

**QUANTIFICATION AND CHARACTERIZATION OF MICROPLASTICS IN
SELECTED WATER BODIES IN AND AROUND DHAKA CITY**

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JUNE, 2021

**Quantification and Characterization of Microplastics in Selected Water Bodies in
and Around Dhaka City.**

by

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In partial fulfilment of the requirements for the Degree of
MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING

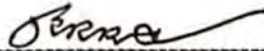


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June, 2021

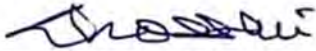
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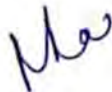
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Dedicated to

My Parents

ACKNOWLEDGEMENT

I wish to express my profound gratitude and sincere appreciation to my supervisor Dr. Muhammad Ashraf Ali, Professor, Department of Civil Engineering, BUET for his constant support, guidance, encouragement, suggestions during designing and carrying out this study. It was an honour and get the opportunity to work under his supervision. Without his constant support in each stage the study wouldn't have possible to carry out.

I wish to express my gratitude and sincere appreciation to my respected defence committee members Dr. Md. Delwar Hossain, Professor and Head, Department of Civil Engineering, BUET; Dr. Md. Mafizur Rahman, Professor, Department of Civil Engineering, BUET; Dr. Ganesh Chandra Saha, Professor, Department of Civil Engineering, Dhaka University of Engineering and Technology for their valuable advice and comments.

I would also like to acknowledge the support from Dr. A.B.M. Badruzzaman, Professor, Department of Civil Engineering, BUET during our laboratory work.

I would like to thank to the members of the Environmental laboratory for their support and cordial cooperation during carrying out this research work. This work would not have been possible without their support. Special thanks to Dr. Md. Ehosan Habib for his sincere support during carrying out laboratory works.

ABSTRACT

Today a world without plastics is unimaginable. But their non-biodegradability poses serious threat to the ecosystem, especially to the aquatic environment. Microplastics particles include either manufactured plastics of microscopic size (primary sources) or fragments or fibers of plastics resulting from the breakdown of larger plastic products (secondary sources). Degradation processes of plastics are extremely slow and thus microplastics tend to persist in the aquatic environment for very long periods of time. Exposure of freshwater organisms to microplastics has been found to cause mortality, neurotoxicity, oxidative stress and damage, decrease of individual and population fitness, and other adverse effects. Though freshwater environment is closely associated with the origin microplastics and their transfer to the seas and oceans, limited studies have been conducted on freshwater ecosystem compared to the marine environment. There is virtually no study/data on microplastics for any waterbody in Bangladesh. This study was aimed at identification, quantification and characterization of microplastics in selected water bodies in and around Dhaka City.

In this study, samples were collected from Dhanmondi and Ramna Lakes, Hatirjheel, Buriganga and Turag rivers in both Winter and Summer for identification, quantification and characterization of microplastics. Microplastics were identified by wet sieving where 4.75-mm and 0.3-mm sieves were used to isolate the solid material of appropriate size, then wet peroxide oxidation was carried out using hydrogen peroxide (H_2O_2) to digest labile organic matter while the plastic debris remained unchanged. Then density separation was done using sodium chloride (NaCl) solution to isolate the plastic debris through flotation. The floating solids were then separated from the denser undigested mineral components using a 0.3 mm filter, air dried and weighed. Finally, microplastics were detected using a magnifying glass. The quantity of microplastics was expressed as percentage mass of total solids, and other units (mass per unit area of water surface, and item/no. per unit area of water surface). The microplastics isolated from the samples were characterized through microscopic inspection, fractionation (through sieve analysis) and morphological analysis (size, shape, colour and texture).

The quantity of microplastics from the sampling locations in the five water bodies varied from 0.44% (in Dhanmondi Lake) to 9.34% (in Turag River) of total solids in Winter (dry) season; and 1.08% (in Hatirjheel) to 22.6% (in Turag River) in Summer (wet). In both Summer and Winter, the quantities of microplastics in the inland water bodies (Dhanmondi Lake and Ramna Lake) have been found to be relatively low, compared to those found in the two peripheral rivers – Buriganga and Turag. Size fractionation suggests that larger particles (in the size range of 1.18 mm to 4.75 mm) accounts for major fraction in term of weight of microplastics, while smaller size fractions account for majority of items of microplastics. Except for Hatirjheel, the quantity of microplastics (as % of total solids) at all the sampling locations increased in Summer compared to Winter. Morphological analysis suggests most of the microplastics identified in this study are irregular in shape with rough surface; this probably suggests that these have been introduced to the environment a long time ago. However, some microplastics with larger size and sharp/irregular edges were also identified, particularly in Dhanmondi Lake and Buriganga River, suggesting that these have probably been introduced to the respective water bodies relatively recently. This study gives an idea about the degree of microplastics pollution in different water bodies of Dhaka city in two different seasons.

TABLE OF CONTENTS

ACKNOWLEDGEMENT	vi
ABSTRACT	vii
TABLE OF CONTENTS	viii
LIST OF FIGURES	x
LIST OF TABLES	xii
LIST OF ABBREVIATIONS	xiv
Chapter 1 INTRODUCTION	
1.1 Background	1
1.2 Objectives	3
1.3 Outline of Methodology	3
1.4 Organization of Thesis	4
Chapter 2 LITERATURE REVIEW	
2.1 Introduction	5
2.2 Overview of Microplastics Pollution	5
2.2.1 Plastic Development	5
2.2.2 Microplastics Pollution	7
2.2.3 Types of Microplastics	8
2.2.4 Characteristics of Microplastics	9
2.2.5 Sources of Microplastics into the Freshwater Environment	11
2.2.6 Fate and Transport of Microplastics in Freshwater Systems	17
2.2.7 Effects of Plastics and Microplastics on Freshwater Ecosystems	24
2.2.8 Socio-Economic Impacts	26
2.2.9 Accumulation of Microplastics in Fish, Seafood and other food products	26
2.3 Identification and Quantification of Microplastics	27
2.3.1 Sampling	27
2.3.2 Sample Processing	28
2.3.3 Characterization of Microplastics	31
2.3.4 Quantification of Microplastics	35
Chapter 3 METHODOLOGY	
3.1 General	36
3.2 Samplings	36
3.2.1 Collection of Samples	38
3.3 Processing of Samples for Identification of Microplastics	40
3.3.1 Methods for Analysis of Microplastics	40
3.3.2 Apparatus and Materials used	42
3.3.3 Test Procedure	43
3.4 Characterization of Microplastics	48
Chapter 4 RESULTS AND DISCUSSION	
4.1 Introduction	50
4.2 Quantification of Microplastics in the Selected Water Bodies	50
4.2.1 Microplastics in Dhanmondi Lake	51
4.2.2 Microplastics in Ramna Lake	54

4.2.3	Microplastics in Hatirjheel	58
4.2.4	Microplastics in Buriganga River	60
4.2.5	Microplastics in Turag River	63
4.2.6	Comparison of Quantities Microplastics found in Different Water Bodies	66
4.3	Characterization of Microplastics	69
4.3.1	Size Fractionation of Microplastics	69
4.3.2	Morphology of Microplastics	79
Chapter 5 CONCLUSIONS AND RECOMMENDATIONS		
5.1	Introduction	87
5.2	Conclusions	87
5.3	Limitations of the Study	88
5.4	Recommendations for Future Research	88
REFERENCES		90

LIST OF FIGURES

Figure 2.1:	Shapes of typical Microplastics collected from inland waters	10
Figure 2.2:	Surface texture of typical microplastics collected from inland waters	11
Figure 2.3:	Various ways of Microplastics get into the environment	17
Figure 2.4:	Schematic representation of the different processes playing a role in the transport of macroplastics in a river and lake	18
Figure 2.5:	Schematic representation of the key processes playing a role in the transport of non-buoyant microplastics	19
Figure 2.6:	Fate of micro- and nano-plastics in mammalian bodies	27
Figure 3.1:	Study area from where the sample were collected	38
Figure 3.2:	Surface net made using cloth, used for collection of samples in this study	39
Figure 3.3:	Collection of samples	40
Figure 3.4:	Flow chart showing the method used for the analysis of microplastics in this study	42
Figure 3.5:	A sample retained on No. 50 sieve (after sieving and rinsing)	44
Figure 3.6:	Oven dry samples to determine dry weight	44
Figure 3.7:	Wet Peroxide Oxidation using hotplate	46
Figure 3.8:	Density separation of sample to separate microplastics	46
Figure 3.9:	Sample ready for microscope examination	47
Figure 3.10:	Microplastics fragments separation using magnifying glass	47
Figure 3.11:	Final Microplastics sample	48
Figure 4.1:	Locations of the sampling points	51
Figure 4.2:	Microplastics found at the sampling location S1 in Dhanmondi Lake	52
Figure 4.3:	Comparison of the concentration of microplastics in Dhanmondi Lake (sampling location S1) in Winter and Summer	54
Figure 4.4:	Microplastics found at the sampling location S2 in Ramna Lake	55
Figure 4.5:	Comparison of the concentration of microplastics in Ramna Lake (sampling location S2) in Winter and Summer	57
Figure 4.6:	Microplastics found at the sampling point S3 in Hatirjheel	58
Figure 4.7:	Comparison of the concentration of microplastics in Hatirjheel (sampling location S3) in Winter and Summer	60
Figure 4.8:	Microplastics found at the sampling point S4 in Buriganga River	61
Figure 4.9:	Comparison of the concentration of microplastics in Buriganga River (sampling location S4) in Winter and Summer	63
Figure 4.10:	Microplastics found at the sampling point S5 in Turag River	64
Figure 4.11:	Comparison of the concentration of microplastics in Turag River (sampling location S5) in Winter and Summer	66
Figure 4.12:	Comparison of the percentage of Microplastics found in different water bodies	67
Figure 4.13:	Concentration of microplastics in terms of mass per unit area sampled	68
Figure 4.14:	Concentration of microplastics in terms of number of items per unit area sampled	68
Figure 4.15:	Distribution of microplastics found at the sampling location S1 in Dhanmondi Lake, in Winter and Summer, among different size fractions (in terms of mass)	70

Figure 4.16:	Distribution of microplastics found at the sampling location S1 in Dhanmondi Lake, in Winter and Summer, among different size fractions (in terms of number of items)	71
Figure 4.17:	Distribution of microplastics found at the sampling location S2 in Ramna Lake, in Winter and Summer, among different size fractions (in terms of mass)	72
Figure 4.18:	Distribution of microplastics found at the sampling location in S2 in Ramna Lake, in Winter and Summer, among different size fractions (in terms of number of items)	72
Figure 4.19:	Distribution of microplastics found at the sampling location S3 in Hatirjheel, in Winter and Summer, among different size fractions (in terms of mass)	73
Figure 4.20:	Distribution of microplastics found at the sampling location S3 in Hatirjheel, in Winter and Summer, among different size fractions (in terms of number of items)	74
Figure 4.21:	Distribution of microplastics found at the sampling location S4 in Buriganga River, in Winter and Summer, among different size fractions (in terms of mass)	75
Figure 4.22:	Distribution of microplastics found at the sampling location S4 in Buriganga River, in Winter and Summer, among different size fractions (in terms of number of items)	76
Figure 4.23:	Distribution of microplastics found at the sampling location S5 in Turag River, in Winter and Summer, among different size fractions (in terms of mass)	77
Figure 4.24:	Distribution of microplastics found at the sampling location S5 in Turag River, in Winter and Summer, among different size fractions (in terms of mass)	78
Figure 4.25:	Size fractions of microplastics retained on the sieves (2.36 mm, 1.18 mm, 0.6 mm and 0.3 mm sieves) for microplastics isolated from the sample collected from Turag River in Summer	79

LIST OF TABLES

Table 2.1:	A brief profile of plastic development	6
Table 2.2:	A selective list of additive compounds used to make plastics fit for purpose	7
Table 2.3:	Summary of the main features of the currently existing plastic debris models for freshwater systems	20
Table 2.4:	Polymer type, density, and crystallinity	23
Table 3.1:	GPS locations of sampling points	37
Table 3.2:	Water sampling schedules	37
Table 4.1:	Microplastics as percentage (%) of total solids in the samples from sampling location S1 in Dhanmondi Lake	52
Table 4.2:	Concentration of microplastics in Dhanmondi Lake (sampling location S1) in terms of mass and number of items per unit area sampled	53
Table 4.3:	Microplastics as percentage (%) of total solids in the samples from sampling location S2 in Ramna Lake	55
Table 4.4:	Concentration of microplastics in Ramna Lake (sampling location S2) in terms of mass and number of items per unit area sampled	56
Table 4.5:	Microplastics as percentage (%) of total solids in the samples collected from location S3 in Hatirjheel	58
Table 4.6:	Concentration of microplastics in Hatirjheel (sampling location S3) in terms of mass and number of items per unit area sampled	59
Table 4.7:	Microplastics as percentage (%) of total solids in the samples from the Sampling location S4 in Buriganga River	61
Table 4.8:	Concentration of microplastics in Buriganga River (sampling location S4) in terms of mass and number of items per unit area sampled	62
Table 4.9:	Microplastics as percentage (%) of total solids in the samples from the Sampling location S5 in Turag River	64
Table 4.10:	Concentration of microplastics in Turag River (sampling location S5) in terms of mass and number of items per unit area sampled	65
Table 4.11:	Size fractions of the microplastics found at the sampling location S1 of Dhanmondi lake in Winter and Summer	69
Table 4.12:	Size fractions of the microplastics found at the sampling location S2 of Ramna lake in Winter and Summer	71
Table 4.13:	Size fractions of the microplastics found at the sampling location S3 of Hatirjheel in Winter and Summer	73
Table 4.14:	Size fractions of the microplastics found at the sampling location S4 of Buriganga River in Winter and Summer	75
Table 4.15:	Size fractions of the microplastics found at the sampling location S5 of Turag River in Winter and Summer	76
Table 4.16(a):	Morphological analysis of microplastics from Dhanmondi Lake in Winter	80
Table 4.16(b):	Morphological analysis of microplastics from Dhanmondi Lake in Summer	80
Table 4.17(a):	Morphological analysis of microplastics from Ramna Lake in Winter	81
Table 4.17(b):	Morphological analysis of microplastics from Ramna Lake in Summer	82

Table 4.18(a):	Morphological analysis of microplastics from Hatirjheel in	83
	Winter	
Table 4.18(b):	Morphological analysis of microplastics from Hatirjheel in	83
	Summer	
Table 4.19(a):	Morphological analysis of microplastics from Buriganga River in	84
	Winter	
Table 4.19(b):	Morphological analysis of microplastics from Buriganga River in	84
	Summer	
Table 4.20(a):	Morphological analysis of microplastics from Turag River in	85
	Winter	
Table 4.20(b):	Morphological analysis of microplastics from Turag River in	86
	Summer	

LIST OF ABBREVIATIONS

COVID	Coronavirus disease
DDT	Dichlorodiphenyltrichloroethane
DoE	Department of Environment
EC	Effective Concentration
EDS	Energy dispersive spectroscopy
ENP	Engineered nanoparticles
FAO	Food and Agriculture Organization
FTIR	Fourier transform infrared spectroscopy
HDPE	High-density polyethylene
IR	Infrared spectroscopy
LDPE	Low-density polyethylene
MP	Microplastic
NOAA	National Oceanic and Atmospheric Administration
PAH	Polycyclic aromatic hydrocarbon
PC	Polycarbonate
PCB	Polychlorinated biphenyl
PE	Polyethylene
PETE or PET	Polyethylene terephthalate
PHA	Polyhydroxyalkanoate
PLA	Polylactic Acid
PM	Particulate Matter
PMMA	Polymethyl methacrylate
POP	Persistent organic pollutant
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethane
PVC	Polyvinyl chloride
SEM	Scanning electron microscope
UNDP	United Nations Development Programme
US	United States
UV	Ultraviolet
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

Chapter 1

INTRODUCTION

1.1 Background

Plastics are synthetic organic polymers, which are formed from the polymerization of monomers extracted from oil or gas (Derraik, 2002; Rios et al., 2007; Thompson et al., 2009). The common forms of plastics commonly used include Polyethylene terephthalate (PETE or PET), Polyethylene (PE), Polyvinyl Chloride (PVC), Polypropylene (PP), Polystyrene (PS), Polylactic Acid (PLA), Polycarbonate (PC), Acrylic (PMMA) etc. They can be moulded into shape while soft, and then set into a stiff or slightly elastic form. They are lightweight, durable, inert and corrosion resistant. About 260 million tons of plastics are produced each year globally, about 10 percent of these ends up in the Ocean, (Plastic Debris in the World's Oceans, 2006).

The production of plastics has increased worldwide noticeably since the development of synthetic polymers in the middle of the 20th century (Andrady, 2011). Plastics can become an environmental hazard, when discarded in the aquatic environment (Cole et al., 2011). Plastic debris enter into the aquatic environment in a wide range of sizes, from micrometer to meter range. Microplastics particles include either manufactured plastics of microscopic size, such as scrubbers (Fendall and Sewell, 2009) and industrial pellets that serve as pioneers for manufactured plastic products (primary sources), or fragments or fibers of plastics resultant from the breakdown of larger plastic products (secondary sources) (Cole et al., 2011). Degradation processes of plastics are extremely slow (Roy et al, 2011) and thus microplastics tend to persist for very long time periods in the aquatic environment (Rios et al., 2010).

Exposure of freshwater organisms to microplastics has been found to cause mortality, neurotoxicity, oxidative stress and damage, decrease of individual and population fitness, and several other adverse effects (Au et al., 2015; Bhattacharya et al., 2010; Lagarde et al., 2016). Microplastics and nanoplastics have been found to cause a wide range of adverse effects, such as immobilization, mortality, feeding inhibition, decrease of the reproductive fitness, among several other (Besseling et al., 2014; Jemec et al., 2016; Nasser and Lynch, 2015; Ogonowski et al., 2016; Rehse et al., 2016; Frydkjær et al., 2017).

In recent times, there is increasing societal and scientific concern about the effects of microplastics (MPs), commonly defined as plastic particles with sizes below 5 mm (Hidalgo-Ruz et al., 2012), both on freshwater and marine organisms (Kako et al., 2014; Maximenko et al., 2012; Isobe et al., 2014). Microplastics can be classified as primary and secondary microplastics, depending on the way in which they are produced. Primary microplastics are small plastic particles which are released directly into the environment through domestic and industrial effluents, spills and sewage discharge or indirectly via run-off. Different types of primary microplastics particle include fragments, fibers, pellets, film and spheres (Rummel et al., 2016; Nobre et al., 2015; Kang et al., 2015; Lusher et al., 2015; Li et al., 2016). Spheres are frequently associated with cosmetics and pharmaceutical industries. Secondary microplastics are formed because of gradual degradation/ fragmentation of larger plastic particles that are already present in the environment, as a result of processes such as mechanical transformation (e.g. waves abrasion), UV radiation (photo-oxidation) and biological degradation by microorganisms (Cole et al., 2011). Microplastics in the environment can be further degraded/ fragmented to yield nano-plastics (1–100 nm), which, when compared to other forms of plastic litter, have mostly unidentified fates and toxicological properties (da Costa et al., 2016; Koelmans et al., 2015).

Although presence of microplastics in the marine environment received most attention, in recent years, presence of microplastics in inland water bodies including rivers and lakes are becoming a major concern. Chowdhury et al. (2020) reported that the River Ganges contributes the second largest amount of plastic to ocean, but there is only one report on this issue. In Bangladesh, there appears to be limited awareness about the hazards associated with plastic and microplastics pollution. Chowdhury et al. (2020) presents a review of the plastic pollution in aquatic ecosystems in Bangladesh. It reports that a total of 24 studies relevant to plastic pollution in freshwater and marine environment were published between 2006 and 2019, and the out of these 18 were considered in the study by Chowdhury et al. (2020). Out of these 18, nine focused on plastic pollution in marine environment, eight focused on plastic waste generation and management, and only one focused on freshwater environment. There is virtually no data on the occurrence and quantity of microplastics in water bodies in Bangladesh.

It is therefore important to assess the occurrence of microplastics in the waterbodies in Bangladesh and quantify the concentration of microplastics in these water bodies, as the first step in understanding the adverse impacts of this pollutant on the aquatic ecosystem.

1.2 Objectives

The overall objective of this study is to identify, quantify and characterize microplastics in selected water bodies in and around Dhaka City. Specific objectives include:

- 1) Development of laboratory set up for analysis of microplastics
- 2) Determination of microplastics concentration in selected water bodies in and surrounding Dhaka City (Dhanmondi and Ramna Lakes; Hatirjheel; Buriganga and Turag rivers) through sampling and analysis.
- 3) Characterization of microplastics from different water bodies through visual (microscopic) sorting, size fractionation, concentration determination and morphology analysis using magnifying glass.

1.3 Outline of Methodology

Water samples were collected from five surface water bodies for determining presence of microplastics, and for quantification and analysis of microplastics. The water bodies include Dhanmondi Lake, Ramna Lake, Hatirjheel, Buriganga River and Turag River. The laboratory set up needed for analysis of microplastics was developed as a part of this study, based on standard method/protocol used for determination of microplastics; 4.75-mm and 0.3-mm sieves were used to isolate the solid materials of appropriate size. Then sieved materials were dried to determine the solids mass in the sample. The solids were then subjected to wet peroxide oxidation (WPO) to digest labile organic matter while the plastic debris remained unchanged. The WPO mixture was then subjected to density separation to isolate the plastic fragments through flotation. The floating solids were then separated from the denser undigested mineral components using a density separation process. The floating plastic debris were collected in the density separator using a custom 0.3 mm filter, air dried and weighed. Plastic materials were removed and collected to determine the microplastics concentration. Characterization of microplastics were carried out through visual (microscopic) sorting, size fraction analysis and morphology analysis.

1.4 Organization of Thesis

The thesis has been presented in five chapters.

Chapter One presents background of the study, objective, and outline of methodology in brief.

Chapter Two presents a review of the possible sources of microplastics pollution in the aquatic ecosystem, its impact on the overall environment and the means to mitigate the adverse effects.

This chapter describes related works which have been performed previously.

Chapter Three presents the methodology followed in this research. It includes details of the sampling and analysis of microplastics in water samples, and it describes in detail the laboratory experiments carried out for the quantification and characterization of microplastics.

Chapter Four presents characteristics of microplastics, and the results of the laboratory experiments for the characterization of microplastics. It also presents an assessment of the quantification and characterization of microplastics in the water bodies in Dhaka City.

Finally, Chapter Five summarizes the major conclusions from the present research and presents recommendations for future study.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The overall objective of this research is to identify, quantify and characterize microplastics in selected water bodies within and around Dhaka City. The water bodies selected in this study are: Dhanmondi Lake, Ramna Lake, Hatirjheel and two peripheral rivers of Dhaka city Buriganga and Turag. This Chapter presents a review of related studies on microplastics pollution. This Chapter includes a review of the possible sources of microplastics pollution in the aquatic ecosystem, its impact on the overall environment and the means to ease the adverse effects. This Chapter also presents an overview of the methodologies commonly employed for characterization and quantification of microplastics.

2.2 Overview of Microplastics Pollution

2.2.1 Plastic Development

Plastics are synthetic organic polymers which are formed from the polymerization of monomers extracted from oil or gas (Thompson et al., 2009). The common forms of plastics used in modern days include Polyethylene terephthalate (PETE or PET), Polyethylene (PE), Polyvinyl Chloride (PVC), Polypropylene (PP), Polystyrene (PS), Polylactic Acid (PLA), Polycarbonate (PC), Poly methyl methacrylate (PMMA), etc. In soft stage, they can be moulded into shape, and then set into a rigid or to some extent elastic form. They are lightweight, durable, inactive and corrosion resistant.

Today's foremost usage of plastic materials can be traced back to the 1800s with the development of rubber technology. One of the key breakthroughs in this area was the discovery of vulcanization of natural rubber by Charles Goodyear (Stevenson et al., 2008). Throughout the 1800s several efforts were taken to develop synthetic polymers including polyvinyl chloride (PVC) and polystyrene (PS), but at this time these materials were either too brittle to be commercially feasible or would not retain their shape. The first synthetic polymer that came into mass production was Bakelite, a phenol-formaldehyde resin, developed by Leo Baekeland, the Belgian chemist in 1909 (Vlachopoulos et al., 2003). Later, around the 1930s the modern forms of PVC, polyethylene terephthalate (PET), polyurethane (PUR), and a more processable

PS were developed (Brandsch and Piringer., 2008). The early 1950s saw the development of high-density polyethylene (HDPE) and polypropylene (PP) (Table 2.1). In the 1960s, progress in the material sciences led to the development of plastic materials formed from other natural resources (Lambert, 2015), for example the bacterial fermentation of sugars and lipids, and comprise polyhydroxyalkanoates (PHA), polylactides (PLA), aliphatic polyesters, and polysaccharides (Reddy et al., 2003). PLA is on the verge of entering into bulk production, while PHA production is between pilot plant and commercial stage (Mohan, 2016; Amulya et al., 2015).

Table 2.1: A brief profile of plastic development (Lambert, 2013a)

Year	Polymer type	Inventor/notes
1839	Natural rubber latex	Charles Goodyear
1839	Polystyrène	Discovered by Eduard Simon
1862	Parkesine	Alexander Parkes
1865	Cellulose acetate	Paul Schützenberger
1869	Celluloid	John Wesley Hyatt
1872	Polyvinyl chloride	First created by Eugen Baumann
1894	Viscose rayon	Charles Frederick Cross
1909	Bakelite	Leo Hendrik Baekeland
1926	Plasticised PVC	Walter Semon
1933	Polyvinylidene chloride	Ralph Wiley
1935	Low-density polyethylene	Reginald Gibson and Eric Fawcett
1936	Acrylic or polymethyl methacrylate	Discovered by Rowland Hill and John Crawford
1937	Polyurethane	Otto Bayer and co-workers
1938	Polystyrene	As a commercially viable polymer
1938	Polyethylene terephthalate	John Whinfield and James Dickson
1942	Unsaturated polyester	John Whinfield and James Dickson
1951	High-density polyethylene	Paul Hogan and Robert Banks
1951	Polypropylene	Paul Hogan and Robert Banks
1953	Polycarbonate	Hermann Schnell
1954	Styrofoam	Ray McIntire
1960	Polylactic acid	Patrick Gruber is credited with inventing a commercially viable process
1978	Linear low-density polyethylene	DuPont

Plastics are processable materials based on polymers (Baner and Piringer, 2007) and to make them into materials fit for purpose, they are generally processed with a range of chemical additives (Table 2.2). These compounds are used in order to adjust the material properties and make them appropriate for their intended purpose. Therefore, plastic materials can still vary in

structure and performance within polymer classifications, depending on the category and quantity of additives they are compounded with.

