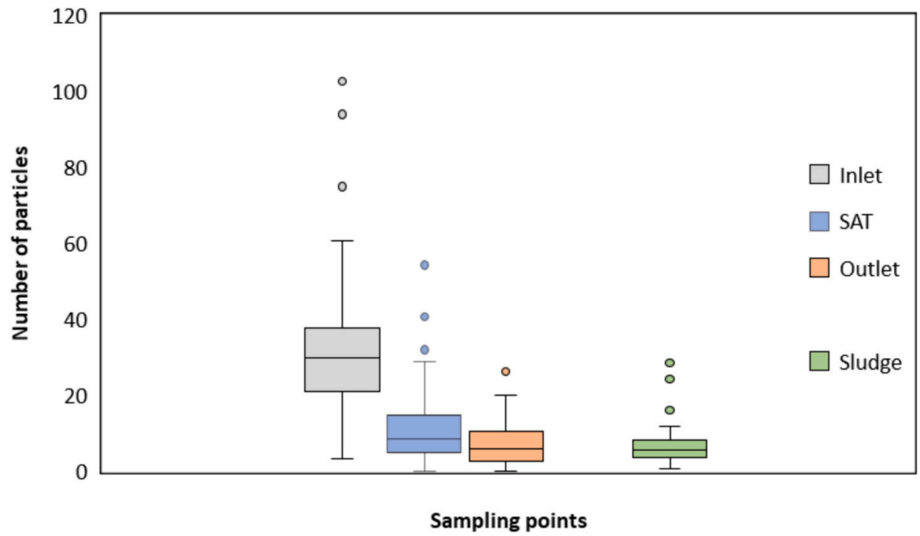


**Fig. 3.** Box plots showing the concentration of microplastics in wastewater (MPPs/L) and sludge (MPPs/g) samples collected from different stages of treatment.

However, the usage of sludge in the land brings out a pathway for MPs to the environment and harms food security and sustainability (Li et al., 2019). The application of sludge to cultivated fields and municipal green areas significantly leads to the accumulation of MPs in soils. In our study, the MPs in the sludge samples were (6.6 ± 4.8 MPP/g) particle/g relatively lower than in the sludge from China (46.3 ± 6.2MPPs/g) (Jiang et al., 2020) and northern Italy(113 ± 57 MPPs/g) (Ngo et al., 2019).

We fitted a negative binomial generalized linear model (estimated using ML) to predict count with the month (formula: count ~ month). The model's explanatory power is substantial (Nagelkerke's $R^2 = 0.51$). The 95 % confidence intervals (CIs) and *p*-values were computed using a Wald z-distribution approximation. The total MP count in July was marginally higher than in April (z-value = 1.86, $p = 0.061$). MP in June, on the other hand, was significantly low compared to April (z-value = −3.54, $p < 0.001$). To get a better understanding of whether the MP count varies with season, we next fitted a similar model to predict count with the season: Winter (Dec – Feb), Spring (Mar – May), Summer (Jun – Aug), and Autumn (Sep – Nov). No significant effect of season on total MP counts was observed.

### 3.2. Morphological characteristics of microplastic particles

We have classified the MPPs into fiber, fragment, foam, and pellet (Hidalgo-Ruz et al., 2012). Fiber is a thread-like long chain with a consistent length. Similarly, a fragment is a piece of a larger particle that has been broken off or detached into a smaller one. A pellet is a small rounded, spherical, or cylindrical plastic body. Furthermore, foam is lightweight and sponge-like plastic. The representative photographs of these particles are given in Fig. 4. The relative ratio of each type of MPs in the samples collected at different stages of the wastewater treatment is also shown in this figure.

In general, the most widely detected MPs in wastewater are fibers, fragments, pellets, and foams (Lares et al., 2018). We found that fibers were the most dominant type of MPs in all types of samples we tested. They accounted for 43 % of MPs in the inlet samples, 51 % in SAT, 54 % in the outlet, and 38 % in sludge samples. Similarly, foams accounted for the lowest number of MPs in all types of samples. Similar results have been reported in other studies (Salvador Cesa et al., 2017).

