EVALUATION OF MICROPLASTICS IN BEACH SEDIMENTS ALONG THE COAST OF DUBAI, U.A.E

by

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Abstract

The unprecedented increase in consumption in conjunction with poor management of plastic waste have resulted in global contamination of both terrestrial and marine environments. Plastic debris undergoes fragmentation, resulting in the formation of microplastics, a synthetic polymers less than 5 mm in size. Significant amounts of microplastics have been globally observed in beach sediments. However, no studies have addressed microplastic contamination of marine sediments and/or coastal water in the United Arab Emirates. In this study, microplastic contamination in beach sediments of sixteen beaches along the Arabian Gulf coast in Dubai have been studied. Five samples of beach sediment were collected approximately from 1 cm below the surface from each beach along a 100 m stretch using a 0.5 m by 0.5 m, steel quadrant along the wrack lines. Density separation was used to extract microplastics from the sediment samples. The number of pieces of microplastics were identified under a 40X dissecting microscope and categorized by color and shape. Furthermore, microplastics polymer types were identified through FT-IR analysis. The results showed that the average weight of microplastic is 0.33 mg. g^{-1} of sediment (or 953 mg.m^{-2}) and the number of microplastic is 59.71 items.kg^{-1} of sediment (or 165 items.m^{-2}) in the study area. A total of 3366 pieces of microplastic were found in the 80 samples with 10 different colors; blue, red, green, yellow, black, white, grey, orange, pink, and transparent. The analysis showed that blue microplastics are more abundant in terms of numbers, while white ones are most abundant in terms of the number of microplastics per square meter (items.m^{-2}) and number of microplastics per kg dry weight of sediment (items.kg^{-1}). Furthermore, four shapes of microplastics were identified including fiber (most dominant), string, pieces, and polystyrene spheres. FT-IR analysis was conducted to identify the polymer type of fibers and strings that were large enough to handle using forceps which were 1396 microplastics. 63.67% of the samples were identified to be polyethylene and 32.94% were found to be polypropylene. XRF analysis identified 14 heavy metals on the extracted microplastics including Cr, Ni, Cu, Zn, and Pb, which are classified as priority pollutants by EPA.

Keywords: ***Microplastic Contamination; Beach Sediments; Wrack lines; FT-IR,* X-ray fluorescence*; Heavy Metals.***

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List of Abbreviations

EPA	Environmental Protection Agency
FT-IR	Fourier Transform Infrared
GPS	Global Positioning System
HDPE	High-density polyethylene
PE	Polyethylene
PP	polypropylene
WWTP	Wastewater Treatment Plant
XRF	X-ray fluorescence
KI	Potassium Iodide

Chapter 1. Introduction

This chapter introduces plastic as a key pollutant of terrestrial, fresh water, and marine environments. Additionally, it characterizes plastic pollutants and focuses on microplastics. The chapter also presents the objectives of this study and the research contribution. Finally, the general organization of the thesis is presented.

1.1. Overview

Plastic has gained immense popularity in various industries owing to it's lightweight, corrosion resistance, strength and cost-effective attributes [1]. Plastic has been used in products related to packaging, construction, and transportation industries. In addition, plastic is being used in the manufacturing of medical equipment, electrical appliances, and industrial machinery [2]. Despite the increasing use of plastic in various industries, the lifetime of plastic products in most industries is short. On fulfilment of the product usage time, plastic products are deemed as waste and require disposal. The common methods of plastic waste management are recycling, incineration or disposal in landfills [3]. From 1950 to 2015, 6300 million metric tons of plastic waste has been generated. 12% of this waste has been incinerated and only 9% is recycled. Consequently, 4900 million metric tons of plastic waste have been dumped in landfills, or are thriving and contaminating our precious ecosystems [2]. Additionally, due to its slow degradation rate and light weight, inadequately disposed plastics are transported by wind and water to various terrestrial, fresh water bodies, and even marine environments. Human activities surrounding the beaches also increases the plastic contamination in marine environments.

The unprecedented amount of plastic debris in marine environments is a matter of great concern to researchers all over the world. Research suggests that about 270,000 tons of plastic debris are floating in water bodies throughout the globe [4]. More plastic wastes are estimated to be present in ocean beds, beaches, and in marine biota in various sizes [5]. Furthermore, plastic debris exists in various sizes in marine environments. There are four categories of plastic debris, based on size, that include macroplastics, mesoplastics, microplastics, and nanoplastics (Table 1.1). Microplastics comprise of plastic debris which are either microscopic or visible to naked eyes. On the contrary, nanoplatics are microscopic and are not visible to the naked eye.