Table 2.2: A selective list of additive compounds used to make plastics fit for purpose (Lambert and Wagner, 2017)

Additive compounds	Function
Plasticizers	Renders the material pliable
Flame retardants	Reduces flammability
Cross-linking additives	Links together polymer chains
Antioxidants and other stabilizers	Increases the durability of plastics by slowing down the rate at which oxygen, heat, and light degrade the material
Sensitizers (e.g. pro-oxidant transition metal complexes)	Used to give accelerated degradation properties
Surfactants	Used to modify surface properties to allow emulsion of normally incompatible substances
Inorganic fillers	Used to reinforce the material to improve impact resistance
Pigments	For color

Microplastics (MPs) have unquestionably been present in the environment for many years. As research focused on the issue more intensively since the early 2000s, MPs are considered contaminants of emerging concern (Sutherland et al., 2010; Lambert et al., 2014; Wagner et al., 2014).

2.2.2 Microplastics Pollution

Microplastics are not a specific kind of plastic, but rather any type of plastic fragment that is less than 5 mm in size is called microplastics according to the European Chemicals Agency (European Chemicals Agency, 2020) and the U.S. National Oceanic and Atmospheric Administration (NOAA) (Arthur et al., 2009; Collignon et al., 2014).

Microplastics is used as a generic term to express a truly heterogeneous mixture of particles ranging in size from a few microns to several millimetres in length/diameter; counting particles of various shapes from totally spherical to lengthened fibres. Microplastics have been reported in a range of colours. Although, pieces that vary in appearance according to their shape, size or colour to ambient natural particulates are most frequently reported, for example blue or red fibres (Hidalgo-Ruz et al., 2012). Small plastic particles were first reported in the marine environment in the early 1970s (Carpenter et al., 1972a).

Microplastics contamination has later been reported on a global scale from the poles to the equator (Barnes et al., 2009; Browne et al., 2011; Hidalgo-Ruz et al., 2012) and MPs pollute the water surface of the open ocean (Law et al. 2010; Collignon et al., 2012; Goldstein et al., 2012; Ivar do Sul et al., 2013), fiord (Sadri and Thompson 2014) and lough (Eriksen et al., 2013) together with marine (Browne et al., 2011; Santos et al., 2009) and freshwater shorelines (Imhof et al., 2013) and subtidal sediments (Browne et al., 2011) under the deep sea (Van Cauwenberghe et al., 2013; Woodall et al., 2014). Microplastics have also been found in significant concentrations in Arctic sea ice (Obbard et al., 2014). Globally, about 260 million tons of plastics are produced each year, about 10 percent of these plastics ends up in the Ocean.

According to UNDP, marine pollution, a devastating majority of which comes from land-based sources, is reaching shocking levels, with an average of 13,000 pieces of plastic debris to be found on every square kilometre of ocean.

2.2.3 Types of Microplastics

The existence of microplastics in the aquatic environment has been reported worldwide. There are two types of microplastics depending on source and formation process: primary and secondary microplastics (Arthur et al. 2009).

Primary microplastics are any fragments or particles of plastic that are already 5.0 mm or less in size before entering the environment. These include microfibers from clothing, microbeads, scrubbers and plastic pellets (also known as nurdles). These plastics are usually used in facewash and cosmetic products or as air blasting media. They are also being used in medicine as vectors for drugs (Patel et al., 2009). Scrubbers are used as exfoliating hand cleansers and facial scrubs which have replaced traditionally used natural ingredients including groundnuts, oatmeal and pumice (Fendall and Sewell, 2009). These are typically marketed as “microbeads” having variety of shapes, sizes and compositions. For example, the occurrence of polyethylene and polypropylene granules (<5 mm) and polystyrene spheres (<2 mm) in one cosmetic product was reported by Gregory (1996). More recently, Fendall and Sewell (2009) reported an abundance of irregularly shaped microplastics, typically <0.5 mm in diameter with a mode size <0.1 mm, in another cosmetic product. Primary microplastics have also been produced for use in air blasting technology. This process involves blasting acrylic, melamine, or polyester microplastics scrubbers at machinery, engines, and boat hulls to remove rust and paint. As

these scrubbers are used repeatedly until they diminish in size and their cutting power is lost, they will often become contaminated with heavy metals (e.g. Cadmium, Chromium, Lead) (Cole et al., 2011).

Small fragments of plastic derived from the breakdown of larger plastic debris, both at sea and on land are secondary plastics. Over time, as a result of physical, biological, and chemical-photo-degradation, including photo-degradation caused by sunlight exposure, can decrease the structural integrity of plastic fragments to a size which is ultimately undetectable to the naked eye (Masura et al., 2015). This procedure of breaking down large plastic material into much smaller pieces is known as fragmentation (Cole et al., 2011). It is considered that microplastics might further degrade to smaller size, although the smallest microplastics reportedly found in the oceans is 1.6 micrometres (6.3×10^{-5} in) in diameter (Conkle et al., 2017). The incidence of microplastics with irregular shapes suggests that fragmentation is a key source (Grossman, 2015).

2.2.4 Characteristics of Microplastics

Particle Shape

Larger plastic fragments have been found in the environment in a wide range of shapes. After collection of samples, possible microplastics are usually examined using stereo microscopes. In accordance with their shapes, microplastics are typically sorted as: sheet, film, line/fiber, fragment, pellet/granule, and foam (see Fig. 2.1). However, there is no set practice, and different sorting protocol might be used by different researchers. The morphological data from the microplastics samples can be used to indicate their potential origins. For example, line/fiber are usually created from fishing lines, clothing, or other textiles, while film is mainly created from bags or wrapping materials (Wu et al., 2018).

Particle Size

Size is another parameter usually assessed for microplastics, but no combined criteria are currently available. Generally, only microplastics >0.333 mm (mesh size of the manta trawl net) are assessed in floating samples collected by trawling. As the test of microplastics <0.05 mm is increasingly difficult, advanced instruments such as Raman microscopy, micro-Fourier transform infrared spectroscopy (μ -FTIR) or scanning electron microscope (SEM) with energy dispersive spectroscopy (EDS) should be used (Imhof et al., 2013). Generally, microplastics

diversity increases with decreasing size (Collignon et al., 2012; Isobe et al., 2015; Imhof et al., 2016).

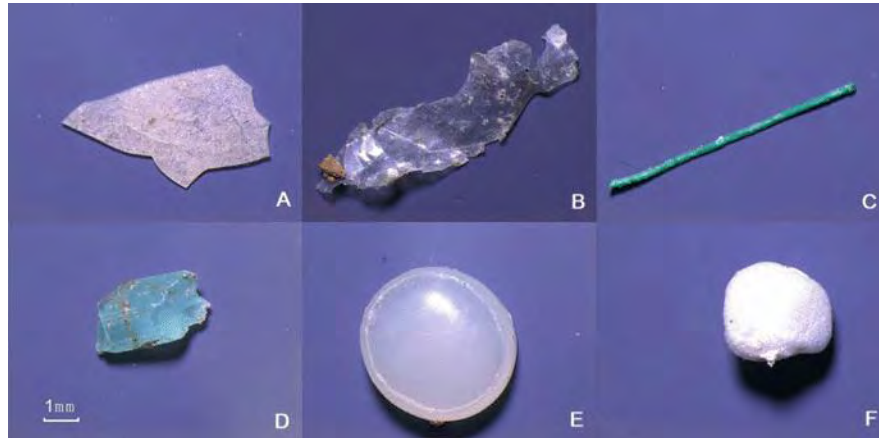


Figure 2.1: Shapes of typical Microplastics collected from inland waters (a, sheet; b, film; c, line/fiber; d, fragment; e, pellet/granule; f, foam) (Wu et al., 2018)

Color

Microplastics can follow their colors from their parent plastic products, but due to weathering, their colors can change. Predators may preferably ingest microplastics with colors resembling their prey (Boerger et al., 2010; Moser and Lee, 1992; Moore, 2008). Therefore, color information of microplastics may be used to indicate their potential to be ingested by aquatic animals (Wu et al., 2018). It may be interesting to explore further how color affects the environmental fate and ecological effects of microplastics. As an example, colorants can often influence the final thermal and UV stability of a plastic material (Saron and Felisberti, 2006; Russell, 2007).

Surface Texture

Once entering the environment, plastics are subject to weathering processes, and these processes will influence the surface of the microplastics (Figure 2.2). Featured surface textures on microplastics can be used to indicate the processes of mechanical and oxidative weathering (Zbyszewski and Corcoran, 2011; Cooper and Corcoran, 2010). Surface textures are usually examined using SEM. Features such as fractures, grooves and mechanical pits are believed to consequence from mechanical weathering, while granules, flakes, and solution pits are considered as oxidative weathering features (Zbyszewski et al., 2014). The surface oxidation

of plastics can be confirmed using FTIR as indicated by the appearance of peaks for carbonyl groups (Zbyszewski et al., 2014; Su et al., 2016).

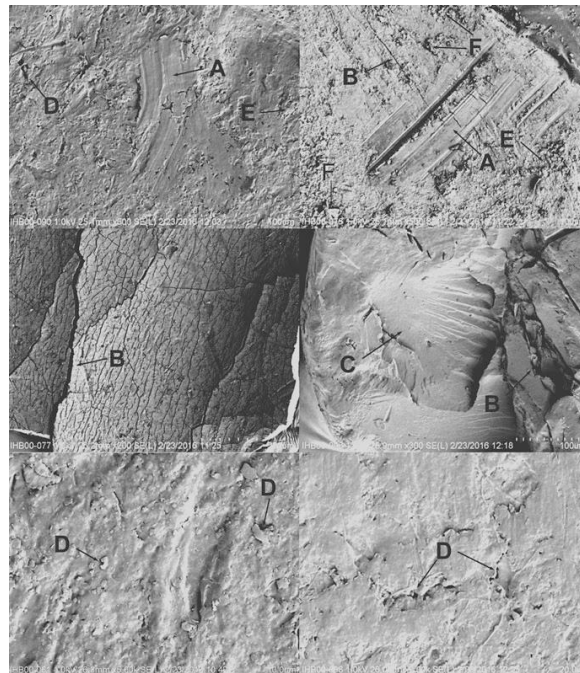


Figure 2.2: Surface texture of typical microplastics collected from inland waters (a, grooves; b, fractures; c, mechanical pits; d, flakes; e, granular; f, solution pits) (Wu et al., 2018)

2.2.5 Sources of Microplastics into the Freshwater Environment

Plastics from various sources enter freshwater environments through various routes. As with bulk plastic matters, MPs can enter the environment by several pathways, and a significant route in one geographical region may be less important in another. For instance, primary MPs used in consumer cosmetics are perhaps more important in affluent regions (Lambert et al., 2014).

MPs have numerous potential release pathways to enter into the environmental release pathways: (1) passage through WWTPs, either from release of fibers from textiles during the washing of clothes, to surface waters or MP use in personal care products, (2) use of biosolids from WWTPs to agricultural lands (Nizzetto et al., 2016a), (3) storm water overflow occurrence, (4) incidental release (e.g. during tire wear), (5) discharge from industrial products or processes, and (6) atmospheric deposition of fibers (Dris et al., 2017a). Plastic films used for production of crops are considered a significant agricultural emission, and their use is assumed to be one of the most vital sources of plastic contamination of agricultural soils (Xu

et al., 2006a; Brodhagen et al., 2014; Kyrikou and Briassoulis, 2007). The advantages of the use of plastic films include conserve of moisture, thereby reducing irrigation; reduce weed growth and increase soil temperature which reduces competition for soil nutrients and reduces fertilizer costs, thereby improving crop yields; and protect against adverse weather conditions (Liu et al., 2014). Though, weathering can make them brittle and difficult to recover resulting in breakdown of the material, and when coupled with consecutive rainfall events, the residues and broken particles can be washed into the soil where they accumulate (Liu et al., 2014; Xu et al., 2006b). Other sources include discharges from manufacturing and constructions sites. Automotive tire wear particles may also release large volumes of synthetic particles (Councill et al., 2004). A short description about these sources are given below.

Environmental Action

As established earlier, plastics do not decompose, but they are broken down. It is mainly the case in aquatic environments where the microplastics are created and have the deepest impacts. Since the plastic wastes and debris float around the seas and oceans, they are exposed to the elements of severe solar radiation and continuous abrasion from the action of wind and water waves.

Over time, these elements break down the plastics into smaller chunks of fragments and the cycle continues endlessly until the remaining debris becomes microscopic. In the terrestrial environment, microplastics are created through human and animal action as the trudge on the plastics makes it easier to break them apart.

Sewage treatment plants

Sewage treatment plants, also known as wastewater treatment plants (WWTPs), remove contaminants from wastewater, primarily from household sewage, using various physical, chemical, and biological processes (Carr et al., 2016). Most plants in developed countries have both primary treatment stage to remove oils, sand, and other large solids using conventional filters, clarifiers, and settling tanks and secondary treatment stages to break down organic matter using biological processes involving bacteria and protozoa. Secondary technologies which are frequently used are activated sludge systems, trickling filters, and constructed wetlands. The optional tertiary treatment stage may include processes for nutrient removal for example, nitrogen and phosphorus removal and disinfection.

In both the primary and secondary treatment stages of the WWTPs, microplastics have been detected. A study estimated that about one particle per litre of microplastics are being released back into the environment, with a removal efficiency of about 99.9% (Carr et al., 2016; Estahbanati and Fahrenfeld, 2016; Mintenig et al., 2017). A 2016 study showed that most microplastics are actually removed during the primary treatment stage where solid skimming and sludge settling are used (Carr et al., 2016). When these treatment facilities are functioning properly, the contribution of microplastics into oceans and surface water environments from WWTPs is not disproportionately large (Carr et al., 2016, Murphy et al., 2016).

Sewage sludge from WWTPs is used for soil fertilizer in some countries, which exposes plastics in the sludge to the weather, sunlight, and other biological factors, causing fragmentation. As a result, microplastics from these biosolids frequently end up in storm drains and sooner or later into bodies of water (Weithmann et al., 2018). In addition, some studies show that microplastics do pass through filtration processes at some WWTPs (Cole et al., 2011). According to a study from the UK, samples taken from sewage sludge disposal sites on the coasts of six continents contained an average one microplastics particle per liter. A significant amount of these particles was of clothing fibers from washing machine effluent (Browne et al., 2011).

Car and truck tires

Secondary microplastics, for example, from car and truck tires or footwear, are more important than primary microplastics by two orders of magnitude. In Denmark, emissions of microplastics to the environment is estimated between 5500 and 14000 tonnes (6100 and 15400 tons) per year, per capita emission ranges from 0.23 to 4.7 kg/year, with a global average of 0.81 kg/year. Among all the potential sources, the emissions from car tires are substantially greater than those of other sources of microplastics, for example, artificial turf (12-50%), airplane tires (2%), brake wear (8%), and road markings (5%). The comparative input of tire wear and tear to the total global amount of plastics ending up in our oceans is estimated to be 5-10%. In atmosphere, the particulate matter (PM_{2.5}) is estimated to consist of 3-7% of tire wear and tear, indicating that it may influence the global health burden of air pollution which has been estimated by the World Health Organization (WHO) at 3 million deaths in 2012 (Kole et al., 2017).

Cosmetics industry

"Microbeads" or "micro-exfoliates", composed of polyethylene, can also be manufactured from polypropylene, polyethylene terephthalate (PET), and nylon, often found in face washes, hand soaps, and other personal care products. These beads are usually washed into the sewage system immediately after use. Their small size prevents them from fully being retained by preliminary treatment screens at wastewater plants, thereby allowing some to enter rivers and oceans (Fendall and Sewell, 2009). Because of the small design of microbeads, an average of 95–99.9% of microbeads are only removed by wastewater treatment plants. So, an average of 0-7 microbeads per liter are being discharged. It has been estimated that because of cosmetic exfoliates, face wash, toothpaste, or other sources, around 808 trillion beads per household are discharged into the environment in a single day. According to a research, there are at least 80 different facial scrub products that are still being sold with microbeads as a main component, though many companies have committed to phasing out the use of microbeads in their products (Anderson et al., 2016).

Clothing

A few studies have shown that many synthetic fibers, e.g. nylon, polyester, acrylics, and spandex, can be released from clothing and endure in the environment (Grossman, 2015). More than 1,900 fibers of microplastics can shed by each garment in a load of laundry, with fleeces releasing the highest percentage of fibers, which is over 170% more than other garments (Browne et al., 2011; Katsnelson, 2015). For an average wash load of 6 kg, over 700,000 fibres could be released per wash (Napper and Thompson, 2016). The process of washing clothes causes garments to lose an average of over 100 fibers per liter of water (Browne et al., 2011). In both indoor and outdoor environments, textile fibers have been studied, to calculate the average human exposure. The concentration was found in indoor to be 1.0–60.0 fibers/m³, whereas the outdoor concentration was much less at 0.3-1.5 fibers/m³ (Dris et al., 2017b). The deposition rate indoors was 1586–11,130 fibers per day/m³ which accumulates to around 190-670 fibers/mg of dust (Dris et al., 2017b).

Manufacturing

Granules and small resin pellets are used as the raw material for the manufacturing of plastic products. As a result of unintentional spillage during land or sea transport, improper use as packing materials, and direct discharge from processing plants, these raw materials can enter

aquatic ecosystems. In an assessment of Swedish waters using an 80 µm mesh, KIMO Sweden found that the typical microplastics concentrations was of 150-2,400 MPs per m³; in a port adjacent to a plastic production facility, the concentration was 102,000 MPs per m³ (Cole et al., 2011).

Many industrial sites in which suitable raw plastics are frequently used are located near bodies of water. If spilled during production, these materials may enter the surrounding environment and pollute waterways (Sundt and Schulze, 2015).

Fishing industry

Pleasurable and commercial fishing, marine vessels, and marine industries together act as sources of plastic which can directly enter the aquatic environment, posing a danger to biota both as macroplastics, and as secondary microplastics. Marine fragments detected on seashores also arises from beaching of materials carried on inshore and oceanic currents. Fishing gear is a type of plastic debris with a marine source. Discarded or lost fishing gear, including plastic monofilament line and nylon netting, is typically buoyant and can, therefore, drift at variable depths within the oceans (Rochman et al., 2015).

Packaging and shipping

Shipping has significantly contributed to marine pollution. Study has shown that in 1970, around the world commercial shipping fleets dumped over 23,000 tons of plastic waste into the marine environment. During 1988, an international agreement (MARPOL 73/78, Annex V) forbidden the waste dumping from ships into the marine environment. The discharge of plastics in the sea, including from marine vessels was prohibited in the US, according to the Marine Plastic Pollution Research and Control Act of 1987 (Derraik, 2002). Yet, shipping remains one of the major sources of plastic pollution, with a contribution of around 6.5 million tons of plastic in the early 1990s (Teuten et al., 2009). Research has shown that on the beaches in Hawaii, approximately 10% of the plastic found are nurdles (Thompson et al., 2009). On July 24, 2012, in one occurrence, 150 tonnes of nurdles and other raw plastic material spilled from a shipping vessel off the shoreline near Hong Kong after a major storm. This waste from Sinopec, a Chinese company, was reported to have piled up in large amounts on beaches (Sundt and Schulze, 2015).

Plastic water bottles

In one survey, 93% of the bottled water from 11 different brands was found to have MPs contamination. Researchers found an average of 325 MPs particles per liter of bottled water. Among the tested brands, Nestlé Pure Life and Gerolsteiner bottles contained the most MPs of about 930 and 807 microplastic particles per liter (MPP/L), respectively. Products from San Pellegrino showed the least quantity of MPs densities. Compared to taps water, water from plastic bottles contained twice as much MPs. Some of the contamination probably comes from the process of bottling and packaging the water (Mason et al., 2018).

Face masks

The use of medical face masks has sharply increased since the emergence of the COVID-19 pandemic, to reach around 89 million masks each month. Single use face masks are made from different types of polymer, such as polypropylene, polyurethane, polyacrylonitrile, polystyrene, polycarbonate, polyethylene, or polyester. The sudden raise in production and consumption of face masks, and their incontrollable litter, was added to the list of environmental challenges, due to the addition of plastic particles waste in the environment. After decomposing, face masks could fragment into smaller size particles (under 5mm) which adding a new source of microplastics (Fadare and Okoffo, 2020).

A study conducted in 2020 by Oceans Asia, a Hong-Kong-based marine conservation organization, declared that our oceans will be flooded with an estimated 1.56 billion face masks in 2020. This will cause in an additional 4,680 to 6,240 metric tonnes of marine plastic pollution. These masks will take at least 450 years to break down, slowly turning into microplastics while negatively impacting marine wildlife and ecosystems. This report used a global production of masks manufactured in 2020 estimated at 52 billion, a conservative loss rate of 3%, and the average weight of 3 to 4 grams for a single-use PP surgical face mask to arrive at the estimate. Plastic pollution kills an assessed 100,000 marine mammals and turtles, more than a million seabirds, and even greater numbers of fish, invertebrates and other animals each year. It also negatively influences fisheries and the tourism industry, and costs the global economy an estimated \$13 billion USD per year (Bondaroff and Cooke, 2020)

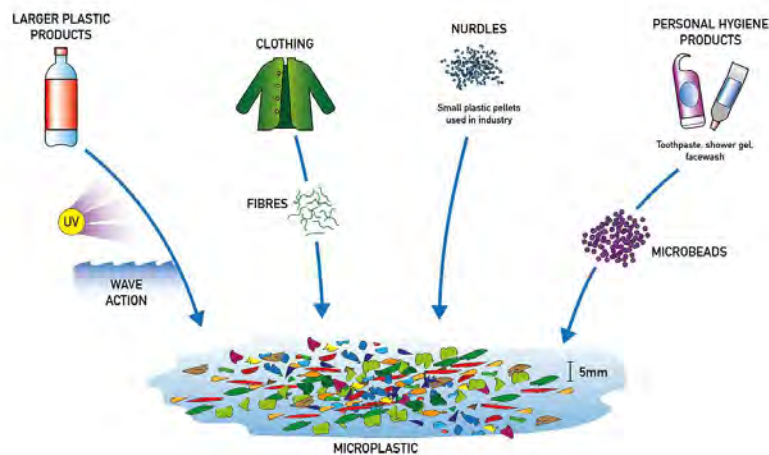


Figure 2.3: Various ways of Microplastics get into the environment (Source: <https://encounteredu.com/discover/images/sources-of-microplastics>)

2.2.6 Fate and Transport of Microplastics in Freshwater Systems

In the freshwater environment, once MPs are released, they will undergo fate and transportation processes. This section describes fate and transport of microplastics.

Environmental Transportation

Plastic particles that enter the environment will not remain stationary. Instead they will be transported between environmental compartments (for instance, from land to freshwater and from freshwater to marine environments), with different residence times in each. For instance, the travel from land to river systems will depend upon dominant weather conditions, distance to a specific river site, and land cover type. The movement of bulk plastics and MPs within the riverine system will be governed by its hydrology (for instance, flow conditions, daily discharge) and the morphology (for instance, vegetation pattern) at a specific river site that will have a large effect upon the propagation of litter because of stranding and other watercourse impediments such as groins and barrages. Microplastics may also be subject to different rates of degradation compared to macroplastics, as they will be transported and distributed to various environment compartments at faster rates than macroplastics. The formation of MP-associated biofilms from LDPE has been investigated in marine setting (Harrison et al., 2014). Transportation to sediments and the development of biofilms over the surface of MPs may also limit rates of degradation as this removes exposure to light.

Models for Fate and Transport of Microplastics in Freshwater Systems

Few models exist that simulate the fate and transport of plastic debris in freshwater systems. Plastic debris includes buoyant macroplastics items that float at the surface e.g. bottles, food wrappers and containers, plastic cutlery, and expanded polystyrene (PS), larger polyethylene (PE), or polypropylene (PP) (Lechner et al., 2014; Gasperi et al., 2014) and conveyed under the influence of wind and water flow (Fig. 2.4). Non-buoyant plastics or buoyant plastics that become more liable to vertical mixing due to their small size (i.e., microplastics and nanoplastics) will become submerged and may be subject to settling in a manner alike to that of natural colloids and suspended solids (Fig. 2.5). Therefore, such natural particles may function as a substitution for some classes of plastic debris, and models simulating the transport of such natural particles can form the basis for the development of transport models for plastic debris.

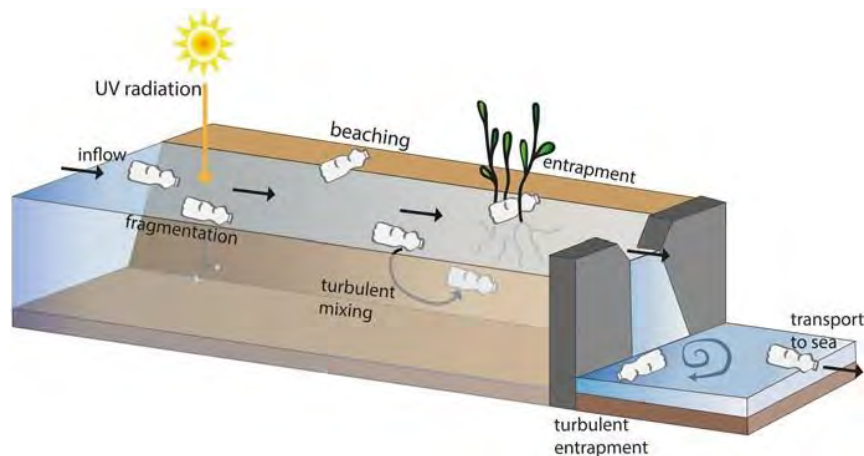


Figure 2.4: Schematic representation of the different processes playing a role in the transport of macroplastics in a river and lake. Turbulent water movement below a weir can “capture” plastic debris for a certain period of time. The scaling of the different components is not representative, and not all processes happen to each plastic piece or in a fixed order (Kooi et al., 2017)

Four categories of models will be discussed in this section: emission-based mass balance models, global models, multimedia models, and spatiotemporally explicit models. The models

differ in their aim, strategy, scale, level of detail, and state of validation (Table 2.3). Here the classification of the models is based on their key characteristics (Kooi et al., 2017).