The occurrence of fibers in municipal WWTPs and untreated sewage has been widely documented in several studies (Liu et al., 2021). The microplastic fibers primarily originate from the laundering of synthetic textiles (Akdogan and Guven, 2019; Liu et al., 2021; Salvador Cesa et al., 2017; Zambrano et al., 2019). Fibers are mostly produced during the textile process of manufacturing through deformation and duplication processes, after which they enter wastewater (Napper and Thompson, 2016; Zambrano et al., 2019). Textile washings are also responsible for producing microplastic fibers. Personal care and cosmetics products, such as laundry detergent, masks, and soaps, contain microplastic fragments and pellets (Carr et al., 2016). Plastic packing bags are the source of the microplastic foams and other microplastic shapes detected in the WWTPs (Kazour et al., 2019).

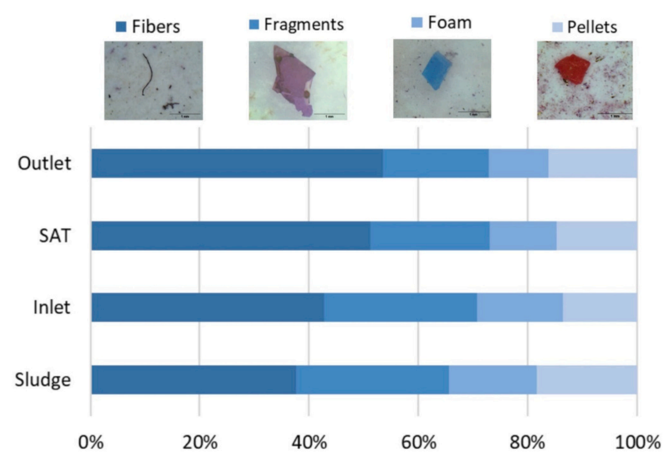


**Fig. 4.** Relative abundance of each type of MPs detected. Images of different shapes of microplastics observed are shown as inset.

### 3.3. Color distribution of microplastics

A wide range of MPs colors have been reported which is useful for identifying potential sources of plastic debris as well as potential contaminations during sample preparation (Hartmann et al., 2019). We used NR staining to better identify the MPPs. The dye could slightly perturb the actual color of MPPs. However, to get preliminary information on the color distribution, we segregated particles into six distinct color types, i.e., red, white, black, blue, yellow, and others. Others were a group of unidentified color particles (Fig. 5A).

At all four sampling units, blue-colored MPs dominated the other colors, similar to studies reported from other WWTPs (Li et al., 2019). Blue-colored MPs accounted for 35 % in the inlet, 37 % in SAT, 38 % in the outlet, and 25 % in the sludge. White-colored MPs were detected the