Table 1.1: Classification of plastic debris based on size [6]

Class	Size Ranges	Visualization
Macroplastics	>2.5 cm	Naked eye
Mesoplastics	0.5 cm - 2.5 cm	Naked eye or optical microscope
Microplastics	0.5 cm - 1 μm	Optical microscope
Nanoplastics	<1 μm	Electron microscope

The presence of macroplastics in marine environments has caused various environmental issues and economic repercussions. The presence of macroplastic debris in marine environments degrades the aesthetic value, and thus negatively affects tourism. Furthermore, shipping and fishing are adversely effected as macroplastics have been documented to get trapped in the machinery used in these industries, causing delays and resulting in monetary losses [7], [8]. Furthermore, the presence of macroplastics in marine environment has resulted in injuries and even death among marine fauna. Various cases have been reported in which marine fauna such as sea turtles, marine birds and fishes have suffered serious injuries and/or death due to entanglement and/or ingestion of macroplastics [9], [10]. Studies have also reported that foreign species are transported to new habitats on macroplastics. This presents serious environmental threat as the introduction of foreign species to a new ecosystem has the potential to disrupt the natural processes in the ecosystem, and thus harm the ecosystem [11]. In recent years, smaller plastic pollutants, microplastics, have gained immense interests in the research community.

Microplastics are defined as synthetic polymers with sizes ranging 1 μm to 5mm [12], [13]. In the literature, microplastics are commonly categorized as primary and secondary based on their origin, with the majority being secondary [14]. Primary microplastics are manufactured with size less than 5mm. Primary microplastic are found in skin care products as microbeads, textiles and medicines [15]. Secondary microplastic, on the other hand, are formed through the disintegration of larger plastics (macro- and meso- plastics). This disintegration can occur due to various processes such as solar UV-induced photo-degradation, thermal reactions, hydrolysis or microbial biodegradation [16]. Research suggests that the majority of microplastics thriving in our environment are secondary in nature [14]. The Commonly found composition of microplastic are polyethylene, polypropylene and polystyrene [17]. Lower quantities of microplastics are composed of polyamide (nylon), polyester, acrylic, polyoximethylene, polyvinyl alcohol, polyvinylchloride and poly methylacrylate [17].

Due to their small size, microplastics have the potential to be ingested by organisms from various levels of the food chain. Owing to the composition of plastics, toxic plasticizers could be leached. Therefore, indirect consumption of microplastics by organisms might be a factor causing the introduction and accumulation of toxins in the food chain [13]. Microplastic contamination has been reported in agricultural lands, landfills, drinking water and in wastewater effluents. These contaminants from terrestrial sources are transported to water bodies through run-off or overflow of water and eventually reach marine environments. Consequently, microplastics have been found in beach sediments and marine waters throughout the globe. However, there is no study documenting the microplastic contamination level in beach sediments along the coast of Dubai. Hence, it is logical to hypothesize that beaches along the coast of Dubai will be contaminated with microplastics. Hence, this research aims at detecting the occurrence, distribution, physical attributes, and polymer type of microplastic contamination in beach sediments along the coast of Dubai.

The presence of microplastics in marine environments pose a significant treat to marine fauna and flora, and humans through four mechanisms highlighted in academic literature [18], [19]. Firstly, on ingestion, direct toxicity of the plastic particles can cause oxidative stress, cell damage, inflammation, and impairment of energy allocation functions. Secondly, plastics constituent of toxic chemical which include heat stabilizers, UV stabilizers, and plasticizers, processing aids, impact modifiers, thermal modifiers fillers, flame retardants, biocides and smoke suppressors. Exposure to plastic would cause indirect exposure to these toxic chemicals. Thirdly, plastic debris act as pathogen and parasite vectors. Hence, human exposure to these microplastics could increase risk of infection. Lastly, resent studies have highlighted that microplastics act as sorption sites for priority pollutants, heavy metals [20], [21] Hence, microplastics not only pollute marine environments but also result in the introduction and accumulation toxic metals in these ecosystems [22]. Based on these studies, it would be rational to hypothesize that hazardous metals are present in primary and secondary microplastics. Hence, this study examines the presence of heavy metals in primary and secondary microplastics retrieved from the 16 sampled beaches in

Dubai. This study will add to the narrow body of literature on presence of heavy metals in microplastics found in beach sediments.