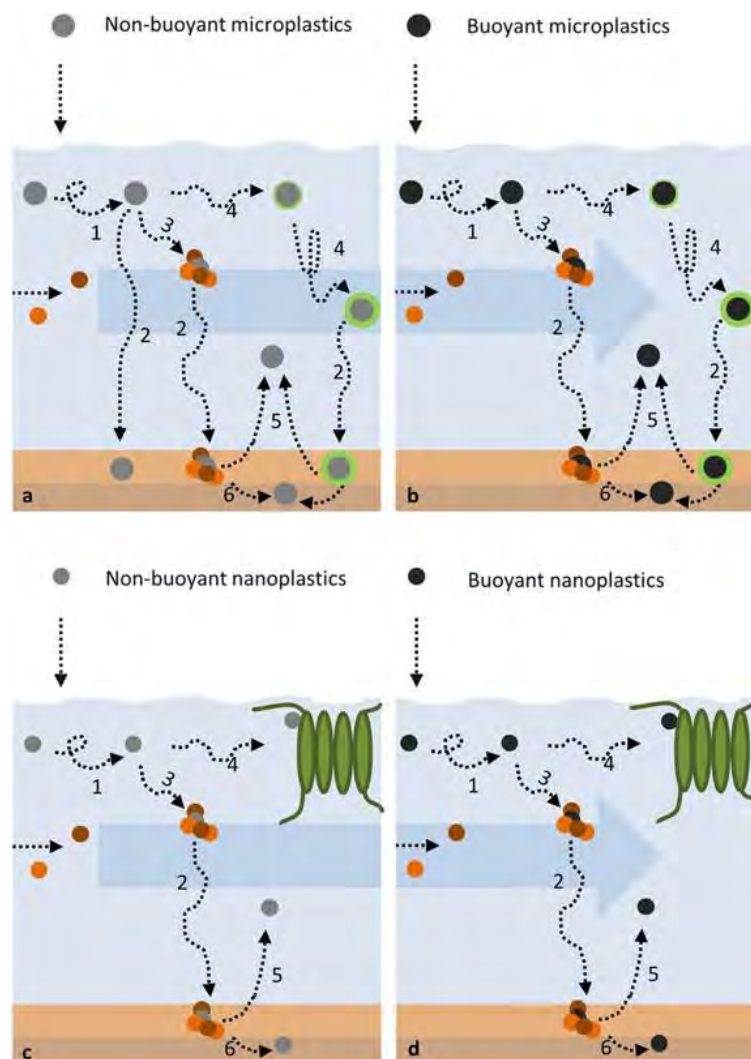


Figure 2.5: Schematic representation of the key processes playing a role in the transport of non-buoyant microplastics (a), buoyant microplastics (b), non-buoyant nanoplastics (c), and buoyant nanoplastics (d) in a river or lake. Processes include (1) turbulent transport, (2) settling, (3) aggregation, (4) biofouling, (5) resuspension, and (6) burial. Aggregates can be formed with, for example, sediment, algae, organic matter, or dissolved substances. The scaling of the different components is not representative, and not all processes happen to each particle or in a certain order. Other processes, such as removal by ingestion, relocation, and hydrodynamic alteration by ingestion and excretion (e.g., zooplankton, mussels), can also affect particle fate but are not depicted here (Kooi et al., 2017).

Table 2.3: Summary of the main features of the currently existing plastic debris models for freshwater systems (Kooi et al., 2017)

	Mass flow models	Global modeling	Multimedia models	Spatiotemporally explicit models	
Reference	Van Wezel et al., 2015	Siegfried et al., 2016	This study, based on Meesters et al., 2014	Nizzetto et al., 2016b	Besseling et al., 2014; Besseling et al., 2017
Plastic size range ^a	Microplastics	Microplastics	Nanoplastic (<100 µm), microplastics	Microplastics, 0.005–0.5, separated in five size classes	Nano- and microplastics. Ten sizes modeled; from 100 nm to 10 mm
Plastic density	All	All	All	Non-buoyant	All
Media included	Effluents	Water	Air, water, soil, sediment	Soil, effluents, water, sediment	Water, sediment
Processes included	Emissions (personal care products), plastic removal in WWTP	Emissions (personal care products, care tires), plastic removal in WWTP, during river transport and by water abstraction	Assumed emissions (1,000 t)	Emissions from sewage sludge, surface runoff, WWTP effluents, advection, settling, resuspension, store depletion	Assumed emissions upstream, advection, dispersion, biofouling, aggregation, degradation, settling, resuspension, burial
Spatial resolution	zero-D	1°latitude by 1°longitude (input) and basis totals (output)	zero-D	10,000 km ² divided in eight segments	40 km river stretch divided in 477 segments of on average 87.7 m
Temporal resolution	Steady state	Annual totals	Steady state	Daily, simulation for 2008–2014	0.01 day, modeled until steady state was reached
Validation type ^b	c, d	c, d	c, d	b, c, d; model was validated for sediment particles and hydrology	b, c, d; model was validated for CeO ₂ submicron particles and hydrology
Key assumptions	Generic, all water ends in WWTP, all used cosmetics end in WWTP, no secondary plastics, no other sources	Homogeneous distribution of parameters per catchment	All processes can be captured by first-order relations	Homogeneous distribution of MP in segment, lumped rainfall and temperature for catchment, pristine particles	Constant concentration upstream, (near-) spherical particles. Dominance of hetero- over Homo-aggregation

	Mass flow models	Global modeling	Multimedia models	Spatiotemporally explicit models	
Model is based on	Mass balance point model	Global NEWS – Nutrient Export from Watersheds	Simple Box and SimpleBox4Nano (SB4N)	Hydro-biogeochemical spatiotemporally multimedia model, INCA-contaminants (Nizzetto et al., 2016c) with surface runoff (Futter et al., 2014) and sediment transport (Lazar et al., 2010) modules	DUFLOW water quality modeling suite, NanoDUFLOW (de Klein et al., 2016)
Review	Simple model which is easily applicable and adjustable. Drawback is the large uncertainty in estimates and the lack of spatial or temporal resolution. Validation with data still uncertain	This model is applicable to >6,000 rivers world-wide. For each river basin, the model calculates plastic in wastewater, removal during treatment, and removal during river transport	Simple model which is easily applicable and adjustable. It includes soil, water, and atmosphere compartments. Drawback is the large uncertainty in estimates and the lack of spatial or temporal resolution	Spatiotemporally explicit, with a high quality on the hydrodynamic processes, including surface runoff. Present version assumes pristine particles, which can result in underestimation of settling because biofouling and aggregation are not included	Spatiotemporally explicit, with a high quality on the hydrodynamic processes, including aggregation and nanoplastic behavior. Promising validation for submicron particles has been performed. Present version assumes near sphericity of the particles, making it less suitable for microplastics fibers

Review is based on the current available versions of the model

^aSize range not indicated when not specified in this table

^bValidation types a, b, and c refer to (a) agreement with empirical data, (b) agreement with hydrology and other particles, (c) conform design criteria, and (d) in agreement with state-of-the art knowledge

Environmental Persistence and Degradation

Most of our current understanding regarding plastic degradation processes is derived from laboratory studies that often investigate a single mechanism such as photo, thermal, or biodegradation (Lambert et al., 2013b). There is limited data on the degradation of plastics under environmentally relevant conditions where several degradation mechanisms occur together. These studies have primarily focused on weight loss, changes in tensile strength, breakdown of molecular structure, and identification of specific microbial strains to utilize specific polymer types. The degradation processes are defined according to the degradation mechanism under research (e.g. thermal degradation) and the experimental result created. In contrast, particle formation rates are often not explored. This is important since polymers such as PE do not readily depolymerize and normally break down into smaller fragments. These fragments then further disintegrate into increasingly smaller fragments eventually forming nanoplastics (Lambert and Wagner, 2016a; Lambert and Wagner, 2016b; Gigault et al., 2016).

The variables that influence in MP degradation and fragmentation processes are environmental exposure conditions, properties, such as density and crystallinity (Table 2.4), and the type and quantity of chemical additives used. Characteristics of molecules that usually counteract degradation are the complexity of the polymer structure and the use of structural features that are difficult to biodegrade. At this point, crystallinity is an important polymer property as the crystalline region consists of more ordered and tightly structured polymer chains. Crystallinity influences physical properties such as density and permeability. This sequentially disturbs their hydration and swelling behavior, which affects accessibility of sorption sites for microorganisms. Stabilizers such as antioxidants and antimicrobial agents act to extend the life of plastics, while biological ingredients act to decompose the plastic in shorter time periods. In total, environmental degradation processes involve MP fragmentation into progressively smaller particles including nanoplastics, chemical conversion of the plastic fragments, degradation of the plastic portions into non-polymer organic molecules, and the alteration/degradation of these non-polymer molecules into other compounds (Lambert et al., 2013b).

Table 2.4: Polymer type, density, and crystallinity (Lambert and Wagner, 2017; Beyler and Hirschler, 2002; Ehrenstein, 2012)

Polymer type	Density (g /cm ³)	Crystallinity
Natural rubber	0.92	Low
Polyethylene–low density	0.91–0.93	45–60%
Polyethylene–high density	0.94–0.97	70–95%
Polypropylene	0.85–0.94	50–80%
Polystyrene	0.96–1.05	Low
Polyamide (PA6 and PA66)	1.12–1.14	35–45%
Polycarbonate	1.2	Low
Cellulose acetate	1.28	High
Polyvinyl chloride	1.38	High
Polylactic acid	1.21–1.43	37%
Polyethylene terephthalate	1.34–1.39	Described as high in (Beyler and Hirschler, 2002) and as 30–40% in (Ehrenstein, 2012)
Polyoxymethylene	1.41	70–80%

Interactions with Other Compounds

An important environmental process is the sorption of hydrophobic pollutants to MPs because this will affect the movement and bioavailability of these pollutants. It is well known that MPs in marine environments concentrate persistent organic pollutants (POPs) such as Dichlorodiphenyltrichloroethane (DDT), Polychlorinated biphenyls (PCBs), and dioxins (Teuten et al., 2009; Endo et al., 2005; Mato et al., 2001). In addition, Ashton et al. (2010) also found concentrations of metals in composite plastic pellet samples retrieved from the high tide line along a stretch of coastline in Southwest England.

Sorption processes normally occurred through physical and chemical adsorption as well as pore-filling processes. Physical adsorption is the reversible sorption process to surfaces of the polymer matrix and does not include the formation of covalent bonds. Chemical adsorption includes chemical reactions between the polymer surface and the sorbate. This type of reaction creates new chemical bonds at the surface of polymer and may depend on how aged the polymer surface is. These processes can be affected by changes in pH, temperature, and ionic strength of the specified environment (Delle, 2001).

Adsorption kinetics depends on polymer type, polymer characteristics, for instance density and crystallinity, the surrounding environment, and the pollutants present. For example, the sorption and diffusion of hydrophobic pollutants are most likely to take place in the amorphous

area of a plastic material, since the crystalline region comprises of more ordered and tightly structured polymer chains. Polymers with structures of short and repeating units, a high symmetry, and strong inter-chain hydrogen bonding have a lower sorption capacity. A good example is LDPE and HDPE. LDPE contains considerable concentrations of branches that restricts the polymer chains from being easily stacked side by side, which results in a low crystallinity and a density of 0.90–0.94 g/cm³ (Bajracharya et al., 2014). On the other hand, HDPE consists basically of linear unbranched molecules, which is chemically the closest in structure to pure polyethylene. So, the linearity HDPE has a high degree of crystallinity and higher density of 0.94–0.97 g cm³ (Bajracharya et al., 2014).

2.2.7 Effects of Plastics and Microplastics on Freshwater Ecosystems

Uptake and Biological Effects

A range of organisms may take MPs from the water column and sediment. This can be done directly through ingestion or dermal uptake, most prominently through respiratory surfaces (e.g. gills). Microplastics particles with much smaller size (e.g. microbeads) are commonly white or opaque in colour, which are commonly mistaken as food by many surface feedings fishes (e.g. plankton). Ingestion of plastics by aquatic organisms is one of the major deleterious environmental impacts in the aquatic environment. Many organisms (e.g. whales, turtles, seabirds, shellfish, and fish) swallow plastic particles, which can accumulate in their digestive system. Swallowing of plastic can cause physical damage or blockage of the intestinal tract, which can lead to infection, starvation and even mortality. The range to which organisms are exposed to physical stress due to MPs uptake depends on particle size, because particles larger than sediment or food particles may be harder to digest (Besseling et al., 2012). Furthermore, the shape of particles is also an important parameter because particles with a more needle-like shape may attach more readily to internal and external surfaces. The indirect effects of microplastics may include physical irritation, which may depend on microplastics size and shape. Smooth spherical particles may be easier to dislodge than the smaller more angular plastic particles, which can cause blockage of gills and digestive tract. In a recent study, the chronic effects of microplastic exposure to *D. magna* were evaluated (Ogonowski et al., 2016). Exposure to secondary microplastics (particle size 2.6 µm) caused elevated mortality, increased inter-brood period, and decreased reproduction but only at very high microplastics levels (105,000 particles L⁻¹). In contrast, no effects were observed in the corresponding primary microplastics (mean particle size 4.1 µm) (Ogonowski et al., 2016).

Effects of Leaching Chemicals

Although plastics are typically considered as biochemically inert, plastic additives, often termed “plasticizers”, may be incorporated into plastics during manufacture to change their properties or extend the life of the plastic by providing resistance to heat (e.g. polybrominateddiphenyl ethers), oxidative damage (e.g. nonylphenol) and microbial degradation (e.g. triclosan). These additives are an environmental concern since they both extend the degradation times of plastic and may, in addition, leach out, introducing potentially hazardous chemicals to biota. The mixture composition and concentration of leachable compounds depend on the physical, chemical, and biological conditions of receipt environments. A useful method for profiling environmental hazards posed by plastics is leaching of water-soluble constituents from plastic products using deionized water (Lithner et al., 2012; Lithner et al., 2009). In a direct toxicity testing approach to assess their acute toxicity to *D. magna*, a research used such leachates (Lithner et al., 2012; Lithner et al., 2009). For instance, with a liquid to solid (L/S) ratio of 10 and 24 h leaching time, leachates from polyvinyl chloride (PVC), polyurethane (PUR), and polycarbonate (PC) were the most toxic with EC50 values of 5–69 g plastic L⁻¹ (Lithner et al., 2009). Higher liquid to solid (L/S) ratios and longer leaching times resulted in leachates from plasticized PVC and epoxy resin products to be the most toxic at (EC50 of 2–235 g plastic L⁻¹) (Bejgarn et al., 2015).

Biological Effects of Sub-Micrometer Plastics

Plastic materials can contain compounds, for instance antimicrobial agents and nanomaterials, depending on their use, that may be toxic to organisms such as bacteria and fungi that play a vital role in ecosystem functioning. It is probable that a combination of microscopic particles, leached additives, and other degradation products may cause subtle effects towards aquatic and terrestrial organisms. In terms of toxicity assessments, there is a need to understand the molecular and cellular pathways and the kinetics of absorption, distribution, metabolism, and excretion mechanisms that may be unique to MPs in the nano-size range. A polylactic polyglycolic acid copolymer particles of 100 nm had a tenfold greater intracellular uptake in an in vitro cell culture when compared to 10 µm particles made of the same material (Desai et al., 1997). Engineered nanoparticles (ENPs) have also been shown to produce cytotoxic, genotoxic, inflammatory, and oxidative stress responses in mammalian and fish systems (Dhawan et al., 2011). A literature review highlighted that the gills, gut, liver, and brain as possible target organs in fish, as well as a range of toxic effects including oxidative stress,

cellular pathologies consistent with tumor formation in the liver, some organ specific ionoregulatory disturbances, and vascular injury (Handy et al., 2008).

2.2.8 Socio-Economic Impacts

Plastic along seashores creates an aesthetic issue, which has negative influences on tourism. Economic losses are associated with reduced tourism revenues, negative impacts on recreational activities, vessel damage, and impairment in marine environments. Stranded seashore plastic also negatively impact shipping, energy production, fishing, and aquaculture resources.

2.2.9 Accumulation of Microplastics in Fish, Seafood and other food products

As marine species are unable to distinguish between food and microplastics/microbeads and therefore indiscriminately feed on microbeads. Since these sea foods (e.g. fish) are regularly consumed by humans, microbeads start accumulating in the food chain, transfer from species to species, with harmful consequences ultimately to humans. For example, among the 25 species contributing mostly to global sea fishing (FAO, 2016), 11 were found to contain microplastics. Microplastics were also found in canned sardines and sprats, salt, beer, honey and sugar. Moreover, drinking water distributed in plastic bottles, glass bottles and beverage cartons obtained from grocery stores in Germany were also found to contain microplastics as does tap water from different countries. Microplastics with size bigger than 150 μm probably are not likely to be absorbed while microplastics smaller than 150 μm may transport from the gut cavity to the lymph and circulatory system, causing systemic exposure. However, the absorption of these microplastics is expected to be limited ($\leq 0.3\%$). Only microplastics with size $\leq 20 \mu\text{m}$ would be able to penetrate organs while the smallest fraction ($0.1 > 10 \mu\text{m}$) would be able to access all organs, cross cell membranes, the blood-brain barrier and the placenta (Figure 2.6). It is possible that the circulation of microplastics in secondary tissues, for instance liver, muscle, and brain, may occur. Furthermore, it is expected that micro- and nano-plastic interactions with the immune system may potentially lead to immunotoxicity and therefore trigger adverse effects (that is, immunosuppression, immune activation and abnormal inflammatory responses).

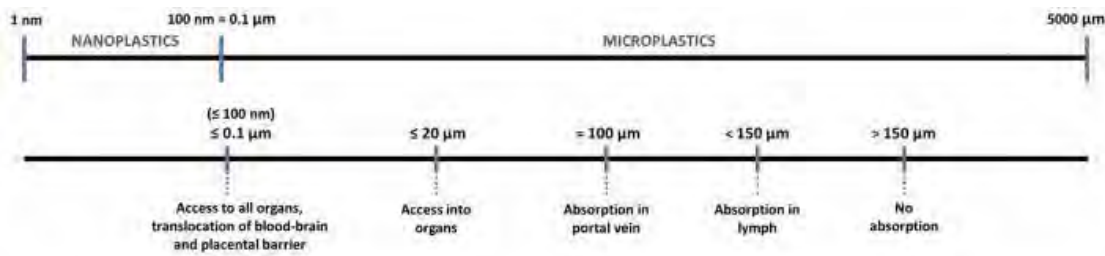


Figure 2.6: Fate of micro- and nano-plastics in mammalian bodies (Lusher et al., 2017; Barboza et al., 2018).

Recently, *in vitro* studies with cerebral and epithelial human cells evidenced for the first time the potential of micro- (10 μm) and nano-plastics (40–250 nm) to cause cytotoxic effects at cell level in terms of oxidative stress, reinforcing the scientific speculations on the possible consequences for human health. Therefore, the knowledge in this field is still very limited and there is little evidence of the impact on human health from eating microplastics. A major challenge regarding this point is that we do not know the amounts of very small microplastics, including those with a size able to enter cells, in the water, sediments, organisms and air; thus the assessment of biota and human exposure is not possible.

2.3 Identification and Quantification of Microplastics

Hidalgo-Ruz et al. (2012) presents a detail review of the processes and methods used for identification and quantification of microplastics. This section presents a summary of these processes and methods.

2.3.1 Sampling

Microplastics sampling in the aquatic environments (sea surface, water column, sediment) needs different methods. Sampling can be-

- (i) Selective Sampling,
- (ii) Bulk Sampling, or
- (iii) Volume-reduced Sampling.

Selective Sampling:

Selective sampling in the field consists of direct extraction from the environment of items that are identifiable by the naked eye, normally on the surface of sediments. Plastic pellets sampling is often selective, as their size range (diameter: 1 to 6 mm) makes them easily detectible in the

flotsam deposits of sandy beaches. Though, when microplastics have no characteristic shapes (viz., irregular, rough, angular) or are mixed with other debris, there is a great risk of overlooking them (Zurcher, 2009), and when selectively sampling them in the field, particular care needs to be taken.

Bulk Sampling:

Bulk samples refer to samples where the whole volume of the sample is taken without reducing it during the sampling process. Bulk samples are most suitable when microplastics cannot be easily identified visually because-

- (i) They are covered by sediment particles,
- (ii) Their abundance is small demanding sorting or filtering of large volumes of sediment/water, or
- (iii) They are too small to be identified with the bared eye.

Volume-reduced Sampling:

Volume-reduced samples in both water and sediment samples refer to samples where the volume of the bulk sample is usually decreased during sampling, keeping only that portion of the sample that is of interest for further processing. Samples can be sieved directly on the beach or onboard the vessel (Frias et al., 2010) for sedimentary environments, while for water samples, volume-reduced samples are usually obtained by filtering large volumes of water with nets. Bulk and volume-reduced samples need further processing in the laboratory.

2.3.2 Sample Processing

For bulk and volume-reduced samples, laboratory processing and subsequent sorting of microplastics is essential. There are four main steps that can be distinguished during laboratory processing of samples:

- (i) Density separation,
- (ii) Filtration,
- (iii) Sieving, and
- (iv) Visual sorting.

Density Separation:

Based on the type of polymer and the manufacturing process, the specific density of plastic particles can vary considerably. For plastic, density values range is from 0.8 to 1.4 g cm⁻³, specifically from 0.85 to 0.94 g cm⁻³ is for polypropylene, from 0.92 to 0.97 g cm⁻³ for polyethylene, and from <0.05 to 1.00 g cm⁻³ for polystyrene (Ye and Andrady, 1991). These values denote to virgin resins, without considering the effect on density of various additives that might be added during product manufacturing. For sand or other sediments, typical densities are 2.65 g cm⁻³. To separate the lighter plastic particles from the heavier sediment grains, this variation is exploited. This is done by mixing a sediment sample with a saturated solution and shaking it for a certain amount of time. After mixing, the sediment is expected to quickly settle to the bottom, while the low-density particles remain in suspension or float to the surface of the solution. Afterward, the supernatant with the plastic particles is extracted for further processing.

Normally the solutions applied for density separation process in different studies are concentrated saline NaCl solution (1.2 g cm⁻³), sodium poly-tungstate solution (1.4 g cm⁻³) (Corcoran et al., 2009), tap water (Zurcher, 2009) and seawater (Kusui and Noda, 2003). Polystyrene in foamed form, high- and low-density polyethylene, and polypropylene are plastics that float in fresh and seawater. In solid form polystyrene also floats in a hyper-saturated saline solution. Finally, the plastics that float in sodium poly-tungstate solution include flexible and rigid polyvinyl chloride (PVCs), polyethylene terephthalate (PETs), and nylon. (Andrady, 2011; Zurcher, 2009)

Shaking time varied widely between studies, according to the size of the sediment sample: it ranged from 30 s (Thompson et al., 2004) up to 2 h (Reddy et al., 2006). The time used for the suspended particles to settle down after shaking ranged from 2 min (Thompson et al., 2004; Browne et al., 2010) up to 6 h (Ng and Obbard, 2006). Recent studies clearly mentioned a repetition of density separation of the sample remains (Browne et al., 2011; Martins and Sobral, 2011).

Filtration

From the supernatant obtained from the density separation, the plastic particles are separated by passing the solution that contains the plastic particles over a filter, usually aided by a vacuum

(Thompson et al., 2004; Ng and Obbard, 2006). In the analysis where density separation is done with freshwater, tweezers are often used to pick up microplastics from the surface of the aqueous supernatant (Zurcher, 2009). Water samples can first be sieved over a sieve with 500 μm mesh size to sort out larger particles before the filtration step (Andrady, 2011).

Throughout the procedure, some portion of the microplastics might stick to the wall of the container that contains the solution, losing part of the sample. Therefore, washing of the receptacle walls onto the filter is suggested. Besides, samples can also become contaminated by various ways. For accurate results it is necessary to reduce sources of contamination and avoid both loss of parts from the sample or overestimation of microplastics because of contamination.

To confirm that there is no procedural sample contamination, control samples should always be used (Norén, 2007). Numerous contamination prevention strategies (e.g., sealing of filters in Petri dishes during drying) have been specified in different studies (Thompson et al., 2004; Ng and Obbard, 2006; Reddy et al., 2006).

Sieving

From samples microplastics can be separated using sieves of variable mesh sizes. Materials that are retained in the sieve are collected (and sorted), whereas those that pass through are normally discarded. Distinguishing size categories of microplastics are usually allowed by the use of sieves with different mesh sizes. The sieves used in different studies had mesh sizes ranging from 0.038 to 4.75 mm.

Visual sorting

Visual examination of the concentrated sample remains a compulsory step in all reviewed studies. To separate the plastics from other materials, such as organic debris (shell fragments, animal parts, dried algae, or seagrasses, etc.) and other items (metal paint coatings, tar, glass, etc.) careful visual sorting of residues is necessary. This is done by direct visual examination of the sample or with the help of a dissecting microscope (Rios et al., 2010; Doyle et al., 2011; Shaw and Day, 1994; Moore et al., 2002; Morét-Ferguson et al., 2010).

Formerly, to remove the foreign substances (like sand and soil) that adhere to the isolated plastic fragments surface can also be washed (McDermid and McMullen, 2004) e.g. by

ultrasonic cleaning in a liquid medium or deionized water (Cooper and Corcoran, 2010). Samples can be preserved without initial sorting in their original form, or from the original sample, they can be immediately sorted to store only the plastics. Plastics particles separated from the sample should be dried and kept in a dark and temperature-controlled environment (stable room temperature) to decrease degradation during storage.