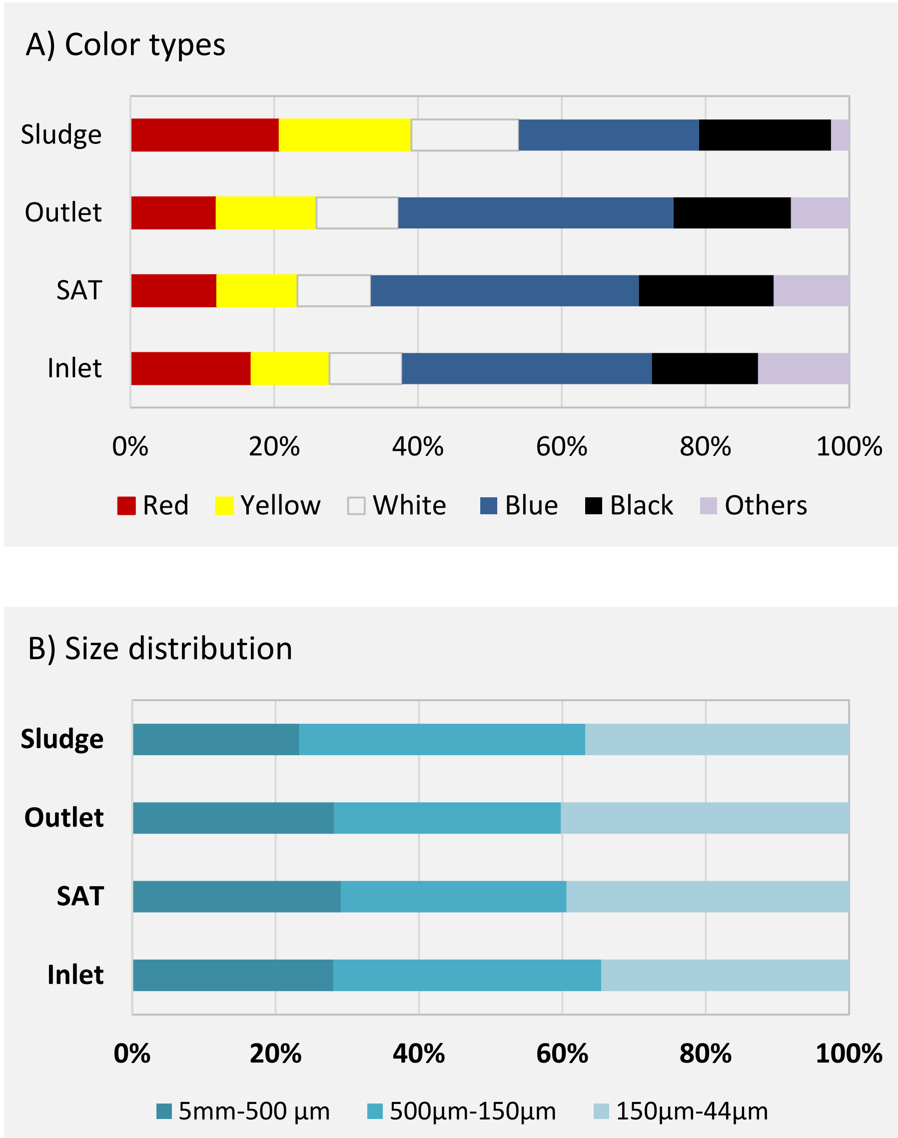


**Fig. 5.** (A) Color type and (B) size distribution of microplastics in wastewater and sludge samples.

least in all sampling units. The colored MPs are very harmful to the environment and may carry heavy metals and organic pollutants. Therefore, the emission of colored plastic should be paid more attention (Oßmann et al., 2018).

### 3.4. Size distribution of microplastics particles

The physical and chemical transformation of MPs and their removal from the WWTP is influenced by their particle size. The particle size distribution of MPs in wastewater and sludge samples at various sampling points is shown in Fig. 5B. All MPs samples were divided into three collections according to different particle sizes using sieves having sizes of 5 mm – 500 μm, 500 μm – 150 μm and 150 μm – 44 μm.

It is interesting to note that sieve size 500 μm – 150 μm contained a higher proportion of particles in the inlet and sludge but sieve size 150 μm – 44 μm dominated the SAT and outlet sampling units. The MPs were identified in the least number in sieve size 5 mm – 500 μm in all sampling units of WWTP. Similar results were reported in other studies including by Mason et al. (Mason et al., 2016). They found that smaller particles (0.125–0.355 mm) were more prevalent than larger particles (>0.355 mm). The smaller particles are ingested by plankton and fishes resulting in toxicological effects (Qiao et al., 2019).

### 3.5. Chemical characterization of microplastics

FTIR spectroscopy is frequently used to identify MP types in environmental samples. The FTIR spectra of a few randomly selected particles (size ≥200 μm) from sludge and non-sludge samples are provided in Fig. 6. MPPs may contain different surface impurities and could have been modified due to environmental and microbial actions. However, they can be identified from characteristic peaks(J.-L. Xu et al., 2020). The -C=O stretching at around 1710 $cm^{-1}$ along with -C-H stretching frequencies in the range 2900–2970 $cm^{-1}$ indicate PET (Achhammer et al., 1951; J.-L. Xu et al., 2020). These features are found in particles P1, P2, P4, P6, P8-P14 suggesting PET MPs. The C—H stretching in the range of 3000–2800 $cm^{-1}$ along with triplicate -C-H bending peaks in the range of 1400–1600 $cm^{-1}$ indicate PS. These features are found in P3, P5, and P7 indicating that the particles are PS. Interestingly, out of 14 particles selected for the FTIR study, all particles (100 %) were confirmed to be MPs. The FTIR result showed that the MPPs obtained from the wastewater and sludge in Guheshwori were primarily made up of PE and PS. These groups of plastics are the most abundant types of

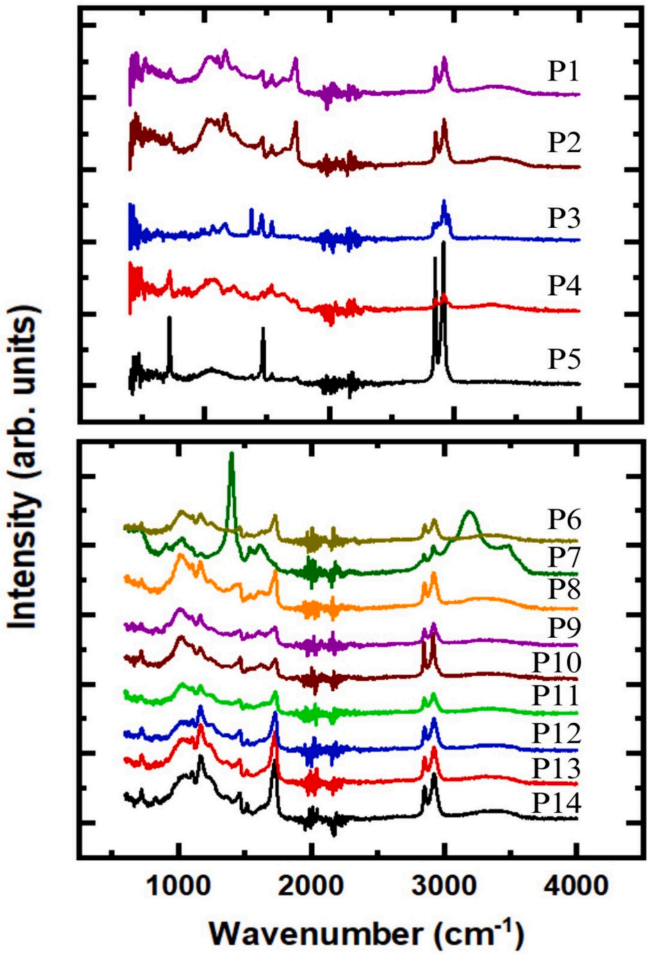


**Fig. 6.** FTIR spectra of selected microplastics particles. Particles P1 to P5 were collected from non-sludge and particles P6 to P14 were collected from sludge. Spectra are overlaid vertically for better comparison.

MPs detected in other WWTPs as reported in the literature(Liu et al., 2021). These MPs originate from plastic products such as food packaging bags, plastic bags, textiles and synthetic clothing, rubber particles, etc. (Liu et al., 2021).

### 3.6. Microplastics removal efficiency of Guheshwori WWTP

The overall MPs removal efficiency of Guheshwori WWTP was 72.5 % from inlet to outlet. However, most of the MPs (64.0 %) were removed before the wastewater reached the SAT in the treatment plant. Our result shows that about 28.5 % of MPs were still released into the river as an effluent. The Guheshwori WWTP removed fragment (74.4 $\pm$ 7.4 %) and foam (76.7 $\pm$ 7.7 %) type of MPs better than the fiber (67.7 $\pm$ 6.8 %) and pellet (70.3 $\pm$ 7.0 %) type MPs (Fig. 7). To test the differences, we computed a general linear model with gamma distribution using the R program. We found that the removal efficiency of foam was significantly higher than fibers ($p = 0.017$) and the removal efficiency of fragments was not significantly different from the fiber.

There are variations in the MPs removal efficiency of WWTPs reported from across the globe. The removal efficiency of MPs varies from country to country depending upon the treatment process. The primary and secondary treatment processes, along with tertiary treatment technology, are the key methods responsible for their removal (Gatidou et al., 2019a). However, it must be noted that these comparisons vary on the cut-off size range of MPs, detection methods, and the treatment process in the WWTPs. The MPs removal efficiency of Guheshwori WWTP is lower than the selected WWTPs in China, Italy, Spain, and Finland but is comparable to a few other WWTPs in China and other countries. The WWTP in Glasgow, UK was able to remove up to 98.41 % MPs (Murphy et al., 2016). A comparison of removal efficiency is presented in Table 1.

The MPs are mainly removed from the wastewater and then entrapped in suspended solids and accumulated in sludge. Despite the efforts of WWTPs to remove MPs from the influent, a considerable amount of MPPs still find their way into the environment. For instance, according to a study in Glasgow, UK (Murphy et al., 2016), the treatment plant released 65 million MPs into the receiving water daily. Therefore, the WWTPs are considered important sources of MPs discharged into the water bodies (Gatidou et al., 2019a; Ziajahromi et al., 2017).