Standardization of plastic particle selection is necessary to avoid misidentification and underestimation of microplastics, following certain criteria to guarantee proper identification. This is very important when the use of more accurate methods (e.g. Fourier transform infrared spectroscopy (FT-IR)) is not possible. To some extent microplastics pieces toward the larger end of the size range (>1 mm) can be visually distinguished according to the following criteria: no cellular or organic structures are evident, fibers should be equally thick throughout their entire length, particles must present clear and homogeneous colors, and if they are transparent or white, they must be examined under high magnification and a fluorescence microscope (Norén, 2007). To separate microplastics from bulk samples or from samples with large amounts of organic debris, new methods need to be developed to improve the efficiency of sampling programs. Molecular mapping made by focal plane array (FPA)-based imaging has recently been examined to detect microplastics by scanning the surface of filters obtained from density separation and filtration of samples (Harrison et al., 2012). To facilitate the visual sorting of microplastics from large sample volumes, enzymatic digestion of organic debris and other approaches could also be explored.

2.3.3 Characterization of Microplastics

A wide variety of microplastics with multiple shapes, sizes, and origins exists due to the diversity of sources. Distribution and impact of microplastics in the environment are determined by the characteristics of microplastics. For example, plastic particles which are denser spend more time in contact and collide more forcefully with abrasive sediment particles with respect to the lighter microplastics do (Browne et al., 2010). These differences are vital as they can affect degradation rates, surface characteristics, and shapes of microplastic particles.

Size Fractions:

There is no general consensus about a specific size nomenclature of microplastics, though it has been recommended that microplastics should be defined as particles less than 5 mm (Arthur

et al., 2009). For microplastics, no minimum size has been defined. The smallest reported size is in sediment samples with diameter of 1 μm and length of 20 μm (Frias et al., 2010). Most studies presented values above 500 μm and 300 μm for sediment samples and seawater samples respectively. This variation depended directly on two main factors: the tools used during sampling and the processing steps. In standard sieves particles $>500 \mu\text{m}$ are retained and can then be sorted using a dissecting microscope. Particles $<500 \mu\text{m}$ were generally only achieved by studies with density separation and filtration, and particles $<2 \mu\text{m}$ are unlikely to be sampled representatively (Browne et al., 2010).

Morphology and Physical Characterization of Microplastics:

The number of categories used in different studies to classify microplastics depends on the criteria of the respective authors, which can differ widely. As they could easily be mistaken for food by marine organisms and seabirds, the variation in sizes, shapes, and colors of microplastics is of particular concern (Thompson et al., 2004; Browne et al., 2008; Gregory, 2009).

Sources and Types of Microplastics:

For plastic pellets, sources were mainly associated to plastic-processing plants close to study sites (Kuriyama et al., 2002). Yet, on urban beaches distant from potential sources plastic pellets have also been found, indicating long-distance marine transport (Costa et al., 2009). During residence at sea some properties of plastic pellets may change. For instance, the specific density of pellets decreased during continued exposure to the marine environment, for high density polyethylene (HDPE) from 0.85 to 0.81 g cm^{-3} and for polystyrene (PS) from 1.41 to 1.24 g cm^{-3} (Morét-Ferguson et al., 2010). Due to weathering and biofouling buoyancy and density of plastics may change during their residence at sea (Morét-Ferguson et al., 2010; Andrady et al., 1998). As a result, the specific densities of many pelagic microplastics do not coincide with that of primary polymers. High specific density microplastics (negative buoyancy) will quickly sink in the open sea and are therefore absent from neuston samples.

Plastic consumer product fragments were of variable types and diverse origins. These particles have been described as “embrittled and weathered, irregularly shaped and sized degradational chunks of plastic” (Gregory, 1978), with sharp, broken edges (Shaw and Day, 1994). The source of these plastic fragments can be line fibers (polypropylene strands), fishing nets, thin

plastic films, industrial raw material (e.g., from ship breaking industry), pellets or polymer fragments of oxo-biodegradable plastic (Doyle et al., 2011; Lattin et al., 2004; Reddy et al., 2006; O'Brine and Thompson, 2010). Other sources of microplastics are facial cleansers (Fendall and Sewell, 2009) and small polyethylene microplastics or polyester fibers of low density which escape from treatment screens at wastewater plants and eventually arrive in the ocean (Browne et al., 2011).

Shape and Erosion of Microplastics:

Plastic fragments differ in shape from irregular to spherical and long-thin fibers. Plastic pellets are mostly spherical to ovoid with rounded ends, also can have tablet-like, oblong, cylindrical, and disk shapes (Abu-Hilal and Al-Najjar, 2009). Most fragments found in subtidal and estuarial sediments were fibers (Browne et al., 2011; Thompson et al., 2004; Browne et al., 2010). The shape of plastic fragments depends on the residence time in the environment and on the fragmentation process as well. Recent break-up of larger pieces or recent introduction of plastic particles into the sea is indicated by sharp edges, while smooth edges are often related with older fragments that have been continuously polished by other particles or sediment (Carpenter and Smith, 1972b; Doyle et al., 2011). Circularity varied inversely with particle size. Larger plastic particles had more elongate shapes and/or irregular surfaces, while progressively smaller particles were consistently more circular (Gilfillan et al., 2009). Likely, particles continue to fragment and degrade to ever smaller particles over time (Andrady, 2011; Doyle et al., 2011).

Degradation and erosion of the plastic particle surface are caused by photodegradation, biological breakdown, chemical weathering, or physical forces (wave action, wind, sandblasting) (Andrady, 2011). This can cause visible cracks on the surface of plastics, creating a wide variety of different shapes particle (Shaw and Day, 1994). For predominantly eroded angular plastic fragments less than 1 cm² numerous surface scratches on may be caused by continuous particle-particle collision (Cooper and Corcoran, 2010).

Although with age plastics undergo various physical and chemical changes, at present no method exists that allows for determining the residence time of the particles in the marine environment. However, estimating drift paths of floating microplastics would be invaluable and, thus, potential source regions.

Color of Microplastics:

Microplastics can have a diverse range of colors. The most common colors found in different studies were white or related (e.g., discolored yellow, clear-white-cream). In circumstances where microplastics are scattered among large quantities of other debris, color can facilitate separation. Eye-catching color particles have a high probability of being isolated for subsequent identification as microplastics, while particles with dull colors are easily overlooked, thus potentially introducing bias.

For a preliminary identification of the chemical composition of the most common pellets, colors have been used (Abu-Hilal and Al-Najjar, 2009). For polypropylene (PP) clear and transparent plastic pellets have been ascribed, while for polyethylene (PE) white plastic pellets have been imposed, although further analyses are required for conclusive identification. Low density PE has opaque colors (although ethyl vinyl acetate corresponds to clear and almost transparent pellets) (Shiber, 1987). It has been suggested that discolored polyethylene pellets may contain higher amounts of Polychlorinated biphenyls (PCBs) than non-discolored pellets, as the discoloration process (yellowing) is indicative of longer exposure time to seawater that enhances the chances of the polymers becoming oxidized (Endo et al., 2005).

Identifying the Chemical Composition of Microplastics:

A wide range of chemical compounds with different characteristics are used to produce plastics. In different reviewed studies, the most common polymers identified were PE, PP, and polystyrene, which is commonly used for packaging (Browne et al., 2010). To identify microplastics polymers several methods have been employed. The different types of spectroscopy which were commonly applied for identification of common polymers (Browne et al., 2011) (PP, PE, and polyester) in different studies were infrared (IR) spectrophotometer (Gregory, 1978), Fourier transform infrared spectroscopy (FT-IR) (Thompson et al., 2004; Frias et al., 2010; Reddy et al., 2006), and near-infrared spectrometer (Hirai et al., 2011). Raman spectroscopy, another chemical analysis (Murray and Cowie, 2011) which also gives information about the crystalline structure of the polymer (Bowmer and Kershaw, 2010). Also, in one study, a differential scanning calorimeter was used (Shiber, 1979).

To determine the polymers that microplastics are made of, characteristic smoke during combustion and solvent assays have also been used in some studies (Carpenter and Smith,

1972b; Gregory, 1978; Gregory, 1983; Austin and Stoops-Glas, 1977). In two studies density-based identification method has been applied (Morét-Ferguson et al., 2010; Morris, 1980), in which a sample is placed in distilled water and concentrated calcium or strontium chloride solutions or ethanol are titrated until the plastic piece is neutrally buoyant.

2.3.4 Quantification of Microplastics

For sediment samples “grams of microplastics per m²” and “microplastics items per m²” (or items per cm²) were the most frequently used units for mass and abundance determination, respectively. For sea surface samples, the most frequently used values for mass was “grams per m²” and for abundance was “items per m²”, while “items per volume” (items m⁻³) was also reported by a significant number of studies. For water column samples, most frequently used values for mass was “items per m³”, while one study quantified mass values in “milligrams per m³”, the plastic replacement rate on Hawaiian beaches was estimated by one study where the value of “pieces per day” was calculated (Cooper and Corcoran, 2010).

Chapter 3

METHODOLOGY

3.1 General

The overall objective of this research was to identify, quantify and characterize microplastics in selected water bodies within and around Dhaka City. As a part of this study, sampling was carried out from three inland water bodies (Dhanmondi Lake, Ramna Lake, Hatirjheel) and two peripheral rivers (Buriganga and Turag) of Dhaka. This Chapter presents the methodologies followed in carrying out this research, including site selection, sampling method and methods for processing of aquatic environmental samples of the five water bodies for identification of microplastics. This Chapter presents development of laboratory methodology for analysis of microplastics with step-by-step method followed for quantification and characterization of the microplastics identified in this study.

3.2 Samplings

To carry out the research, five surface water system within and around Dhaka city were chosen. These included 3 water bodies (lakes) within Dhaka city and two peripheral rivers. The inland water bodies included:

- (a) Dhanmondi Lake,
- (b) Ramna Lake, and
- (c) Hatirjheel

The peripheral water bodies included:

- (a) Buriganga River, and
- (b) Turag River.

Since the environmental conditions of these water bodies vary with season, sampling was carried out during both dry season and wet season. Five distinct point were selected for carrying out the water sampling (shown in Figure 3.1). The five-sampling location are: S1: Area surrounding the #8 Bridge of Dhanmondi Lake, S2: An accessible side near a sewage outlet of Ramna Lake, S3: Near Rampura bridge terminal, Hatirjheel water taxi service, S4: Surrounding area of Buriganga River, Near Babu Bazar Bridge and S5: Surrounding area of Turag River

near Bou Bazar, Uttara. Table 3.1 shows the GPS coordinates of the sampling locations; Table 3.1 also shows the approximate area of the water bodies over which the samplings were carried out. Table 3.2 shows the sample collection schedule. One sample was carried out from each of the sampling sites during the dry season (winter) of 2018 and one sample each was carried out during the summer of 2019.

Table 3.1: GPS locations of sampling points

Sampling Location	Latitude	Longitude	Approx. Area Sampled (m²)
S1(Dhanmondi Lake)	23°44'52" N	90°22'42"E	16
S2 (Ramna Lake)	23°44'11" N	90°24'00"E	10
S3 (Hatirjheel)	23°46'05"N	90°25'18"E	10
S4 (Buriganga River)	23°42'34"N to 23°42'29" N	90°24'07"E to 90°24'05"E	166
S5 (Turag River)	23°52'54" N	90°24'15"E to 90°24'23"E	230

Table 3.2: Water sampling schedules

Date of Sampling	Time of Sampling	Sampling Location	Season
14 th November, 2018	9:00 am -11:00 am	Dhanmondi Lake (surrounding the #8 Bridge)	Winter
28 th November, 2018	9:00 am - 11:00 am	Raman Lake (storm water outlet)	
8 th December, 2018	2:30 pm - 3:00 pm	Hatirjheel (near water taxi service, Rampura Bridge Terminal)	
23 rd December, 2018	9:00 am - 10:00 pm	Buriganga River (near Babu Bazar Boat Terminal)	
29 th December, 2018	11:00 am - 12:00 pm	Turag River (near Bou Bazar, Uttara)	
2 nd March, 2019	9:00 am - 11:00 am	Dhanmondi Lake (surrounding the #8 Bridge)	Summer
2 nd March, 2019	12:00 pm - 2:00 pm	Raman Lake (storm water outlet)	
16 th March, 2019	9:00 am – 11:00 am	Buriganga River (near Babu Bazar Boat Terminal)	
23 rd March, 2019	9:00 am – 11:00 am	Hatirjheel (near water taxi service, Rampura Bridge Terminal)	
06 th July, 2019	9:00 am – 11:00 am	Turag River (near Bou Bazar, Uttara)	

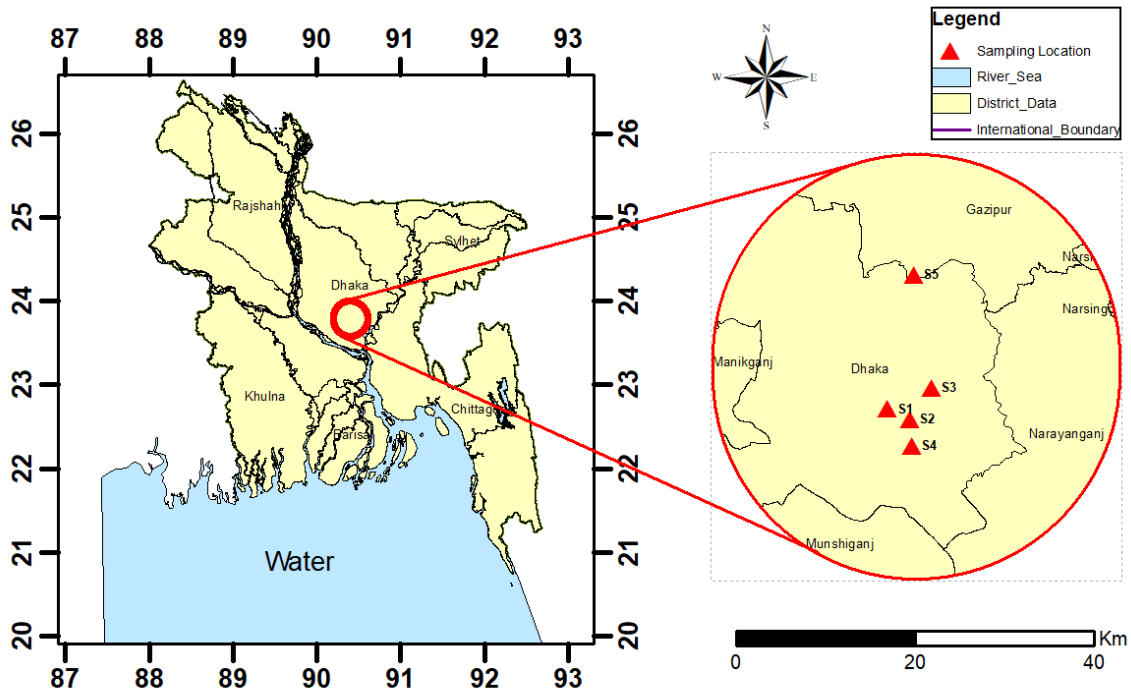


Figure 3.1: Study area from where the sample were collected

3.2.1 Collection of Samples

The standard practice for collection of samples from water bodies (for identification and analysis of microplastics) is to use any type of net with pore size less than 0.3-mm in size. In this study, a sampling net was prepared using a piece of cotton cloth with pore size less than 0.3-mm, as shown in Figure 3.2. During each sampling operation, samples were collected approximately from the top 15 cm of the water surface, and the approximate area of the water surface over which the sampling was carried out (using the prepared net) was estimated. Figure 3.3 shows photographs taken during sampling from the five water bodies.

Sampling was carried out at five distinct locations. Samples from Dhanmondi Lake (from the area surrounding the #8 Bridge) were collected on 14th November, 2018 and 2nd March, 2019 using a boat. There was no sewage or storm water outlet nearby, and main sources of suspended materials appeared to be litters dumped in water by the visitors of the park/Lake and fallen leaves from surrounding trees. The samples were collected using a boat.



Figure 3.2: Surface net made using cloth, used for collection of samples in this study

In Raman Lake, there was no boat, so we collected samples from an accessible side near a storm water outlet on 28th November, 2018 and 2nd March, 2019. Main sources of microplastics/suspended materials in this water body could be from the flows coming through the storm water outlet and the activities of people visiting Ramna Park.

Samples from Hatirjheel were collected on 8th December, 2018 and 23rd March, 2019 from a stagnant location near Hatirjheel Water Taxi Service, Rampura Bridge Terminal. A lot of water hyacinth had been observed near the location. The water was turbid and there was turbulence in the water due to the continuous movement of passenger boats. Significant suspended materials (including plastics and possibly microplastics) accumulated at the sides of the water body at the sampling location.

The samples from Buriganga River were collected on 23rd December, 2018 and 16th March, 2019 from near Babu Bazar Boat Terminal using a boat. The water appeared to be highly polluted and blackish in color. A lot of water hyacinth had been observed. There was also turbulence in water as there was relentless movement of boats and launches which may have certain impact on the formation of microplastics.

The samples from Turag River were collected on 29th December, 2018 and 6th July, 2019 from near Bou Bazar, Uttara using a boat. The water of the river was blackish in color and appeared

to be polluted. There was presence of glitters, which is most likely due to a secondary microplastics source. There were a number of storm water/sewage outlets nearby.

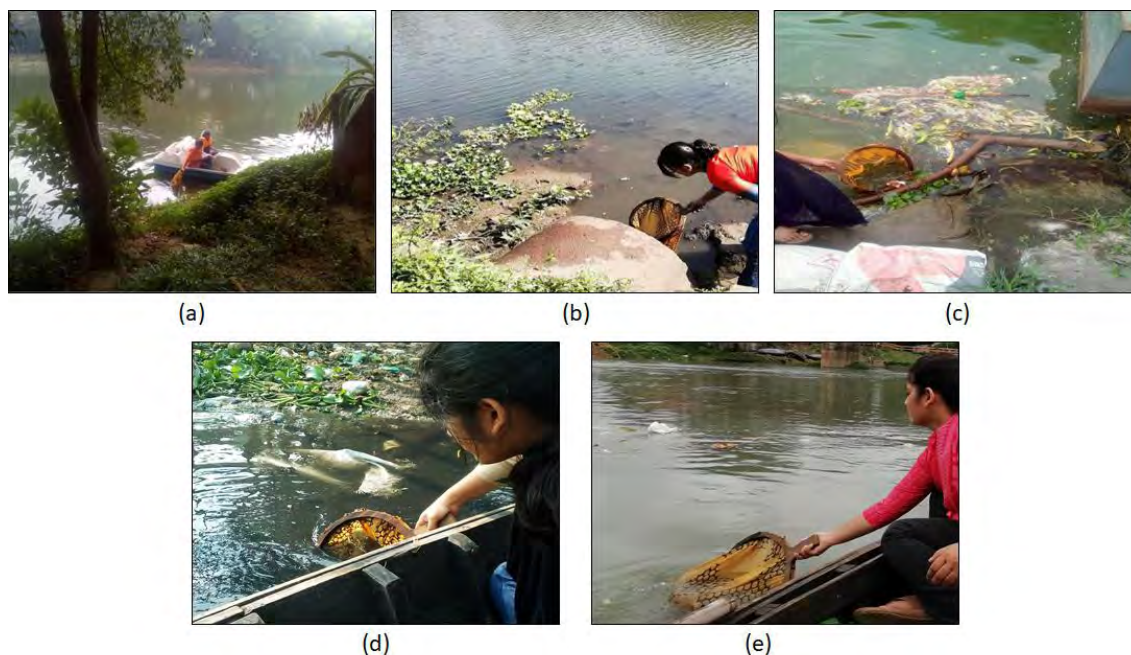


Figure 3.3: Collection of samples from (a) Dhanmondi Lake, (b) Ramna Lake, (c) Hatirjheel, (d) Buriganga River, (e) Turag River.

3.3 Processing of Samples for Identification of Microplastics

Collected samples were processed for analysis of microplastics, using a number of physical and chemical processes. This Section describes the methodology used for processing of collected samples for identification of microplastics.

3.3.1 Methods for Analysis of Microplastics

The term “microplastics” was first used in the year 2004 and is associated with a classification based on size. There is no general consensus about a specific size nomenclature, although it has been suggested that microplastics should be defined as particles < 5 mm (Hidalgo-Ruz et al., 2012). The minimum size of the collected microplastics directly depends on the sampling and processing methods. For seawater samples, reported mesh sizes varied from $53 \mu\text{m}$ to 3 mm (Hidalgo-Ruz et al., 2012). The laboratory method followed in this study (Masura et al., 2015) used a size range of 0.3 mm to 4.75 mm in defining microplastics.

The commonly employed methods for analysis of microplastics, including those employed for identification and characterization of microplastics (Masura et al., 2015), are shown in Figure 3.4 in the form of a flow chart. The processes involve wet sieving, determination of mass of total solids (i.e., collected solids with size fraction between 4.75-mm to 0.3-mm), wet peroxide oxidation (WPO), density separation, examination through a magnifying glass (for identification of microplastics), gravimetric analysis, concentration determination, size fractionation and morphology analysis.

Wet sieving was carried out to identify fraction that are > 0.3 mm and < 4.75 mm (this is the size fraction referred to as “microplastics”). Wet peroxide oxidation was carried out with the aid of aqueous 0.05 M Fe (II) solution and 30% hydrogen peroxide to digest labile organic matter while the plastic debris remain unchanged. The density of the WPO mixture were increased by adding ~ 5 M NaCl aqueous solution and then density separation was done to isolate the plastic debris through flotation. The floating plastic debris were collected in the density separator using a custom 0.3 mm filter. After air drying, a magnifying glass was used to remove and collect plastic materials. Through gravimetric analysis, the quantity of microplastics were determined and was expressed as percentage mass of total solids (i.e., solids with size fraction between 4.75-mm to 0.3-mm, isolated and dried after wet seiving), and other units (e.g., mass per unit area of water surface; item/no. per unit area of water surface).

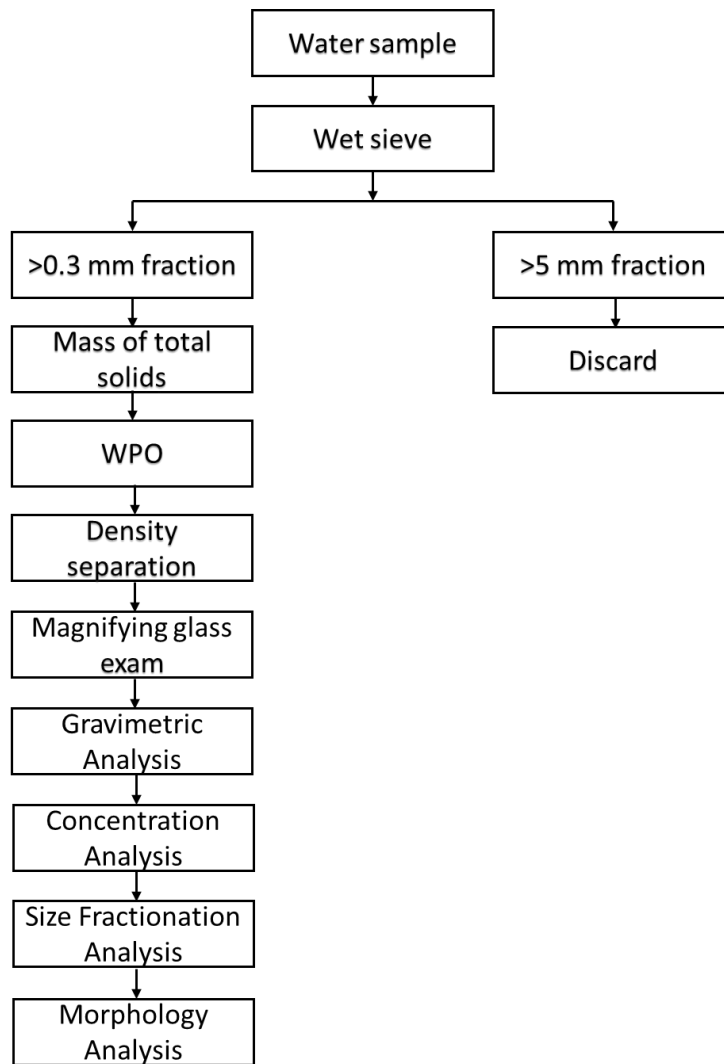


Figure 3.4: Flow chart showing the processes used for the analysis of microplastics in this study

3.3.2 Apparatus and Materials used

The apparatus and materials used for analysis microplastics in this study are as follows:

1. Stainless steel sieves, each measuring 8 in (diameter) and 2 in (depth) *4.75 mm mesh (# 4) *2.36 mm mesh (# 8) *1.18 mm mesh (# 16) *0.6 mm mesh (# 30) *0.3 mm mesh (# 50)
2. Squirt bottle containing distilled water
3. 500-mL glass beaker
4. Analytical balance (precise to 0.1 mg)
5. Metal spatula
6. Drying oven (90°C)

7. Iron (Fe (II)) solution (0.05 M): Prepared by adding 7.5 g of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ (= 278.02 g/mol) to 500 mL of water and 3 mL of concentrated sulfuric acid
8. 30% Hydrogen peroxide
9. Stir bar
10. Laboratory hot plate
11. Watch glass
12. Sodium chloride (commercial table salt is sufficient)
13. Standard Metal Forceps
14. Aluminum foil
15. Filter paper
16. 4-mL glass vials
17. Magnifying glass

3.3.3 Test Procedure

This Section briefly describes the step-by-step approach followed for determination of microplastics.

Wet sieving

Before wet sieving, the sample was processed to remove larger objects (e.g., large pieces of vegetation, large pieces of floating materials, etc.). Each sample was then poured through a stacked arrangement of 4.75-mm (No. 4) and 0.3-mm (No. 50) stainless steel mesh sieves (Figure 3.4). It should be noted that in the absence of a 5.0 mm sieve, the 4.75 mm (No. 4) standard sieve was used for sieving the samples.

The portion of sample passing through No. 4 sieve and retained on No. 50 sieve (see Figure 3.5) was then rinsed with water from a squirt bottle filled with distilled water to transfer all residual solids to the No. 50 sieve. This process also removes salts from the surfaces of the sample. The process was repeated to ensure that all the materials has been well washed, drained, and sorted. The material retained on 4.75-mm sieve were discarded.



Figure 3.5: A sample retained on No. 50 sieve (after sieving and rinsing)

Determination of the Mass of Total Solids

A clean and dry 500-mL beaker was weighed (after washing with distilled water, drying in an oven, and then keeping in a desiccator) to the nearest 0.1 mg and then the solids collected in the 0.3-mm sieve were transferred into the tared beaker using a spatula and minimal rinsing with a squirt bottle containing distilled water. It was ensured that all solids are transferred into the beaker and then the beaker was placed in a drying oven at 90 °C for 24 hours for drying (Figure 3.6).