## 4. Conclusions

The goal of this study was to identify and quantify MPs in wastewater and sludge samples from Guheshwori WWTP, Kathmandu Nepal. The highest number of MPs were detected in the inlet than other sampling units. The most widely detected physical characteristics were pellets,

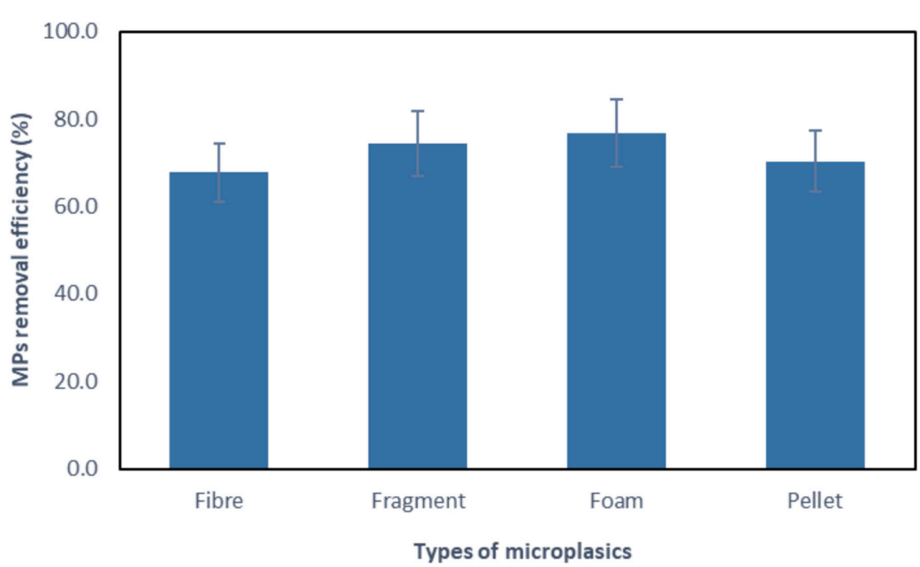


**Fig. 7.** Removal efficiency of MPs in Guheshwori WWTP.

**Table 1**
Microplastics removal efficiency of WWTPs in various countries.

| WWTP location | Size range | Removal efficiency | Reference |
|---|---|---|---|
| Guheshwori WWTP, Kathmandu, Nepal | 44–5000 μm | 72.5 % | Our work |
| Changsha, China | | 68–72 % | (Long et al., 2022) |
| Guilin, China | 500–5000 μm | 89.2–93.6 % | (Zhang et al., 2021) |
| Changzhou, China | 100–5000 μm | 90.0 % | (X. Xu et al., 2019) |
| Italy | 63–5000 μm | 84.0 % | (Magni et al., 2019) |
| Mikkeli, Finland | 250–5000 μm | 98.3 % | (Lares et al., 2018) |
| Madrid, Spain | 25–104 μm | >90.0 % | (Edo et al., 2020) |
| Cádiz, Spain | 100–5000 μm | 90.0 % | (Franco et al., 2021) |
| Glasgow, UK | > 65 μm | 98.4 % | (Murphy et al., 2016) |

foam, fragments, and fibers. White, red, black, yellow, and blue MPs were major types of colors identified. Smaller particles (150–44 μm) were found to be more prevalent. Our results showed that the Guheshwori WWTP removed 72.5 % MPs from the wastewater. The plant may not have been designed for removing MPs, but it still removed a significant number of MPs. We recommend that future WWTPs should consider removing MPs while designing the plant. We also found that a major portion of MPs removed from the wastewater are transferred to the sludge. Since sludge from WWTP contains a large quantity of MPs, the use of such sludge as manure should be reconsidered as it may contaminate the soil. The characteristics of MPs in the environment and the fate of MPs in effluent and sludge should be looked upon in future research. In our study, we did not count particles smaller than 44 μm. Future research may focus on finer particles as well. Furthermore, long-term monitoring is recommended to gain a deeper understanding of the characteristics of MPs in the WWTP. This monitoring should include possible chemical and physical changes that MPs undergo during the treatment. Additionally, investigating their role as carriers for the transfer of emerging micropollutants would be important.

## CRediT authorship contribution statement

**Smriti Bastakoti:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Asmita Adhikari:** Writing – review & editing, Investigation, Formal analysis. **Bishan Man Thaiba:** Writing – review & editing, Methodology, Investigation. **Bhanu Bhakta Neupane:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Funding acquisition. **Bhoj Raj Gautam:** Writing – review & editing, Visualization, Methodology, Investigation, Funding acquisition. **Mohan B. Dangi:** Writing – review & editing, Conceptualization. **Basant Giri:** Writing – review & editing, Visualization, Supervision, Resources, Project administration, Funding acquisition, Formal analysis, Conceptualization.

## 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.

## Data availability

Data included in the manuscript

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