Figure 3.6: Oven dry samples to determine dry weight

The mass of the beaker with dried solids was determined using an analytical balance to the nearest 0.1 mg. Subtraction of the mass of the beaker was from this weight provided the mass

of total solids (i.e., solids with size fraction between 4.75-mm to 0.3-mm) collected on the sieve (sieved No. 50). This is the mass of all microplastics (if present in water) and suspended solids retained on the sieve.

Wet Peroxide Oxidation (WPO)

Hydrogen peroxide mixture is highly reactive. So, laboratory safety practices and policies were strictly followed for handling this mixture before completing this analysis. As noted earlier, wet peroxide oxidation is carried out to dissolve all particulate natural organic matter present in the sample.

20 mL of aqueous 0.05 M Fe (II) solution was added to the beaker containing the 0.3 mm size fraction of collected solids and then 20 mL of 30% hydrogen peroxide was added into it.

The mixture was then let to stand on lab bench at room temperature for five minutes prior to proceeding to the next step. A stir bar was then added to the beaker and the beaker cover with Aluminium foil. The mixture is then heated to 75°C on a hotplate (Figure 3.7).

As soon as gas bubbles are observed at the surface, the beaker was removed from the hotplate. As the reaction appears has the potential to cause overflow of liquid from the beaker, distilled water was added to slow the reaction. Heating was continued to 75° C for an additional 30 minutes. As natural organic materials were visible, we added another 20 mL of 30% hydrogen peroxide. The process was repeated until no natural organic materials were visible.

Then ~6 g of salt (NaCl) per 20 mL of sample was added to increase the density of the aqueous solution (~5 M NaCl) and heating the mixture to 75° C was continued until the salt dissolved.



Figure 3.7: Wet Peroxide Oxidation using hotplate

Density Separation

The WPO solution were then transferred for density separation in a beaker. The WPO beaker was rinsed with distilled water to transfer all remaining solids to the beaker and then covered loosely with aluminium foil and the solids were allowed to settle overnight. Visual inspection of settled solids was done for identification of any microplastics (Figure 3.8). If any are present, then the microplastics were removed using forceps and the residuals were discarded (Masura et al., 2015).



Figure 3.8: Density separation of sample to separate microplastics

All the floating solids were collected in a clean 0.3-mm custom sieve. The beaker was rinsed several times with distilled water to transfer all solids to the 0.3-mm sieve. Then the sieve was allowed to air dry while loosely covered with aluminium foil for 24 hours (Figure 3.9).



Figure 3.9: Sample ready for microscope examination

Identification of Microplastics

A clean and dry vial was taken, and the weight was measured including the label and cap. Under a magnifying glass (Figure 3.10), a forceps was used to collect all identifiable microplastics from the 0.3-mm sieve and these were transferred to the tared vial (Figure 3.11).



Figure 3.10: Microplastics fragments separation using magnifying glass



Figure 3.11: Final Microplastics sample

Gravimetric Analysis

The mass of the vial and microplastics was weighed to the nearest 0.1 mg. Subtraction of the mass of the vial was done to get the mass of microplastics collected on the sieve. The quantity of microplastics was expressed as percentage mass of total solids (i.e., total solids in the size fraction between 4.75-mm to 0.3-mm), and other units (e.g., mass per unit area of water surface; item/no. per unit area of water surface).

3.4 Characterization of Microplastics

Since microplastics come from diverse sources, wide varieties of microplastics are found in nature that differ in shapes, sizes and chemical composition. These characteristics of microplastics determine their distribution and impact on the environment. The most important characteristics of microplastics (Hidalgo-Ruz et al., 2012) include: (a) Size fraction; (b) Morphology and physical characteristics; and (c) Chemical composition. This Section describes the methodologies followed for characterization of microplastics isolated from the samples collected from the 5 water bodies in and around Dhaka city.

Size Fractionation of Microplastics

For fractionation of microplastics a set of sieves with opening sizes of 2.36-mm, 1.18-mm, 0.6-mm and 0.3-mm were used. The microplastics isolated from all the samples were sieved individually to determine the size fraction of the microplastics. After sieving, the amount of microplastics retained on each sieve was collected in pre-weighed vials and weighed to the

nearest 0.1 mg., and the quantity of microplastics was determined by subtraction of the mass of the tared vial from this weight.

Morphology Analysis

The size, shape, and color of microplastics in an aquatic environment are important because they could be easily mistaken for food by aquatic organisms and birds. The size, shape, colour and texture of each individual microplastics were determined visually using a magnifying glass and the data were compiled.

Chemical Composition

Plastics are synthetic polymers made from a wide range of chemical compounds. The most common polymers identified in microplastics include PE (polyethylene), PP (polypropylene), and polystyrene, which are commonly used for packaging (Hidalgo-Ruz et al., 2012). As discussed in Chapter 2, among the several methods used for identification of chemical composition of microplastics, identification based on infrared (IR) spectroscopy has been most widely used. This method compares the IR spectrum of each microplastics particle (one by one) with spectra of known polymers. Other method employed for identification of chemical composition include Fourier transform infrared spectroscopy (FT-IR), near-infrared spectrometer, and Raman spectroscopy, etc.

In this study, efforts were made to determine chemical composition of the isolated microplastics using IR or any other techniques available in local laboratories. Unfortunately, no suitable laboratory could be identified (within and outside BUET) with equipment and expertise for the determination of chemical composition of microplastics. Therefore, it was not possible to determine chemical composition of microplastics in this study.

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

The overall objective of this research was to identify, quantify and characterize microplastics in samples collected from three lakes (Dhanmondi Lake, Ramna Lake, and Hatirjheel) and two peripheral rivers (Buriganga River and Turag River) in two different seasons. The detail methodology followed to carry out the research is presented in Chapter 3, including methodology followed for collection of samples, and the experimental set up for the identification and characterization of microplastics. This Chapter presents detail results of the laboratory experiments carried out for quantifying and characterizing the microplastics identified in the selected water bodies.

4.2 Quantification of Microplastics in the Selected Water Bodies

As described in Chapter 3, sampling was performed during the Winter Season (November-December) and Summer season (March-July) during the year 2018-2019 from five locations within and around Dhaka city. Figure 4.1 shows the locations of the sampling points (S1, S2, S3, S4 and S5). As noted earlier, S1 is located in Dhanmondi Lake, near Bridge Number 8. S2 is located in Ramna lake, near a sewage outlet. S3 is located in Hatirjheel, near Rampura Bridge Water Taxi Service Terminal. S4 is located in Buriganga River, near Babu Bazar Bridge, and S5 is located in Turag River near Bou Bazar.

The amount of microplastics obtained from a given amount of sample gives us an idea about the type and content of microplastics present in the water body. The quantity of microplastics was determined following the method described in Chapter 3; the quantity of microplastics has been expressed as a percentage of the total solids (i.e., solids with size fraction between 4.75-mm to 0.3-mm), mass per unit sampling area (of the water body), and number of items per unit area of water body sampled. This Section presents the quantification of microplastics identified in the 5 water bodies considered in this study. It also presents a comparison of the quantity of microplastics in different water bodies within and around Dhaka city in two different seasons.

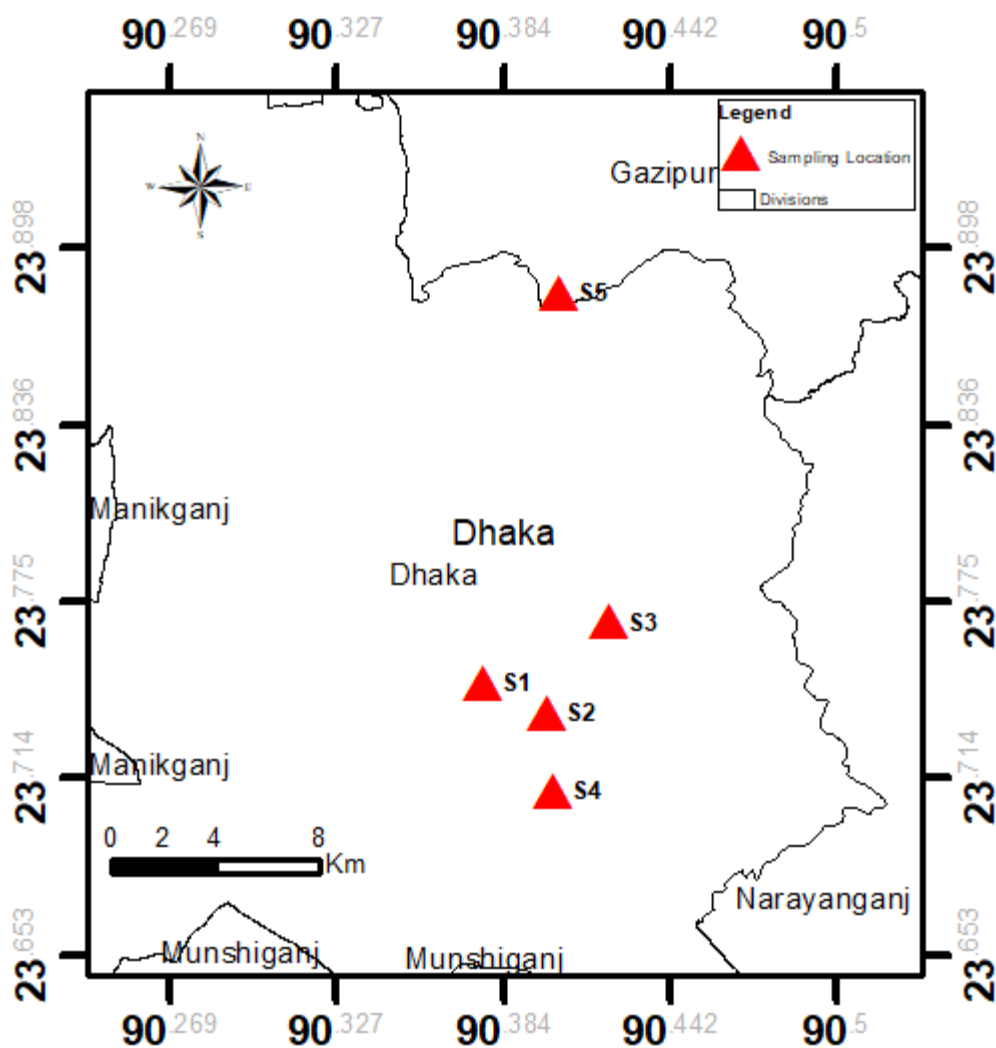


Figure 4.1: Locations of the sampling points (S1: Area surrounding the #8 Bridge of Dhanmondi Lake, S2: An accessible side near a sewage outlet of Ramna Lake, S3: Near Rampura bridge terminal, Hatirjheel water taxi service, S4: Surrounding area of Buriganga River, Near Babu Bazar Bridge and S5: Surrounding area of Turag River near Bou Bazar, Uttara.)

4.2.1 Microplastics in Dhanmondi Lake

Figure 4.2 shows the microplastics extracted from the samples collected from the sampling point (S1) in Dhanmondi Lake. It shows that the quantity of microplastics is significantly higher in samples collected in Summer (March, 2019) compared to that in Winter (November, 2018). Table 4.1 shows the quantity of microplastics present in the sample, and the quantity of

Microplastics as a percentage of total solids (collected samples with size fraction between 4.75-mm to 0.3-mm).

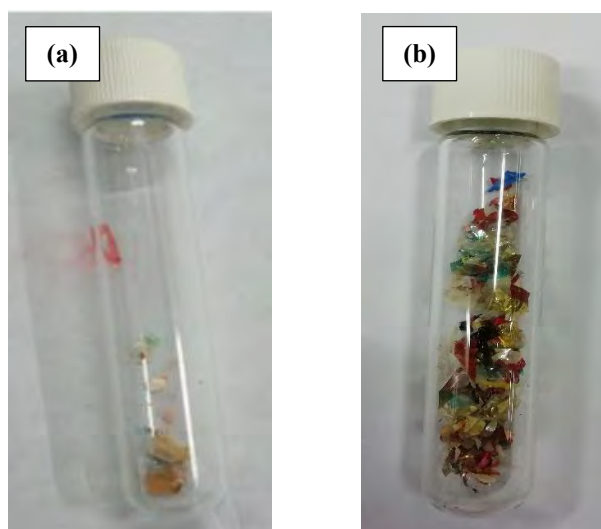


Figure 4.2: Microplastics found at the sampling location S1 in Dhanmondi Lake:
(a) in Winter, (b) in Summer

Table 4.1: Microplastics as percentage (%) of total solids in the samples from sampling location S1 in Dhanmondi Lake

Sampling Time	Empty Vial Weight (gm)	Vial + Microplastics (gm)	Weight of Microplastics (gm)	Total solids (gm)	Microplastics as % of Total Solids
Winter (November)	14.55	14.604	0.054	12.36	0.44
Summer (March)	14.4519	15.0507	0.5988	14.95	4.01

* “Total Solids” refer to the solids with size fraction between 4.75-mm to 0.3-mm (isolated after wet sieving) after oven drying at 90 °C for 24 hours.

The percentage of microplastics in Dhanmondi Lake has been found to be only about 0.44% of total solids for the sample collected in Winter, which is not a very significant amount. Since Dhanmondi Lake is located in a residential area, the probable sources of microplastics include degradation and abrasion of larger plastic products. Dumping of plastic products into the lake which includes ice cream packets, chips packets, and polythene could be a major reason for the formation of microplastics. The microplastics in this Lake were primarily low-density plastics since most of them were obtained from the floating material during the laboratory work. Low density plastic is a thermoplastic made from the monomer ethylene. Low density plastic is very flexible, translucent with high impact strength and has a density value of about

0.91–0.93 g/cm³ (Lambert and Wagner, 2017). It should be noted that after the renovation work in the recent past, Dhanmondi Lake does not receive any domestic sewage directly through sewer. Therefore, the source of microplastics is most likely direct disposal of plastic materials (e.g., by people visiting the Lake area) and from storm runoff.

The percentage of microplastics in Dhanmondi Lake has been found to be about 4.01% of total solids for the sample collected in Summer, which is significantly higher than that found in Winter. It should be noted that the day we collected the sample was a rainy day. Entry of macro and microplastics through storm runoff could be responsible for higher microplastics in Summer. As most of the microplastics were found from the floating materials, this indicates that the microplastics were mostly low-density plastics.

Microplastics concentration is often expressed in terms of mass per unit area of water body sampled or number of items per unit area of water body sampled. Table 4.2 shows the concentration of microplastics at the sampling location (S1) in Dhanmondi Lake in term of these units. It shows that the quantity of microplastics identified in Summer is significantly higher, both in terms of mass (over 11 times that in Winter) and number (over 7 times that in Winter). Figure 4.3 shows comparison of concentration of microplastics at the sampling location (S1) in Dhanmondi Lake in different units. This suggests that the quantity of microplastics at a particular location could vary significantly with time.

Table 4.2: Concentration of microplastics in Dhanmondi Lake (sampling location S1) in terms of mass and number of items per unit area sampled

Sampling Time	Weight of Microplastics (gm)	No. of Microplastics (Item)	Total Area Sampled (m ²)	Concentration of Microplastics (g/m ²)	Concentration of Microplastics (Items/m ²)
Winter (November)	0.054	71	16	0.003	4.4
Summer (March)	0.5988	538	16	0.037	33.6

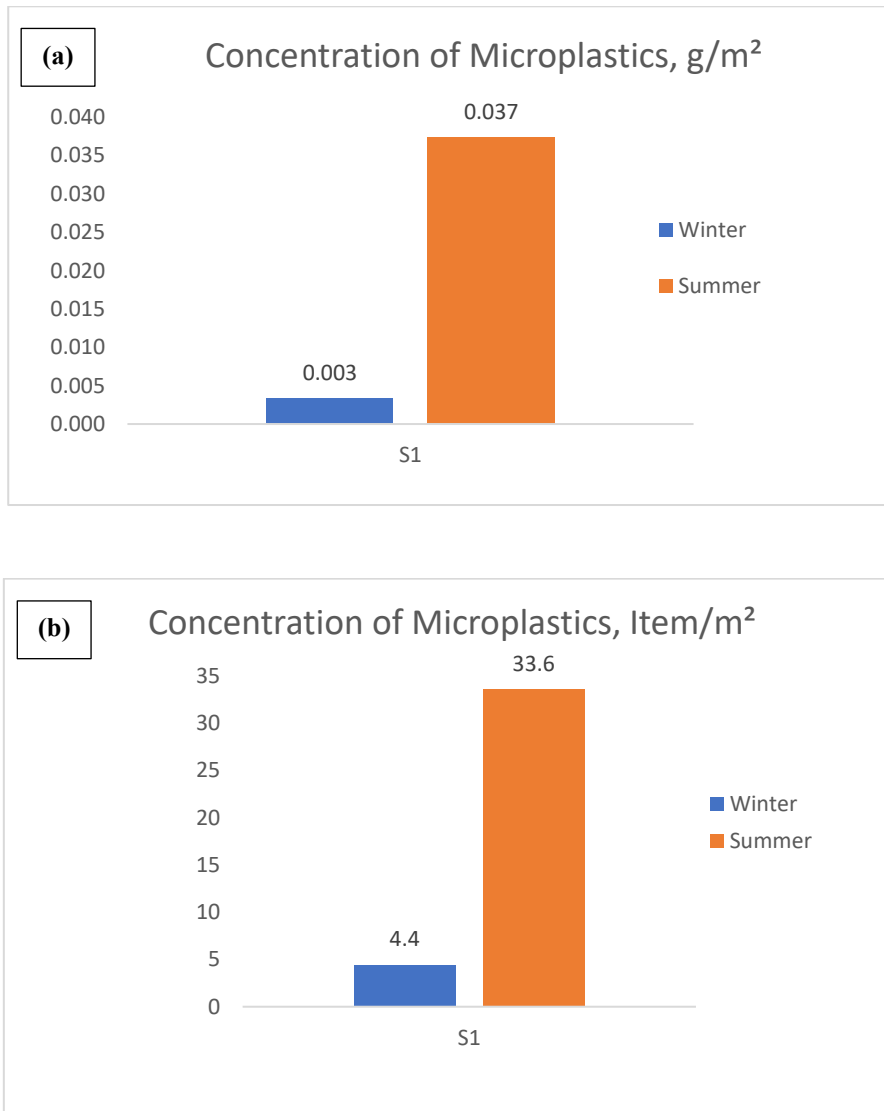


Figure 4.3: Comparison of the concentration of microplastics in Dhanmondi Lake (sampling location S1) in Winter and Summer: (a) in terms of mass per unit area sampled; and (b) in terms of item per unit area sampled.

4.2.2 Microplastics in Ramna Lake

Figure 4.4 shows the Microplastics extracted from the samples collected from Ramna Lake (sampling location S2). Table 4.3 shows the quantity of microplastics present in the sample, and the quantity of microplastics as a percentage of total solids (i.e., solids with size fraction between 4.75-mm to 0.3-mm). The quantity of microplastics found in Summer (March, 2019) is slightly higher than that found in Winter (November, 2018) from the same sampling location.

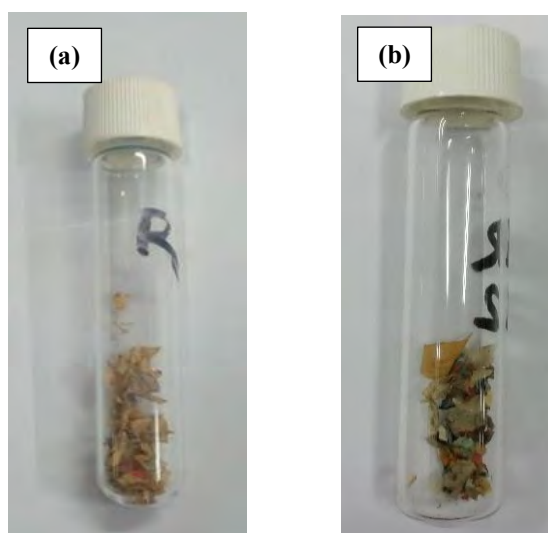


Figure 4.4: Microplastics found at the sampling location S2 in Ramna Lake:
(a) in Winter, (b) in Summer

Table 4.3: Microplastics as percentage (%) of total solids in the samples from sampling location S2 in Ramna Lake

Sampling Time	Empty Vial Weight (gm)	Vial + Microplastics (gm)	Weight of Microplastics (gm)	Total solids (gm)	Microplastics as % of Total Solids*
Winter (November)	14.37	14.5319	0.1619	15.58	1.04
Summer (March)	14.4958	14.6952	0.1994	17.85	1.12

* “Total Solids” refer to the solids with size fraction between 4.75-mm to 0.3-mm (isolated after wet sieving) after oven drying at 90 °C for 24 hours.

The percentage of microplastics in the Ramna Lake has been found to be about 1.04% of total solids for the sample collected in Winter. The microplastics found here (in Winter) were not colourful. The sample was collected from a location close to a storm water outlet. Like in Dhanmondi Lake, the fragmentation of larger plastic products such as chips packets, polythene bags, toys, tapes and ice-cream packets might have resulted in the formation of microplastics. The microplastics were mostly high-density plastic since most of the microplastics were obtained from the sediment during the laboratory analysis. High density plastics are normally thermoplastic polymer produced from the monomer ethylene. HDPE has large strength to density ratio. The density of HDPE ranges from 0.94 to 0.97 g/cm³ (Lambert and Wagner, 2017). HDPE has stronger intermolecular forces and tensile strength than the LDPE.

The percentage of Microplastics in the Ramna Lake has been found to be about 1.12% of total solids for the sample collected in Summer, which is slightly higher than that in Winter. It should be noted that the day we collected the sample, was a rainy day. The microplastics found here were slightly colourful. The microplastics were both low- and high-density plastics, since the microplastics were collected from both the floating part and the sediment during the laboratory analysis.

Table 4.4 shows the concentration of microplastics at the sampling location (S2) in Ramna Lake in term of mass per unit area and number of items per unit area. It shows that mass of microplastics collected in Summer is higher than that in Winter, but the number of items in Winter is higher than that in Summer. This suggests that microplastics isolated from the sample collected in Summer are of higher density than those isolated from the samples collected in Winter. Figure 4.5 shows comparison of concentration of microplastics at the sampling location (S2) in Ramna Lake in different units. This suggests that the characteristics of microplastics at a particular location could vary significantly with time.

Table 4.4: Concentration of microplastics in Ramna Lake (sampling location S2) in terms of mass and number of items per unit area sampled

Sampling Time	Weight of Microplastics (gm)	No. of Microplastics (Item)	Total Area Sampled (m ²)	Concentration of Microplastics (g/m ²)	Concentration of Microplastics (Items/m ²)
Winter (November)	0.1619	336	10	0.016	33.6
Summer (March)	0.1994	193	10	0.020	19.3

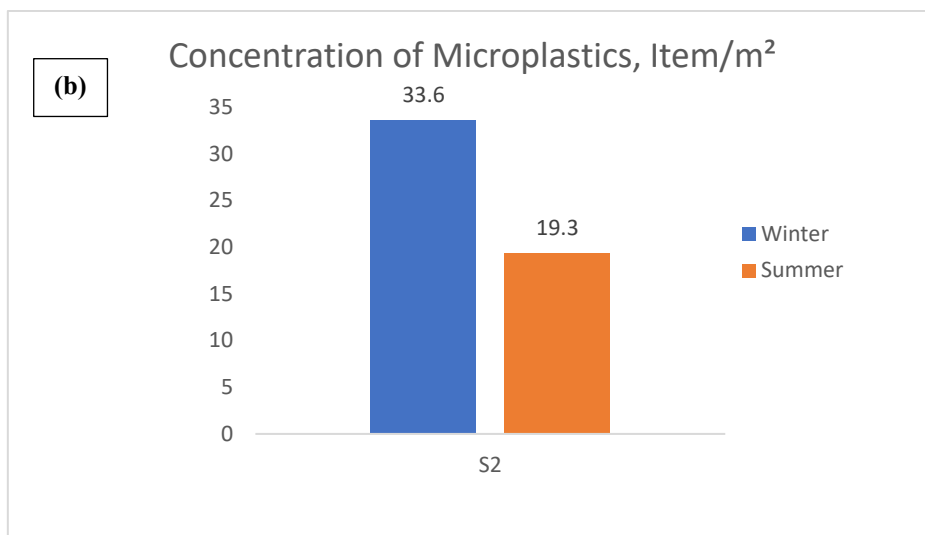
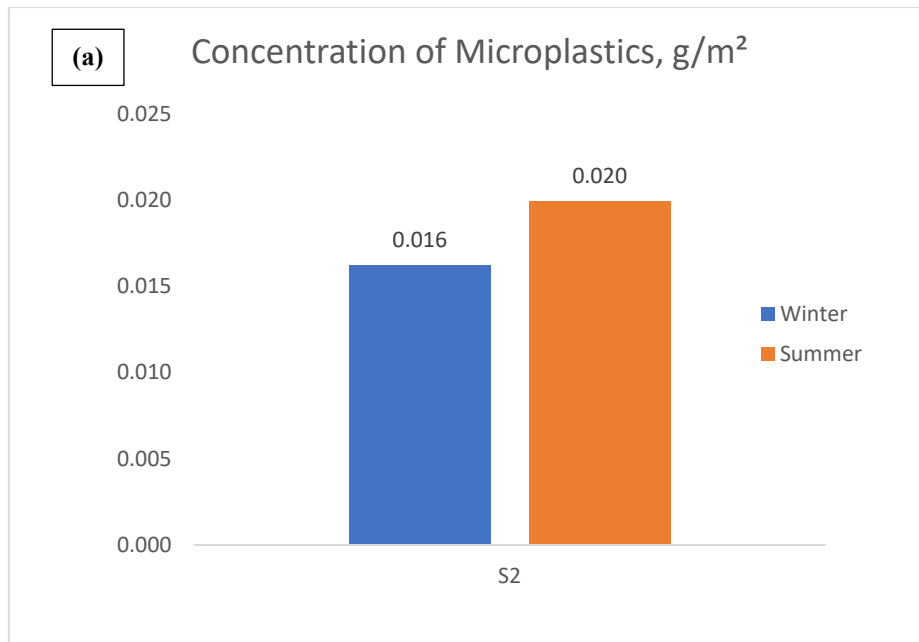


Figure 4.5: Comparison of the concentration of microplastics in Ramna Lake (sampling location S2) in Winter and Summer: (a) in terms of mass per unit area sampled; and (b) in terms of item per unit area sampled.

4.2.3 Microplastics in Hatirjheel

Figure 4.6 shows the microplastics extracted from the samples collected from Hatirjheel (sampling location S3). Table 4.5 shows the quantity of microplastics present in the sample, and the quantity of microplastics as a percentage of total solids (i.e., solids with size fraction between 4.75-mm to 0.3-mm).

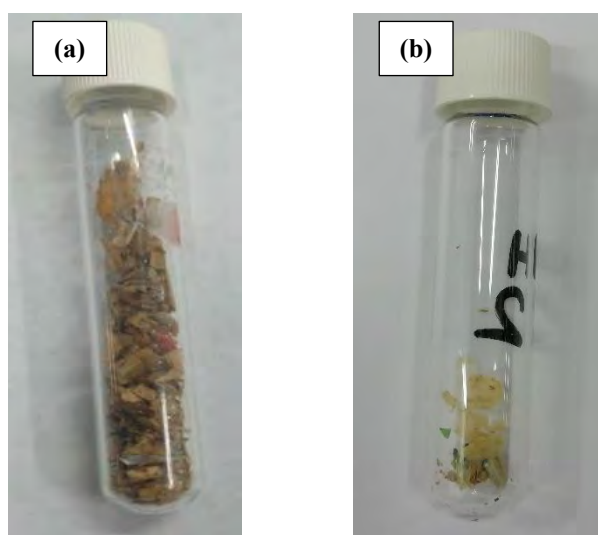


Figure 4.6: Microplastics found at the sampling point S3 in Hatirjheel:
(a) in Winter, (b) in Summer

Table 4.5: Microplastics as percentage (%) of total solids in the samples collected from location S3 in Hatirjheel

Sampling Time	Empty Vial Weight (gm)	Vial + Microplastics (gm)	Weight of Microplastics (gm)	Total solids (gm)	Microplastics as % of Total Solids*
Winter (December)	14.59	15.3685	0.7785	19.97	3.90
Summer (March)	14.48	14.5167	0.0367	3.39	1.08

* “Total Solids” refer to the solids with size fraction between 4.75-mm to 0.3-mm (isolated after wet sieving) after oven drying at 90 °C for 24 hours.

The percentage of microplastics found in samples collected in Winter (December, 2018) from the sampling location S3 in Hatirjheel was 3.90% of total solids. The amount is quite significant when compared to the percentage of microplastics found in the other two Lakes (Dhanmondi and Ramna). The microplastics were not very colourful.

It should be noted that Hatirjheel receives huge amount of storm water mixed with domestic sewage (especially during the wet season). This is a potential source of microplastics in Hatirjheel. Besides, since geo-bags have been placed to protect banks from soil erosion, plastic fibers found in the sample could have resulted from these geo-bags.

The percentage of microplastics found in the samples collected in Summer (March, 2019) from Hatirjheel was 1.08% of total solids, which is much less than the Winter season. Due to hot weather with higher temperature, gathering of people was drastically reduced in this time period; this could be a cause of the reduction of microplastics in samples collected in Summer. So, this can be a cause of less microplastics. Most of the microplastics were found from the floating materials (during analysis); this indicates that the microplastics were mostly low-density plastics.

Hatirjheel is a recreational place where many visitors come every day to view the scenic landscape. The visitors often carry with them plastic bottles, chips packets, polythene filled with ground nut, biscuits and newspapers and leave those after use. These could eventually contribute to the pollution of the water body with plastic products. These larger plastics then fragment to form the smaller pieces of microplastics which pose serious hazard to the aquatic lives present in the water body. Table 4.6 shows the concentration of microplastics at the sampling location (S3) in Hatirjheel in term of mass and number per unit area sampled. It shows significant increase in the quantity (over 21 times) and number (over 8 times) of microplastics at the sampling location during Winter, compared to that in Summer. Figure 4.7 shows comparison of concentration of microplastics at the sampling location (S3) in Hatirjheel in different units. This suggests that both number and characteristics of microplastics could vary significantly at a sampling location depending on many factors.

Table 4.6: Concentration of microplastics in Hatirjheel (sampling location S3) in terms of mass and number of items per unit area sampled

Sampling Time	Weight of Microplastics (gm)	No. of Microplastics (Item)	Total Area Sampled (m ²)	Concentration of Microplastics (g/m ²)	Concentration of Microplastics (Items/m ²)
Winter (December)	0.7785	639	10	0.078	63.9
Summer (March)	0.0367	75	10	0.004	7.5

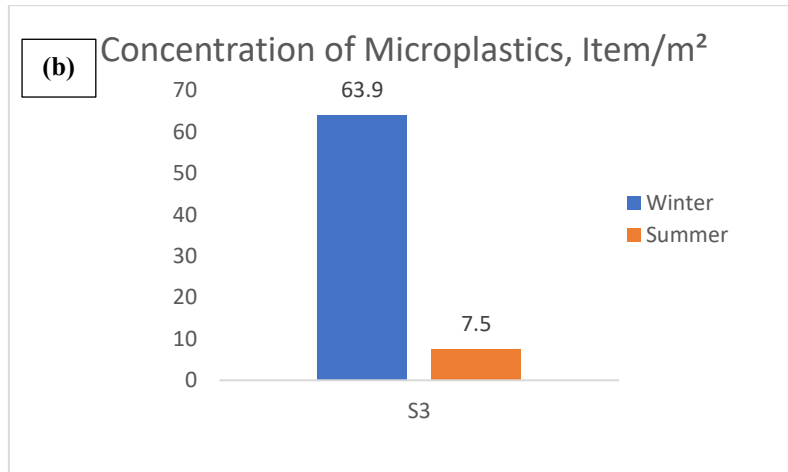
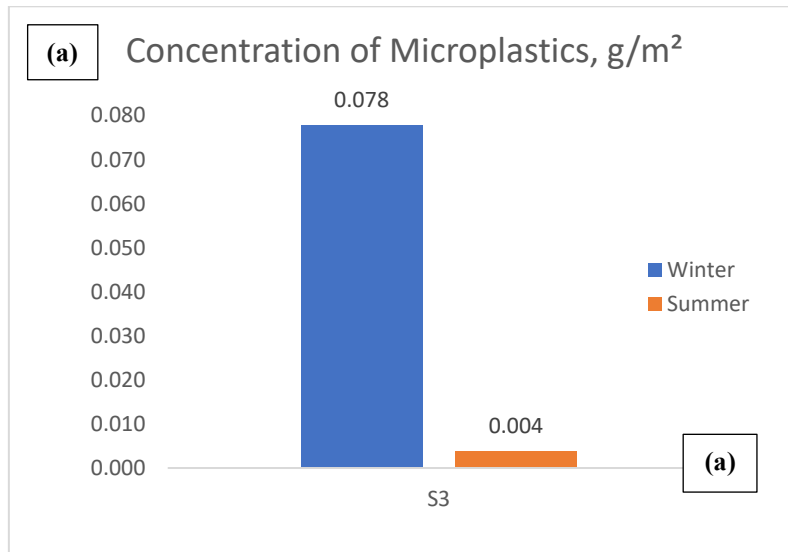


Figure 4.7: Comparison of the concentration of microplastics in Hatirjheel (sampling location S3) in Winter and Summer: (a) in terms of mass per unit area sampled; and (b) in terms of item per unit area sampled.

4.2.4 Microplastics in Buriganga River

Figure 4.8 shows the microplastics extracted from the samples collected from a sampling location (S4) in Buriganga River. The figure clearly shows that the quantity of microplastics identified in Summer (March, 2019) is much higher than that in Winter (December, 2018). Table 4.7 shows the quantity of microplastics present in the sample, and the quantity of microplastics as a percentage of total solids (collected samples with size fraction between 4.75-mm to 0.3-mm).

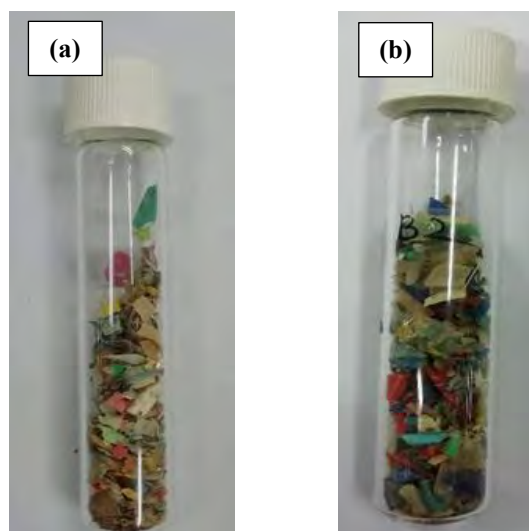


Figure 4.8: Microplastics found at the sampling point S4 in Buriganga River:
(a) in Winter, (b) in Summer

Table 4.7: Microplastics as percentage (%) of total solids in the samples from the Sampling location S4 in Buriganga River

Sampling Time	Empty Vial Weight (gm)	Vial + Microplastics (gm)	Weight of Microplastics (gm)	Total solids (gm)	Microplastics as % of Total Solids*
Winter (December)	14.49	15.134	0.644	20.13	3.2
Summer (March)	14.31	16.1	1.79	10.57	16.9

* “Total Solids” refer to the solids with size fraction between 4.75-mm to 0.3-mm (isolated after wet sieving) after oven drying at 90 °C for 24 hours.

Buriganga River is one of the most polluted rivers in Bangladesh. The microplastics found in samples from the sampling point (S4) in Buriganga River was 3.2% of total solids in Winter. From visual inspection it is seen that the microplastics of Buriganga River is very colourful (see Figure 4.8). This possibly indicates that these microplastics have resulted from a wide variety of sources. Household plastic products such as plastic buckets, plastic bottles, and polythene might have degraded to form the smaller pieces of microplastics. Since the river receives significant domestic and industrial sewage, the plastic wastes most probably came from these sources. It is also suspected that the dumping of plastic wastes by the nearby slum dwellers such as ice-cream packets, chips packets, and plastic bottle caps could be a major reason for the formation of microplastics.

The microplastics obtained from Buriganga River in Summer was 16.9% of total solids, which is much higher than the Winter season. The higher quantity could be due to entry of microplastics with storm runoff. Also, from visual inspection it is seen that the microplastics found in Summer are colourful and similar to those found in Winter (see Figure 4.8). This probably suggests that the source of microplastics in Winter and Summer are similar. Also, both low- and high- density plastic particles were found in the sample collected in Summer.

Table 4.8 shows the concentration of microplastics at the sampling location (S4) in Buriganga River in term of mass and number per unit area sampled. It shows that the mass of microplastics is higher, but the number of items is lower in Summer. This probably suggests that the item identified in Summer are larger and/or heavier. Figure 4.9 shows comparison of concentration of microplastics at the sampling location (S4) in Buriganga in different units. It suggests that the quantity and characteristics of microplastics at a particular location could vary with time.

Table 4.8: Concentration of microplastics in Buriganga River (sampling location S4) in terms of mass and number of items per unit area sampled

Sampling Time	Weight of Microplastics (gm)	No. of Microplastics (Item)	Total Area Sampled (m ²)	Concentration of Microplastics (g/m ²)	Concentration of Microplastics (Items/m ²)
Winter (December)	0.644	971	166	0.004	5.8
Summer (March)	1.79	676	166	0.011	4.1

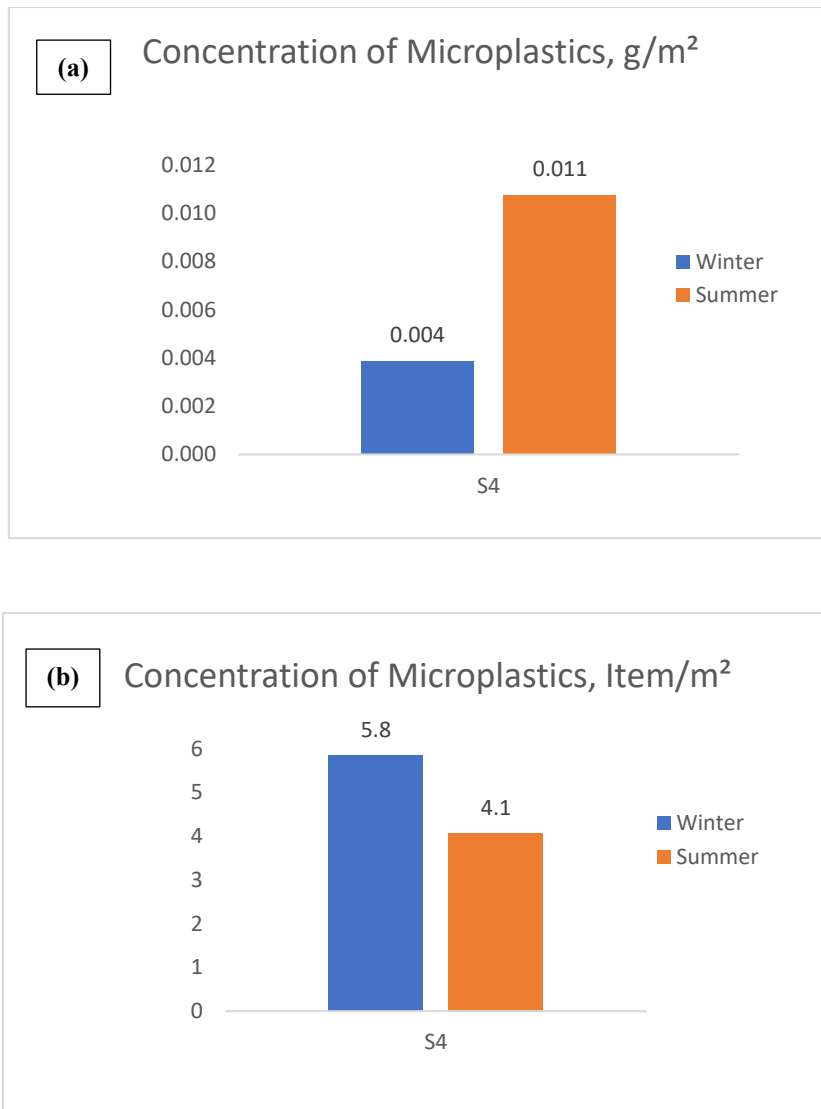


Figure 4.9: Comparison of the concentration of microplastics in Buriganga River (sampling location S4) in Winter and Summer: (a) in terms of mass per unit area sampled; and (b) in terms of item per unit area sampled.

4.2.5 Microplastics in Turag River

Figure 4.10 shows the microplastics extracted from the samples collected from the sampling location S5 in Turag River. It shows completely different nature of microplastics in Winter (December, 2018) and Summer (July, 2019). Table 4.9 shows the quantity of microplastics present in the sample, and the quantity of Microplastics as a percentage of total solids (i.e., solids with size fraction between 4.75-mm to 0.3-mm).

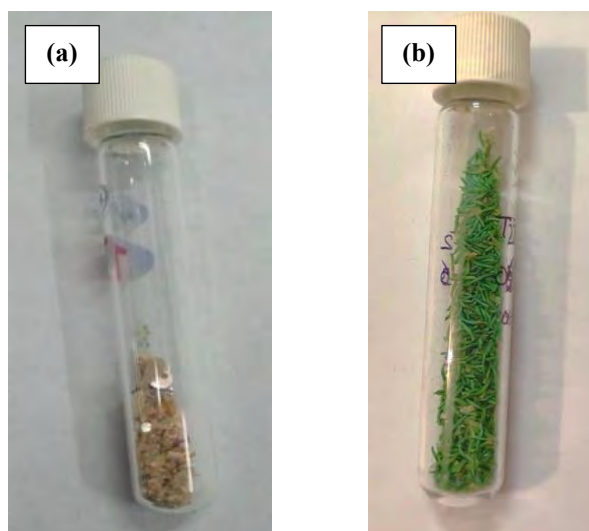


Figure 4.10: Microplastics found at the sampling point S5 in Turag River:
(a) in Winter, (b) in Summer

Table 4.9: Microplastics as percentage (%) of total solids in the samples from the Sampling location S5 in Turag River

Sampling Time	Empty Vial Weight (gm)	Vial + Microplastics (gm)	Weight of Microplastics (gm)	Total solids (gm)	Microplastics as % of Total Solids*
Winter (December)	14.4	15.8592	1.4592	15.62	9.3
Summer (July)	14.6698	15.8169	1.1471	5.07	22.6

* “Total Solids” refer to the solids with size fraction between 4.75-mm to 0.3-mm (isolated after wet sieving) after oven drying at 90 °C for 24 hours.

The quantity of microplastics found in samples collected in Winter from Turag River (sampling location S5) was 9.3% of total solids, which is a high percentage. Even though from visual appearance the quantity seems smaller (Fig. 4.10a), but due to higher density the mass of the isolated microplastics was high. These microplastics might have originated from the degradation of hard plastics which may include feeders, plastic containers for milk, shampoos and conditioners, detergents, and bleaches. Glitters were found profoundly in this sample. One of the reasons could be that glitters and plastic embroidery works from the clothing might have drained into the river. Domestic sewage from domestic sources and nearby slums could also contribute to the microplastics in the river. Since many industries including pharmaceutical industries, dyeing industry, textile industry etc. are located in the vicinity of the river, there are a variety of sources which might contribute microplastics in the river.

Although the mass of microplastics found in the sample collected in Summer from this sampling point was lower than that in Winter, the microplastics concentration in terms of percentage of total solids was much higher (22.6%). This is because the total solids in the sample collected in Summer was much lower (over three times) than that in Winter. The color of majority of microplastics (green) identified in Summer from the sampling location S5 is different from the microplastics identified from the other locations. Majority of these microplastics have been found to be similar in color (green) and texture. This suggest that they most likely came from the same source, most likely from an industrial source located nearby. It should be noted that the day we collected the sample was a rainy day.

Table 4.10 shows the concentration of microplastics at the sampling location (S5) in Turag River in term of these units. Figure 4.10 and information presented in Table 4.10 suggest that the nature of microplastics collected from the sampling location in Winter and Summer are completely different. The microplastics identified in Summer are mostly identical, green in color, higher in number (than those identified in Winter) and light weight. This suggests that nearby local sources could contribute significant microplastics at a particular location. Figure 4.11 shows comparison of concentration of microplastics at the sampling location (S5) in Turag River in different units.

Table 4.10: Concentration of microplastics in Turag River (sampling location S5) in terms of mass and number of items per unit area sampled

Sampling Time	Weight of Microplastics (gm)	No. of Microplastics (Item)	Total Area Sampled (m ²)	Concentration of Microplastics (g/m ²)	Concentration of Microplastics (Items/m ²)
Winter (December)	1.4592	1,160	230	0.006	5.0
Summer (July)	1.1471	3,267	230	0.005	14.2

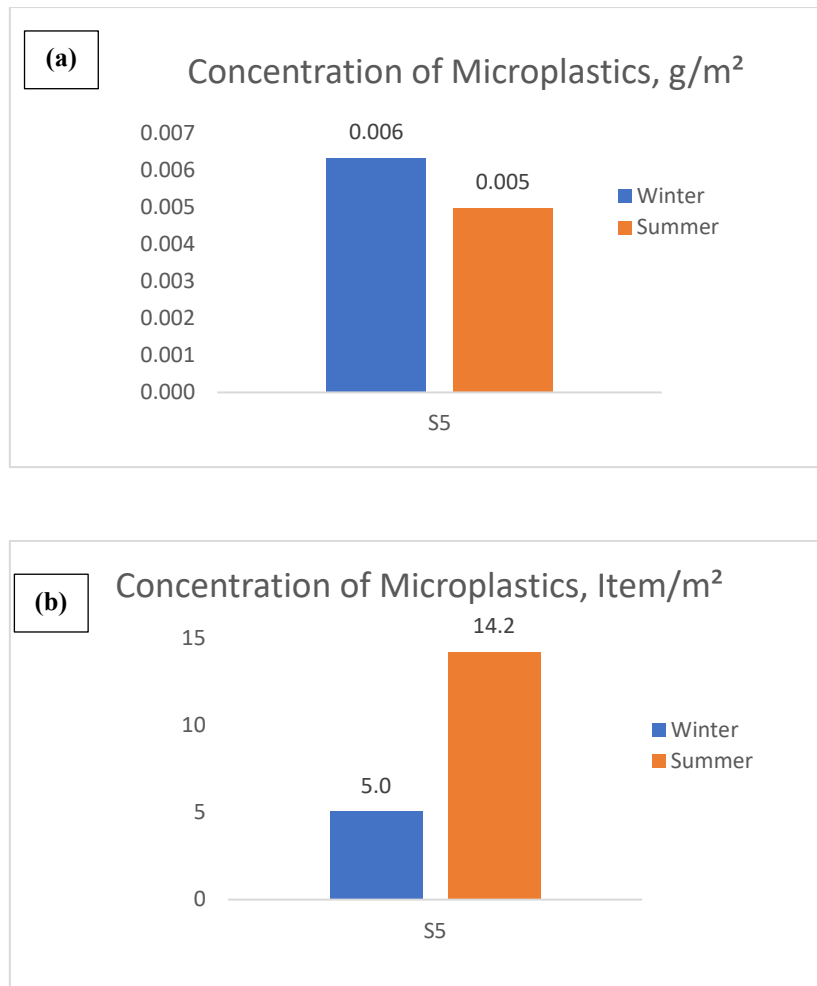


Figure 4.11: Comparison of the concentration of microplastics in Turag River (sampling location S5) in Winter and Summer: (a) in terms of mass per unit area sampled; and (b) in terms of item per unit area sampled.

4.2.6 Comparison of Quantities Microplastics found in Different Water Bodies

This section presents a comparison of the quantities of microplastics found at the sampling locations of the 5 water bodies covered in this study. It should be noted that direct comparison of the quantities of microplastics could be misleading. This is because the samplings covered only a small part of the water bodies; covering a wider area was difficult because of unavailability of suitable water vessel for sampling. Thus, the results obtained represent microplastics concentration in the particular sampling areas of the water bodies (and not representative of the entire water body). Besides, the areas sampled in the five water bodies were different; varying from 10 m² to 230 m². Thus, the comparison presented here is basically summarizes of the quantities of microplastics identified at the five sampling points.

Figure 4.12 shows the quantity of microplastics found at the different sampling points (in terms of “% of total solids”) in Winter and Summer seasons. It shows that the quantity of microplastics (as % of total solids) increased in Summer (compared to that in Winter) for all sampling points, except for Hatirjheel. The higher quantities of microplastics in Summer could be due to entry of microplastics with runoff. The relatively lower concentration (as % of total solids) could be due to reduced number of visitors in Hatirjheel area during the hot Summer period. Discussions presented above also reveal that the quantities of microplastics (as percentage of total solids) also depend on composition of microplastics (e.g., density of materials).

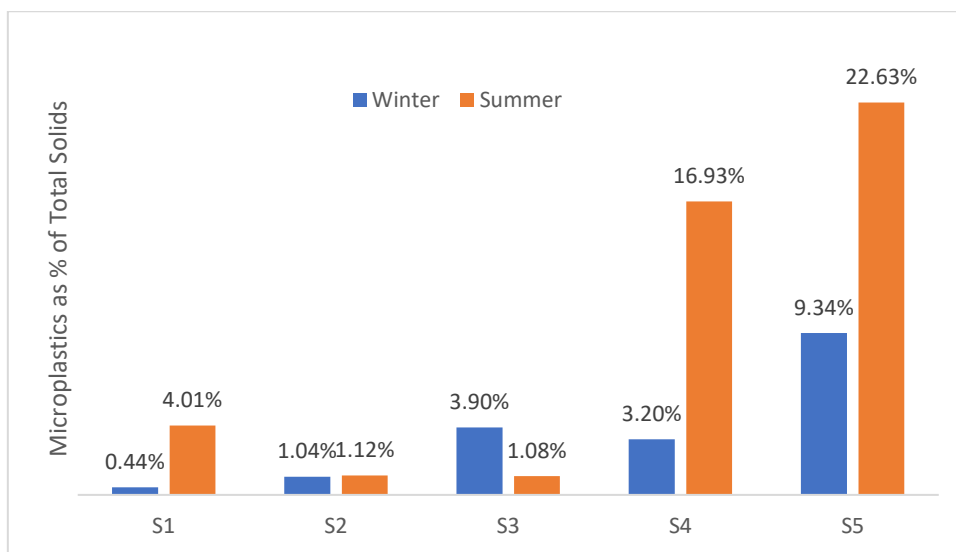


Figure 4.12: Comparison of the percentage of Microplastics found in different water bodies

Figure 4.13 shows the concentration of microplastics in the sampling areas in Winter and Summer in terms of mass per unit area sampled. It should be noted however, that the quantities should not be directly compared, since the areas sampled at the different sampling points varied significantly. The figure shows higher quantities of microplastics in terms of “mass per unit area sampled” in Hatirjheel possibly because in this water body samples were collected from a smaller area with relatively higher concentration of microplastics. Nevertheless, Fig. 4.13 shows a range of microplastics concentration that could be expected in the water bodies in and around Dhaka city.

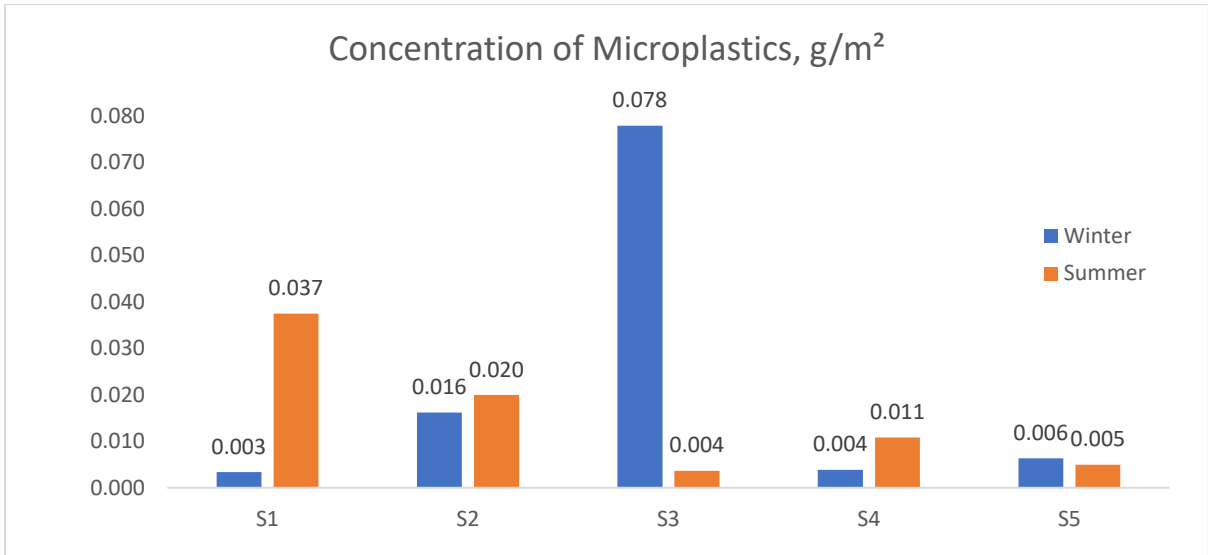


Figure 4.13: Concentration of microplastics in terms of mass per unit area sampled

Figure 4.14 shows the concentration of microplastics in the sampling area in Winter and Summer in terms of number of items per unit area sampled. As noted earlier, these quantities should not be directly compared, since the areas sampled at the different sampling points varied significantly. Higher quantities of microplastics in terms of “item per unit area sampled” in Hatirjheel possibly is probably because of smaller sampling areas. Fig. 4.14 shows a range of microplastics items that could be expected in the water bodies in and around Dhaka city.

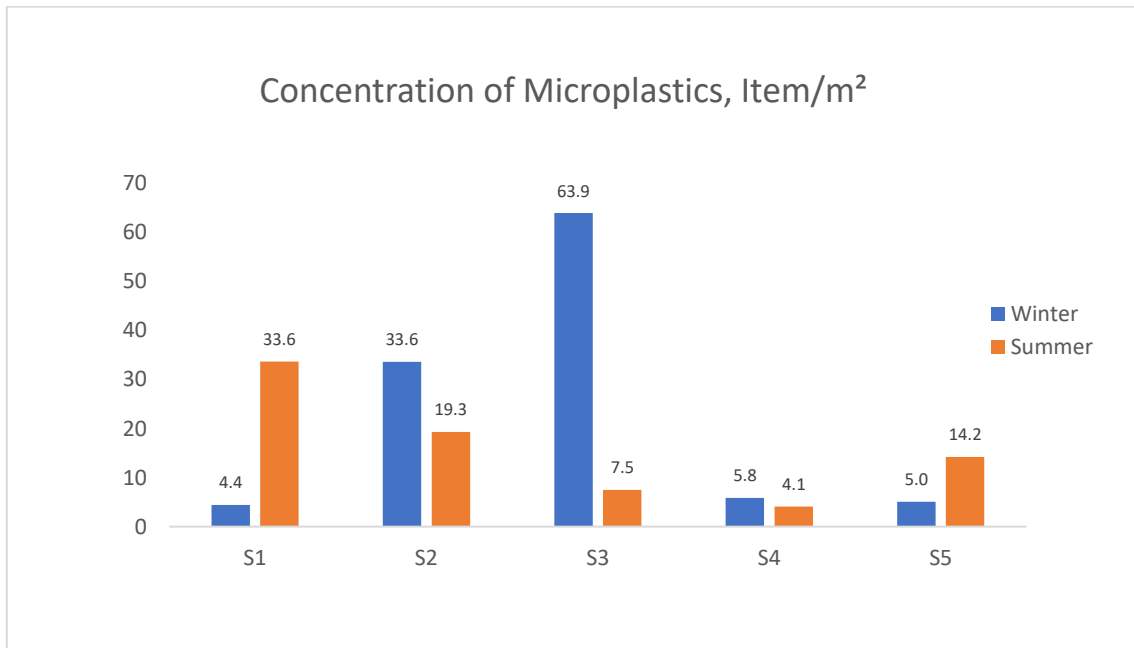


Figure 4.14: Concentration of microplastics in terms of number of items per unit area sampled

4.3 Characterization of Microplastics

4.3.1 Size Fraction of Microplastics

Size ranges or fractions of microplastics is one of its important characteristics. As discussed in Chapter 3, in this study size fraction of microplastics from each source was determined through sieve analysis. For fractionation of microplastics a set of sieves with openings of 2.36-mm, 1.18-mm, 0.6-mm and 0.3-mm were used. This section presents the size fractions of microplastics from the different sampling locations.

Size Fraction of Microplastics from Dhanmondi Lake

Table 4.11 presents the results of sieve analysis of microplastics from Dhanmondi Lake. It shows the weight and percentages (of total weight) of microplastics retained in each sieve, and the total number of items retained on each sieve. Figure 4.15 shows the comparison of microplastics identified in samples collected in Winter (November, 2018) and Summer (March, 2019) from Dhanmondi Lake (location S1), based on the results of the sieve analysis; Fig. 4.16 shows comparison of numbers of items under different size fractions.

Table 4.11: Size fractions of the microplastics found at the sampling location S1 of Dhanmondi lake in Winter and Summer

Sieve Size (mm)	Microplastics in Samples Collected in Winter (Total Weight: 0.054 g)			Microplastics in Samples Collected in Summer (Total Weight: 0.5988 g)		
	Wt. of Microplastics Retained on Sieve	% of Microplastics Retained on Sieve	No. of Items Retained on Sieve	Wt. of Microplastics Retained on Sieve	% of Microplastics Retained on Sieve	No. of Items Retained on Sieve
2.36	0.0015	2.78	2	0.3618	60.42	62
1.18	0.044	81.48	13	0.1952	32.60	104
0.6	0.0079	14.63	27	0.0367	6.13	236
0.3	0.0006	1.11	29	0.0051	0.85	136

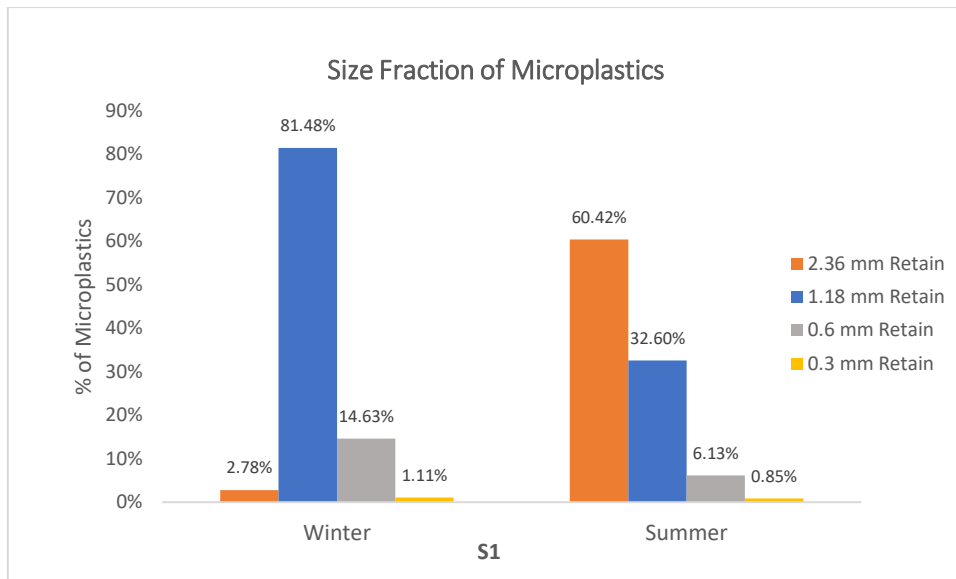


Figure 4.15: Distribution of microplastics found at the sampling location S1 in Dhanmondi Lake, in Winter and Summer, among different size fractions (in terms of mass)

Figure 4.15 shows that relatively larger particles (greater than 1.18 mm in size) are dominant in the microplastics identified in the samples collected from the sampling location (S1) in Dhanmondi Lake. The size fraction between 1.18 mm and 2.36 mm accounted for about 81.5% of microplastics identified from the samples collected in Winter, while the size fraction 2.36 mm to 4.75mm accounted for about 60.4% of microplastics identified in samples collected in Summer. On the other hand, smaller size microplastics accounted for majority of the items of microplastics identified. For example, the size fractions ranging from 0.3 mm to 1.18 mm accounted for about 70% of total items of microplastics identified in samples collected in Summer and also in Winter it is about 78% of total items of microplastics identified.

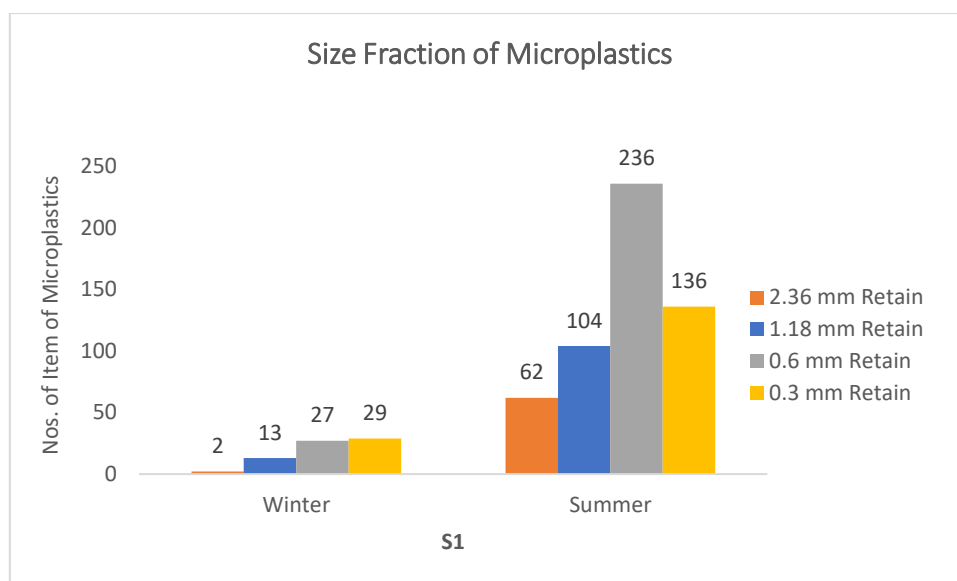


Figure 4.16: Distribution of microplastics found at the sampling location S1 in Dhanmondi Lake, in Winter and Summer, among different size fractions (in terms of number of items)

Size Fraction of Microplastics from Ramna Lake

Table 4.12 presents the results of sieve analysis of microplastics isolated from the samples collected from Ramna Lake in Winter (November, 2018) and Summer (March, 2019). It shows the weight and percentages (of total weight) of microplastics retained in each sieve, and the total number of items retained on each sieve. Figure 4.17 shows the comparison of microplastics identified from the samples collected in Winter and Summer from Ramna Lake (location S2), based on the results of the sieve analysis; Fig. 4.18 shows comparison of numbers of items under different size fractions.

Table 4.12: Size fractions of the microplastics found at the sampling location S2 of Ramna lake in Winter and Summer

Sieve Size (mm)	Microplastics in Samples Collected in Winter (Total Weight: 0.1619 g)			Microplastics in Samples Collected in Summer (Total Weight: 0.1994 g)		
	Wt. of Microplastics Retained on Sieve	% of Microplastics Retained on Sieve	No. of Items Retained on Sieve	Wt. of Microplastics Retained on Sieve	% of Microplastics Retained on Sieve	No. of Items Retained on Sieve
2.36	0.0555	34.28	22	0.0196	9.83	15
1.18	0.059	36.44	52	0.162	81.24	77
0.6	0.0397	24.52	117	0.0166	8.32	76
0.3	0.0077	4.76	145	0.0012	0.60	25

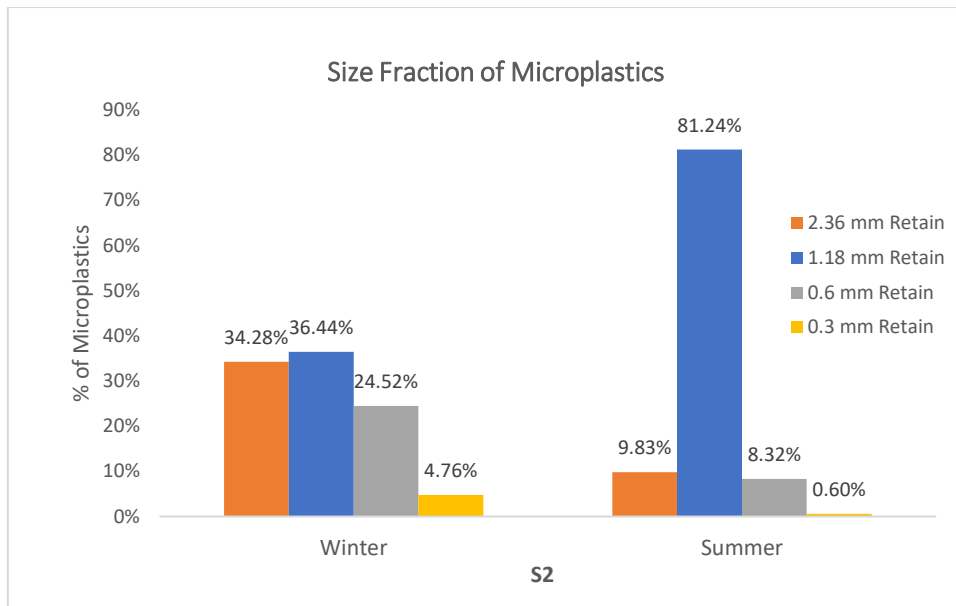


Figure 4.17: Distribution of microplastics found at the sampling location S2 in Ramna Lake, in Winter and Summer, among different size fractions (in terms of mass)

Figure 4.17 shows that the size distribution of microplastics from Ramna Lake is somewhat similar to that found for those from Dhanmondi Lake. Relatively larger size fractions (> 1.18 mm) accounted for over 70% of microplastics in Winter and over 90% of microplastics in Summer. However, the size fraction retained on 0.6 mm size accounted for about 25% of the microplastics in samples collected in Winter. In terms of number, the size fractions ranging from 0.3 to 1.18 mm in size were the dominant (see Fig. 4.18).

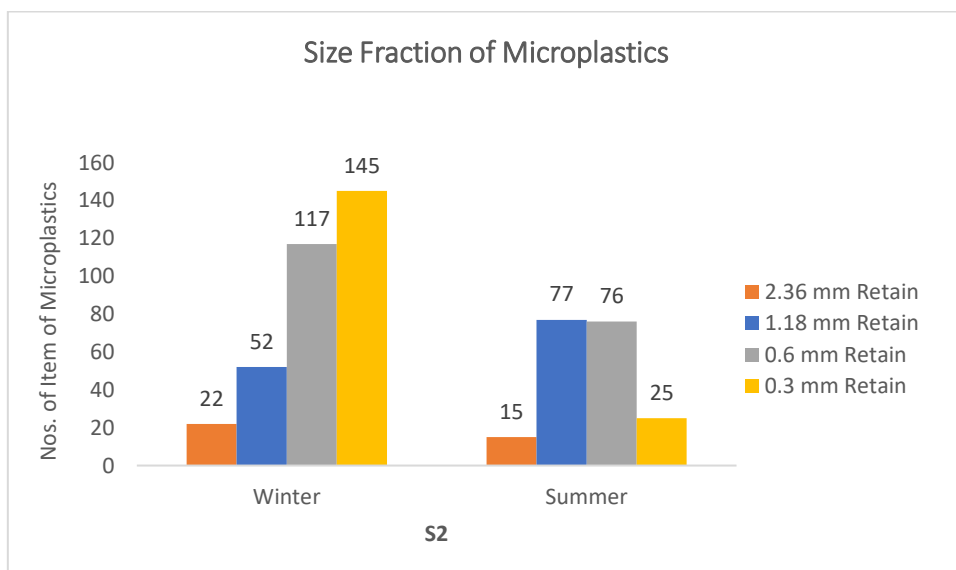


Figure 4.18: Distribution of microplastics found at the sampling location in S2 in Ramna Lake, in Winter and Summer, among different size fractions (in terms of number of items)

Size Fraction of Microplastics from Hatirjheel

Table 4.13 shows the results of sieve analysis of microplastics isolated from the samples collected from Hatirjheel. It shows the weight and percentages (of total weight) of microplastics retained in each sieve, and the total number of items retained on each sieve. Figure 4.19 shows the comparison of microplastics identified from the samples collected in Winter (December, 2018) and Summer (March, 2019) from Hatirjheel (location S3), based on the results of the sieve analysis; Fig. 4.20 shows comparison of numbers of items under different size fractions.

Table 4.13: Size fractions of the microplastics found at the sampling location S3 of Hatirjheel in Winter and Summer

Sieve Size (mm)	Microplastics in Samples Collected in Winter (Total Weight: 0.7785 g)			Microplastics in Samples Collected in Summer (Total Weight: 0.0367 g)		
	Wt. of Microplastics Retained on Sieve	% of Microplastics Retained on Sieve	No. of Items Retained on Sieve	Wt. of Microplastics Retained on Sieve	% of Microplastics Retained on Sieve	No. of Items Retained on Sieve
2.36	0.3366	43.24	72	0.0254	69.21	12
1.18	0.3621	46.51	189	0.0082	22.34	11
0.6	0.0687	8.82	253	0.0028	7.63	19
0.3	0.0111	1.43	125	0.0003	0.82	33

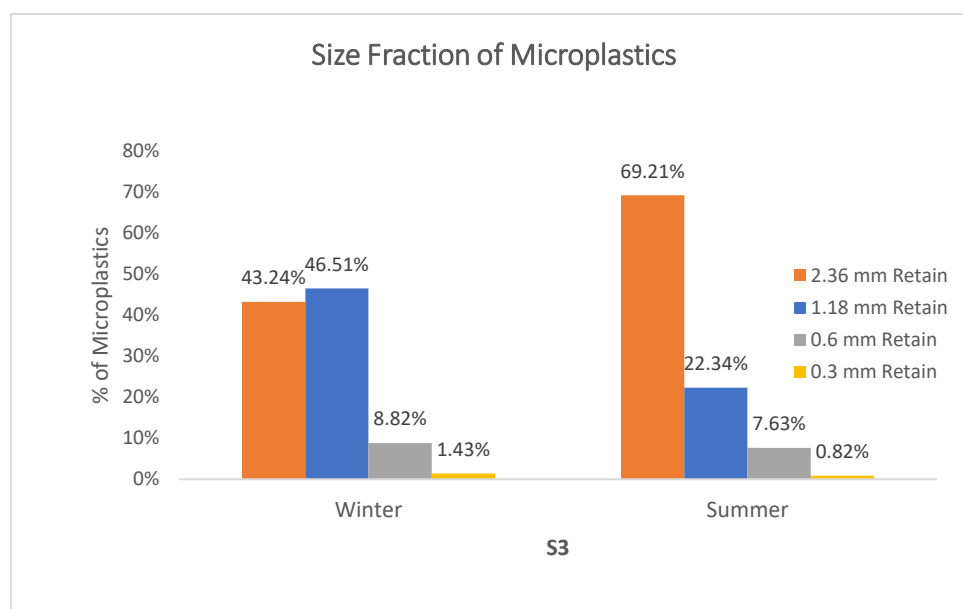


Figure 4.19: Distribution of microplastics found at the sampling location S3 in Hatirjheel, in Winter and Summer, among different size fractions (in terms of mass)

Figure 4.19 shows that the larger size fractions are dominant in the microplastics identified from Hatirjheel samples both in Winter and Summer. The largest size fraction ranging from 2.36 to 4.75 mm accounted for about 43% and 69% of microplastics in Winter and Summer, respectively. The largest two size fractions, ranging from 1.18 mm to 4.75 mm accounted for about 90% and 92% of the microplastics in Winter and Summer, respectively. In general, the sizes of microplastics usually get reduced with time due to abrasion, degradation and other process. As before, the relatively smaller sized microplastics contributed more to the overall number of items, as could be seen from Fig. 4.20.

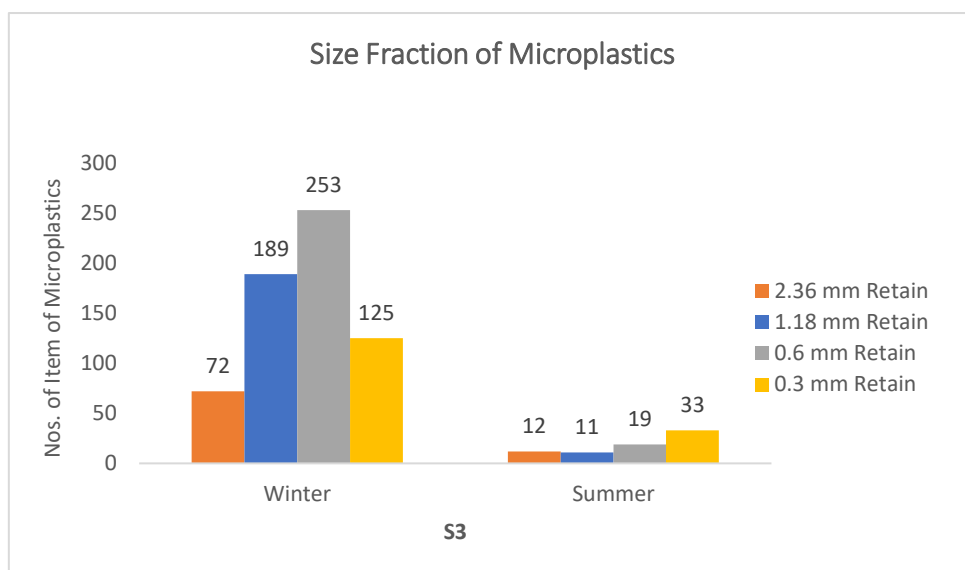


Figure 4.20: Distribution of microplastics found at the sampling location S3 in Hatirjheel, in Winter and Summer, among different size fractions (in terms of number of items)

Size Fraction of Microplastics from Buriganga River

Table 4.14 shows the results of sieve analysis of microplastics isolated from the samples collected from Buriganga River in Winter (December, 2018) and Summer (March, 2019) seasons. It shows the weight and percentages (of total weight) of microplastics retained in each sieve, and the total number of items retained on each sieve. Figure 4.21 shows the comparison of microplastics identified from the samples collected in Winter and Summer from Buriganga River (location S4), based on the results of the sieve analysis; Fig. 4.22 shows comparison of numbers of items under different size fractions.

Table 4.14: Size fractions of the microplastics found at the sampling location S4 of Buriganga River in Winter and Summer

Sieve Size (mm)	Microplastics in Samples Collected in Winter (Total Weight: 0.644 g)			Microplastics in Samples Collected in Summer (Total Weight: 1.79 g)		
	Wt. of Microplastics Retained on Sieve	% of Microplastics Retained on Sieve	No. of Items Retained on Sieve	Wt. of Microplastics Retained on Sieve	% of Microplastics Retained on Sieve	No. of Items Retained on Sieve
2.36	0.3741	58.09	75	1.1989	66.98	127
1.18	0.1978	30.71	228	0.498	27.82	172
0.6	0.0639	9.92	368	0.089	4.97	221
0.3	0.0082	1.27	300	0.0041	0.23	156

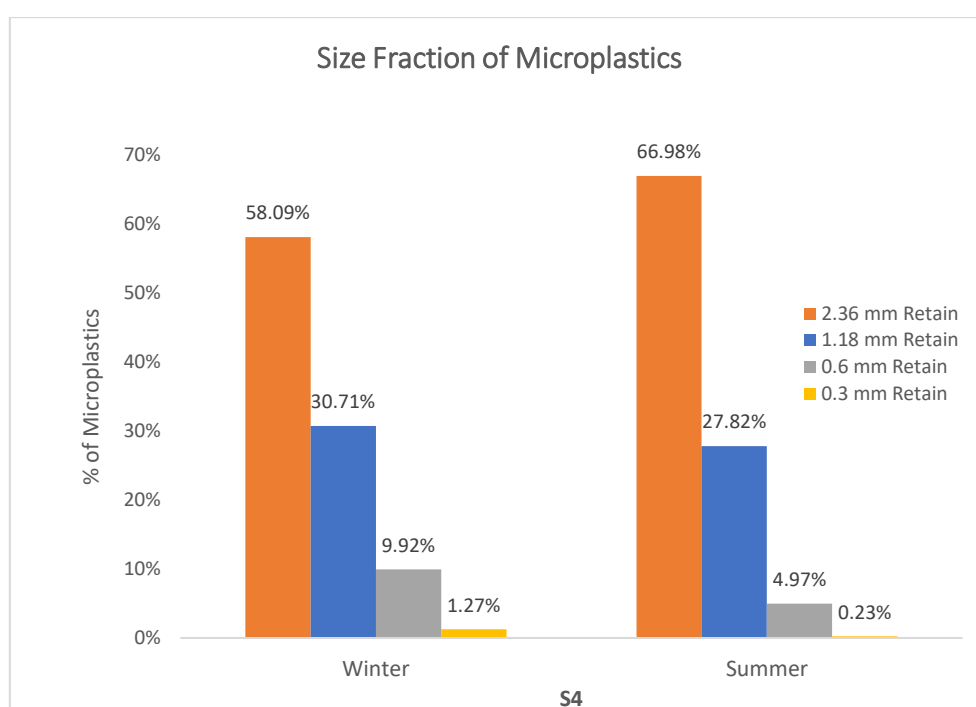


Figure 4.21: Distribution of microplastics found at the sampling location S4 in Buriganga River, in Winter and Summer, among different size fractions (in terms of mass)

Like Hatirjheel, size fractions of microplastics from Buriganga River have been found to be dominated by larger sized microplastics in both Winter and Summer (Fig. 4.21). The largest size fraction ranging from 2.36 to 4.75 mm accounted for about 58% and 67% of microplastics in Winter and Summer, respectively. The largest two size fractions, ranging from 1.18 mm to 4.75 mm accounted for about 89% and 95% of the microplastics in Winter and Summer, respectively. As discussed above, the larger fraction bigger size microplastics in Buriganga River probably suggests that these are relatively fresh/new. As before, the relatively smaller

sized microplastics contributed more to the overall number of items, as could be seen from Fig. 4.22.

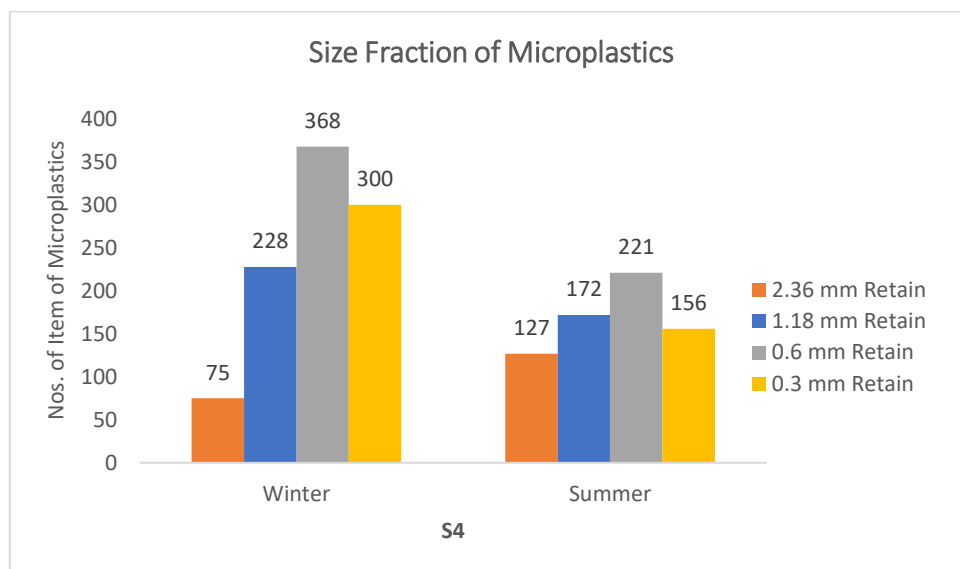


Figure 4.22: Distribution of microplastics found at the sampling location S4 in Buriganga River, in Winter and Summer, among different size fractions (in terms of number of items)

Size Fraction of Microplastics from Turag River

Table 4.15 shows the results of sieve analysis of microplastics isolated from the samples collected from Turag River in Winter (December, 2018) and Summer (July, 2019) seasons. It shows the weight and percentages (of total weight) of microplastics retained in each sieve, and the total number of items retained on each sieve. Figure 4.23 shows the comparison of microplastics identified from the samples collected in Winter and Summer from Turag River (location S5), based on the results of the sieve analysis; Fig. 4.24 shows comparison of numbers of items under different size fractions.

Table 4.15: Size fractions of the microplastics found at the sampling location S5 of Turag River in Winter and Summer

Sieve Size (mm)	Microplastics in Samples Collected in Winter (Total Weight: 1.4592 g)			Microplastics in Samples Collected in Summer (Total Weight: 1.1471 g)		
	Wt. of Microplastics Retained on Sieve	% of Microplastics Retained on Sieve	No. of Items Retained on Sieve	Wt. of Microplastics Retained on Sieve	% of Microplastics Retained on Sieve	No. of Items Retained on Sieve
2.36	0.1659	11.37	11	0.07	6.10	52
1.18	0.7454	51.08	133	0.0864	7.53	164
0.6	0.4938	33.84	540	0.9369	81.68	1556
2.36	0.0541	3.71	476	0.0538	4.69	1495

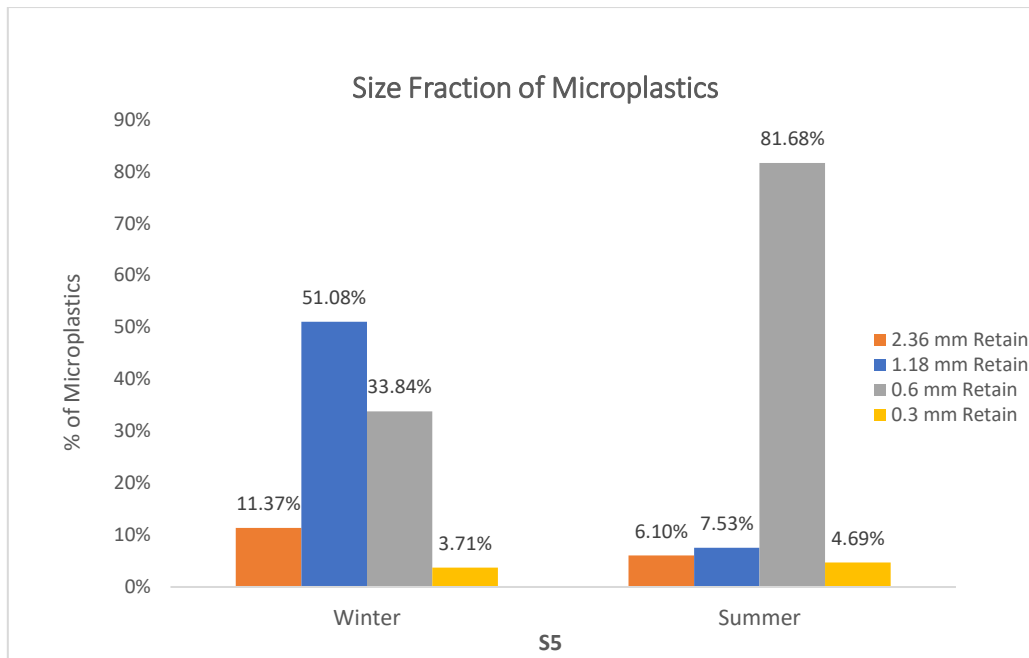


Figure 4.23: Distribution of microplastics found at the sampling location S5 in Turag River, in Winter and Summer, among different size fractions (in terms of mass)

The size distribution of microplastics isolated from the samples collected from Turag River appears to be somewhat different than those of the other sampling locations (especially Hatirjheel and Buriganga River). In these microplastics, the contribution of smaller size fractions was significant (see Fig. 4.23). For example, the size fraction in the range 0.6 mm to 1.18 mm accounted for about 82% of total microplastics in Summer, while this size range accounted for about 34% of total microplastics in Winter. In terms of number of items, the smaller sized microplastics were even more dominant, as shown in Fig. 4.24. The smallest size range from 0.3 to 0.6 mm accounted for about 41% and 46% of total number of items in Winter and Summer, respectively.

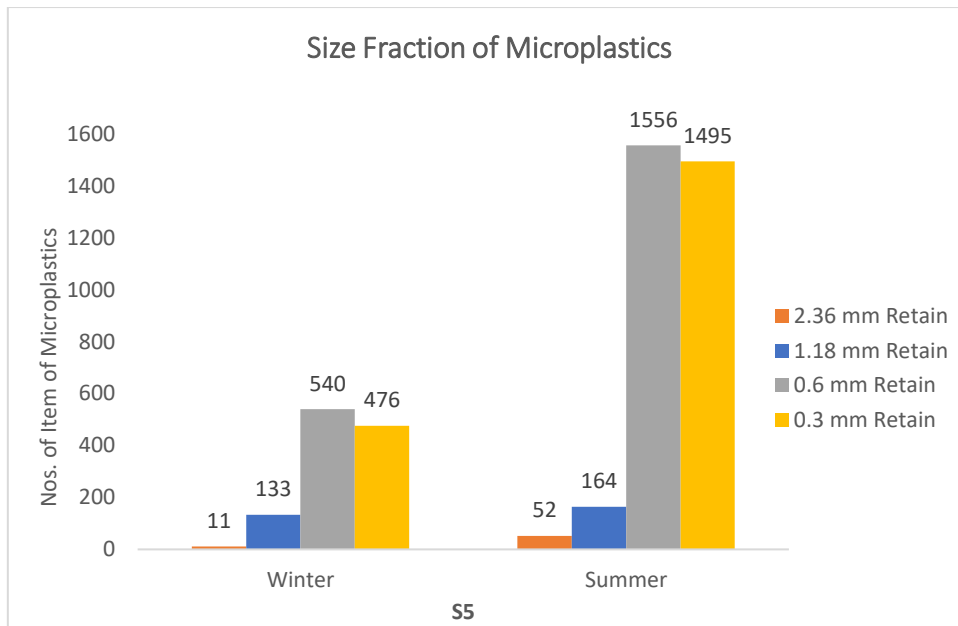


Figure 4.24: Distribution of microplastics found at the sampling location S5 in Turag River, in Winter and Summer, among different size fractions (in terms of mass)

One of the reasons for the dominance of smaller sized microplastics in the samples collected in Summer is the presence of one particular type of microplastics. Fig. 4.25 shows the different size fractions of the microplastics (after sieve analysis) isolated from the sample collected from Turag River in Summer. It shows that size fraction ranging from 0.6 mm to 1.18 mm accounts for significant fraction of total microplastics, and that this fraction consists of a green color microplastics of similar texture. As discussed earlier (in Section 4.2.5), the green colored microplastics possibly originated from an industrial source on the bank of the river, close to the sampling location.



Figure 4.25: Size fractions of microplastics retained on the sieves (2.36 mm, 1.18 mm, 0.6 mm and 0.3 mm sieves) for microplastics isolated from the sample collected from Turag River in Summer

4.3.2 Morphology of Microplastics

The sizes, shapes and color of microplastics is of particular interest because they are often mistaken for food by aquatic organisms and certain birds. Microplastics vary in shape from irregular to spherical and long-fibers. The shape of plastic fragments depends on the fragmentation process as well as residence time in the environment (Hidalgo-Ruz et al., 2012). Sharp edges usually indicate either recent introduction into the environment or recent break-up of larger pieces, while smooth edges are often associated with older fragments. Degradation and erosion of particle surfaces are caused primarily by biological breakdown, photo-degradation, chemical weathering, or physical forces, such as wave action, wind, etc. Surface texture of microplastics may affect the concentration of sorbed chemicals; increased surface areas of smaller microplastics are likely to increase sorption of chemicals.

Color is also an important parameter for microplastics. Diverse color of microplastics have been reported in the literature; however, the most common colors include white and related colors (e.g., discoloured yellow, white-cream) (Hidalgo-Ruz et al., 2012). Particles with eye catching color are usually easily identified during analysis, while those with dull colors are often overlooked, thus potentially introducing bias in the analysis.

In this study, morphology (shape and color) of microplastics particles was analysed for each individual microplastics item using a high-resolution magnifying glass. This Section presents the results of the analysis.

Morphology of Microplastics from Dhanmondi Lake

Table 4.16(a) and Table 4.16(b) shows results of morphological analysis of microplastics isolated from samples collected from Dhanmondi Lake (location S1) in Winter (November, 2018) and Summer (March, 2019), respectively. Table 4.16(a) shows that most of the microplastics, particularly in the larger size range, are irregular in shape with sharp edge; this probably suggests (as explained above) that these have been introduced in the environment recently. On the other hand, the particles with brownish or off-white colour and rough surface probably suggest long residence time in water. Microplastics isolated from sample collected in Summer also show similar characteristics with respect to shape [Table 4.16(b)], most of the microplastics were irregular in shape.

Table 4.16(a): Morphological analysis of microplastics from Dhanmondi Lake in Winter

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
4.75 mm > x > 2.36 mm	2.78 (2)	Irregular in Shape	White, Brown	Smooth
2.36 mm > x > 1.18 mm	81.5 (13)	Irregular in Shape	Green, Black, Brown, Transparent, White	Mostly smooth, some Rough
1.18 mm > x > 0.60 mm	14.6 (27)	Mostly irregular, some round	Blue, Transparent, White	Mostly smooth, some rough
0.60 mm > x > 0.30 mm	1.11 (29)	Mostly irregular, some round	Off-white, White, Blue, Silver	Smooth

Table 4.16(b): Morphological analysis of microplastics from Dhanmondi Lake in Summer

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
4.75 mm > x > 2.36 mm	60.4 (62)	Mostly irregular, some triangle, and rectangle	Red, White, Blue, Silver, Black, Golden, Magenta, Green, Transparent	Mostly smooth, some rough
2.36 mm > x > 1.18 mm	32.6 (104)	Mostly irregular, some triangle, and rectangle	Red, White, Blue, Silver, Black, Golden, Magenta, Green, Transparent	Mostly smooth, some rough

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
1.18 mm > x > 0.60 mm	6.13 (236)	Mostly irregular, some triangle, rectangle, and round	Red, White, Blue, Silver, Black, Golden, Magenta, Green, Transparent	Mostly rough, some smooth
0.60 mm > x > 0.30 mm	0.85 (136)	Mostly irregular, some triangle, rectangle, and fiber like shape	Red, White, Blue, Silver, Golden, Green, Transparent	Mostly smooth, some rough

Morphology of Microplastics from Ramna Lake

Table 4.17(a) and Table 4.17(b) show results of morphological analysis of microplastics isolated from samples collected from Ramna Lake (location S2) in Winter (November, 2018) and Summer (March, 2019), respectively. Table 4.17(a) shows that most of the microplastics, both the larger and smaller sizes, are irregular in shape and mostly have rough surface; this probably suggests (as explained above) that these have been introduced in the environment long time ago. Also, the particles with brownish or off-white colour and rough surface probably suggest long residence time in water. Microplastics isolated from sample collected in Summer also show similar characteristics with respect to shape [Table 4.17(b)], most of the microplastics were irregular in shape.

Table 4.17(a): Morphological analysis of microplastics from Ramna Lake in Winter

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
4.75 mm > x > 2.36 mm	34.3 (22)	Mostly irregular, some rectangle and fiber like shape	White, Brown, Green, Transparent	Mostly rough, some smooth
2.36 mm > x > 1.18 mm	36.4 (52)	Irregular in Shape	White, Blue	Mostly rough, some smooth
1.18 mm > x > 0.60 mm	24.5 (117)	Mostly irregular, some rectangle	Red, White, Blue, Silver, Black, Pink, Off-white, Green, Transparent	Mostly rough, some smooth
0.60 mm > x > 0.30 mm	4.76 (145)	Mostly irregular, some rectangle, triangle and round	Red, White, Blue, Silver, Black, Brown, Green, Transparent	Mostly rough, some smooth

Table 4.17(b): Morphological analysis of microplastics from Ramna Lake in Summer

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
4.75 mm > x > 2.36 mm	9.83 (15)	Mostly irregular, some triangle	Blue, Brown, Orange, Transparent	Mostly rough, some smooth
2.36 mm > x > 1.18 mm	81.2 (77)	Mostly irregular, some triangle and rectangle,	Red, Green, Blue, Silver, Indigo, Ash, Brown, Orange, Transparent, White	Mostly rough, some smooth
1.18 mm > x > 0.60 mm	8.32 (76)	Mostly irregular, some triangle and rectangle	Red, Blue, Sky blue, Yellow, Orange, Ash, Silver, White	Mostly rough, some smooth
0.60 mm > x > 0.30 mm	0.60 (25)	Mostly irregular, some triangle, rectangle, and round	Red, Green, Blue, Silver, Indigo, Pink, Black, Off-white, Sky-Blue, Brown, Orange, Light green,	Smooth

Morphology of Microplastics from Hatirjheel

Table 4.18(a) and Table 4.18(b) show results of morphological analysis of microplastics isolated from samples collected from Hatirjheel (location S3) in Winter (December, 2018) and Summer (March, 2019), respectively. Table 4.18(a) shows that most of the microplastics are irregular in shape and mostly have rough surface; this probably suggests (as explained above) that these have been introduced in the environment long time ago. Also, most of the particles here are with brownish or off-white colour and rough surface that probably suggest environmental weathering and long residence time in water. Microplastics isolated from sample collected in Summer also show similar characteristics with respect to shape [Table 4.18(b)], most of the microplastics were irregular in shape.

Table 4.18(a): Morphological analysis of microplastics from Hatirjheel in Winter

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
4.75 mm > x > 2.36 mm	43.2 (72)	Mostly irregular, some rectangle, fiber like and cylinder like, shape	Red, White, Blue, Green, Transparent	Mostly rough, some smooth
2.36 mm > x > 1.18 mm	46.5 (189)	Mostly irregular, some triangle and rectangle,	Red, White, Blue, Green, Brown, Black, Transparent	Mostly rough, some smooth
1.18 mm > x > 0.60 mm	8.82 (253)	Mostly irregular, some triangle, and fiber like shape	Red, Green, Silver, Black, White, Brown, Transparent	Mostly rough, some smooth
0.60 mm > x > 0.30 mm	1.43 (125)	Mostly irregular, some rectangle and fiber like shape	White, Black, Brown, Green, Orange, Light Green, Transparent	Mostly rough, some smooth

Table 4.18(b): Morphological analysis of microplastics from Hatirjheel in Summer

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
4.75 mm > x > 2.36 mm	69.2 (12)	Mostly irregular, some rectangle	Ash, Transparent	Mostly rough, some smooth
2.36 mm > x > 1.18 mm	22.4 (11)	Mostly irregular, some rectangle, triangle, and fiber like shape	White, Blue, Green	Mostly rough, some smooth
1.18 mm > x > 0.60 mm	7.63 (19)	Mostly irregular, some rectangle and triangle	Red, White, Brown, Green, Transparent	Mostly rough, some smooth
0.60 mm > x > 0.30 mm	0.82 (33)	Mostly irregular, some round	Red, Pink, Blue, Off-White	Smooth

Morphology of Microplastics from Buriganga River

Table 4.19(a) and Table 4.19(b) shows results of morphological analysis of microplastics isolated from samples collected from Buriganga River (location S4) in Winter (December, 2018) and Summer (March, 2019), respectively. Table 4.19(a) shows that some of the microplastics, particularly in the larger size range, are irregular in shape with sharp edge; this probably suggests (as explained above) that these have been introduced in the environment recently. But most of the microplastics are irregular in shape with rough surface; this probably suggests (as explained above) that these have been introduced in the environment long time

ago. The particles with brown or off-white colour also probably indicate long residence time in water. Also, most of the particles here are colourful; that probably suggest diverse sources of microplastics. Microplastics isolated from sample collected in Summer also show similar characteristics with respect to shape [Table 4.19(b)], most of the microplastics were irregular in shape.

Table 4.19(a): Morphological analysis of microplastics from Buriganga River in Winter

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
4.75 mm > x > 2.36 mm	58.1 (75)	Mostly irregular, some rectangle	Red, Green, Blue, Pink, Black, Off-white, Brown, Orange, Light green, Transparent, White	Mostly rough, some smooth
2.36 mm > x > 1.18 mm	30.7 (228)	Mostly irregular, some rectangle	Red, Green, Blue, Silver, Indigo, Pink, Black, Off-white, Ash, Brown, Orange, Light green, Transparent, White	Mostly rough, some smooth
1.18 mm > x > 0.60 mm	9.92 (368)	Mostly irregular, some rectangle and triangle	Red, Green, Blue, Yellow, Indigo, Pink, Black, Off-white, Ash, Brown, Orange, Light green, Transparent, White	Mostly rough, some smooth
0.60 mm > x > 0.30 mm	1.27 (300)	Mostly irregular, some rectangle	Red, Green, Blue, Silver, Indigo, Pink, Black, Off-white, Sky-Blue, Brown, Orange, Light green,	Mostly rough, some smooth

Table 4.19(b): Morphological analysis of microplastics from Buriganga River in Summer

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
4.75 mm > x > 2.36 mm	67.0 (127)	Mostly irregular, some triangle, rectangle, cylindrical and round	Red, White, Blue, Indigo, Sky blue, Light green, Green, Ash, Silver, Yellow, Violet, Brown, Magenta, Transparent	Mostly rough, some smooth
2.36 mm > x > 1.18 mm	27.8 (172)	Mostly irregular, some triangle and rectangle	Red, White, Silver, Green, Ash, Grey, Indigo, Light green, Transparent	Mostly rough, some smooth
1.18 mm > x > 0.60 mm	4.97 (221)	Mostly irregular, some triangle, rectangle, and fiber like shape	Red, White, Blue, Indigo, Pink, Light green, Green, Orange, Ash, Silver, Black,	Mostly rough, some smooth

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
			Yellow, Brown, Transparent	
0.60 mm > x > 0.30 mm	0.23 (156)	Mostly irregular, some triangle, and fiber like shape	Red, White, Blue, Green, Brown	Mostly rough, some smooth

Morphology of Microplastics from Turag River

Table 4.20(a) and Table 4.20(b) shows results of morphological analysis of microplastics isolated from samples collected from Turag River (location S5) in Winter (December, 2018) and Summer (July, 2019), respectively. Table 4.20(a) shows that most of the microplastics are irregular in shape with smooth edge; this probably suggests (as explained above) that these have been introduced in the environment long time ago. Also, most of the particles are with brown or off-white colour also probably indicate long residence time in water. Microplastics isolated from the sample collected in Summer also show almost similar characteristics with respect to shape [Table 4.20(b)], most of the microplastics were irregular in shape and off-white or brown in colour. However, the microplastics in the size range 0.60 to 1.18 mm were different; most of these microplastics were fiber like and green in color that probably came the broken parts (due to environmental weathering) of plastic ropes.

Table 4.20(a): Morphological analysis of microplastics from Turag River in Winter

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
4.75 mm > x > 2.36 mm	11.4 (11)	Mostly irregular, some round	Blue, Red, White, Off-white, Brown, Transparent	Mostly smooth, some rough
2.36 mm > x > 1.18 mm	51.1 (133)	Mostly irregular, some round	Red, White, Blue, Off-white, Black	Mostly rough, some smooth
1.18 mm > x > 0.60 mm	33.8 (540)	Mostly irregular, some round and triangle	Blue, Red, Pink, White, Silver, Black, Indigo, Off-White, Green, Transparent	Mostly rough, some smooth
0.60 mm > x > 0.30 mm	3.71 (476)	Mostly irregular, some round triangle and fiber like shape	Black, Red, Silver, Green, Light Green, Transparent	Mostly rough, some smooth

Table 4.20(b): Morphological analysis of microplastics from Turag River in Summer

Microplastics Size Range	% by Weight (Item No.)	Microplastics Shape	Microplastics Color	Microplastics Texture
4.75 mm > x > 2.36 mm	6.10 (52)	Mostly irregular, some round and rectangle	Green, Off-white, Transparent	Mostly rough, some smooth
2.36 mm > x > 1.18 mm	7.53 (164)	Mostly irregular, some fiber like shape	Blue, Green, Off-white, Transparent	Mostly rough, some smooth
1.18 mm > x > 0.60 mm	81.7 (1556)	Mostly fiber like, some rectangle and round	Light Green, Green, Off-white, Transparent	Mostly rough, some smooth
0.60 mm > x > 0.30 mm	4.69 (1495)	Mostly irregular, some rectangle and fiber like shape	Light Green, Green, Brown, Silver, White, Off-white, Transparent	Mostly rough, some smooth

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Plastic and microplastics pollution have become a major concern in recent times. The objective of this research was to assess occurrence of microplastics and determine their quantity in five selected water bodies in and surrounding Dhaka city. Another major objective was to characterize the microplastics from the water bodies through microscopic inspection, fractionation (through sieve analysis) and morphological analysis. As a part of this study, a method has been developed for the quantification of microplastics in the laboratory. In this study, samples were collected from specific sampling points in five different water bodies during both Winter and Summer. The samples were processed for identification of microplastics and the isolated microplastics were subsequently quantified and analyzed for characterization. This Chapter presents the major conclusions from the study; it also presents the limitations of the study and recommendation for future studies.

5.2 Conclusions

Major conclusions from this study are summarized below:

- (1) Microplastics have been detected at the sampling locations of all 5 water bodies covered in this study in both Winter (November-December) and Summer (March-July).
- (2) Except for Hatirjheel, the quantity of microplastics (as % of total solids) at the sampling locations increased in Summer (March-July) compared to Winter (November-December).
- (3) In both Summer and Winter, the quantities of microplastics (as % of total solids) in the inland water bodies (Dhanmondi Lake and Ramna Lake) have been found to be relatively low, compared to those found in the two peripheral rivers – Buriganga and Turag. The quantity of microplastics (as % of total solids) varied from 0.44% for the Dhanmondi Lake sampling point in Winter to 22.6% for the Turag River sampling point in Summer.
- (4) The quantity (weight, number) and characteristics (size, morphology) of microplastics at a particular sampling location varied in Winter and Summer; a number of factors appear to be responsible for this variation that include weather condition (presence or absence of

rainfall/runoff), visitors around the waterbody, and discharge of industrial/domestic sewage.

- (5) Size fractionation of microplastics suggest that larger particles (in the size range of 1.18 mm to 4.75 mm) accounts for major fraction (in term of weight) of microplastics. On the other hand, the smaller size fractions account for majority of items of microplastics. However, microplastics from Turag River was an exception; here smaller microplastics (less than 1.18 mm in size) accounted for major fraction of microplastics both in terms of weight and number.
- (6) Morphological analysis suggests most of the microplastics identified in this study are irregular in shape with rough surface; this probably suggests that these have been introduced in the environment long time ago. However, microplastics with larger size and sharp/irregular edges were identified particularly in Dhanmondi Lake and Buriganga River, suggesting that these have been introduced in the respective water bodies relatively recently.

5.3 Limitations of the Study

In this study, sampling for identification of microplastics was carried out at a specific location in each of the five selected water bodies. However, due to unavailability of suitable water vessels, sampling could not be carried out over a wider area of the water body. This limitation should be addressed in future studies.

In this study, efforts were made to determine chemical composition (e.g., whether these are polyethylene, polypropylene, polystyrene, or polyvinyl chloride) of the isolated microplastics using IR or any other techniques available in local laboratories. Unfortunately, no suitable laboratory could be identified (within and outside BUET) with equipment and expertise for the determination of chemical composition of microplastics. Therefore, it was not possible to determine chemical composition of microplastics in this study.

5.4 Recommendations for Future Research

The following recommendations are made for future study:

- (1) Efforts should be made to collect representative samples (for analysis of microplastics) covering wider areas of water body in order to better quantify microplastics in water bodies.

- (2) Efforts should be made to determine chemical composition of microplastics for better understanding of their origin.
- (3) Efforts should be made to assess possible impacts of microplastics, especially on aquatic ecosystem (e.g., impact on fish species).
- (4) More studies should be carried out for identification and quantification of microplastics in water bodies in and around Dhaka city, and their impact on environment and ecosystem.

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