1.2. Thesis Objectives

The primary goal of this study is to study the levels of microplastic contamination in the marine sediments of the beaches in Dubai. The study aims to fill the gap in literature on the plastic pollution in Dubai.

The specific objectives of this study are as follows:

- Determine the levels of microplastics in beach sediments in Dubai
- Characterize the identified microplastics based on color, shape, and polymer type
- Analyse the samples for the presence of heavy metal on the extracted microplastics

1.3. Research Contribution

The contributions of this research can be summarized as follows:

- Narrow the gap in academic literature by studying microplastic contamination in marine sediments in the Dubai beaches. As there are no previous studies on plastic pollution in marine environment in Dubai, this study makes a major contribution to the existing knowledge of microplastic contamination Determining the extent of microplastics contaminations in beach sediments will help understand the extent of microplastics contamination in the beaches of Dubai. Furthermore, an understanding of the extent of microplastics contaminations will help in formulating strategies to manage and, in the long term, mitigate the contamination of microplastic
- Identification of beaches contaminated by types of microplastics which pose a threat to marine fauna. Physical attributes of microplastics constitute an important factor when considering ingestion by marine fauna. Certain microplastics' shape and color have been suggested to make them more enticing to marine fauna due resemblance to their food [23]–[26]. Zooplanktons, fish, sea turtles, seals and other marine fauna have been reported to ingest microplastics which are fibrous in shape and have blue, white, yellow and black

coloration [23], [27], [28]. Additionally, the negative impact on marine fauna in areas related to ingestion of microplastics has been documented [29]. Hence, identification of the beaches contaminated by microplastics which are more likely to be ingested by marine fauna is a significant step towards the evaluation of potential problems with the beaches contaminated by microplastics in Dubai. Such information could prove to be vital to stakeholders to identify the source of this microplastics, and formulate mitigation measures in order to safeguard the marine fauna and the environment.

- Bridge the gap in literature by documenting the presence of heavy metals in microplastics found in beach sediments. The interaction between metals and plastic has been ignored due to the fact that plastic is considered inert to metallic ions. However, few studies have reported that microplastics found in marine sediments adsorb heavy metals. Hence, this study adds to existing, narrow body of research and help to advance knowledge in heavy metal contamination associated with microplastic in marine environments.

1.4. Thesis Organization

The present thesis is divided into five, organized chapters. Following this introductory section (Chapter 1), Chapter 2 introduces the common sources of microplastics. It reviews the literature that presents microplastic contamination in marine environments and evaluates the negative impact of such contamination on marine and terrestrial fauna, flora, and humans. Furthermore, the chapter presents research on adsorption of heavy metals by microplastics in marine environments. Chapter 3 presents the study area, sampling locations, sampling procedure, laboratory experiments for the extraction of microplastic, microscopic identification procedure of microplastic, FT-IR analysis procedure, and heavy metal identification process. Subsequently, Chapter 4 presents analysis of the results of different experiments carried out on the samples including measured quantities of microplastic contamination, coloration, shape, polymer type, and heavy metals adsorbed on extracted microplastics. Chapter 5 presents the conclusion of this research.

Chapter 2. Background and Literature Review

This chapter provides a detailed review of the sources of microplastics and further assesses the microplastic contamination in terrestrial ecosystems, specifically in beach sediments. Furthermore, it explains the negative impact of microplastic contamination on marine fauna. Finally, it reviews the adsorption of heavy metals and traces such metals in marine settings.

2.1. Sources of Microplastics

In literature, microplastics are usually classified into two types, primary or secondary, depending on their origin [14]. Primary microplastics are those produced having size under 5 mm. Contradictorily, secondary microplastics are formed through fragmentation of bigger plastics.

2.1.1. Primary microplastics. Primary microplastics have found their application in various products and industries. Some of the common uses of products with primary microplastics are as follows:

- Micro-beads have been used in facial cleansers to exfoliate the skin more effectively in comparison to the traditional exfoliators such as sugar, oatmeal and almonds [9], [30]. The size of these primary microplastics depends on the purpose of the final product they are used in. Literature suggests that the sizes of microplastics found in cosmetic products range from less than 5mm to as small as less than 0.1mm in some products.
- Microplastics have been increasingly manufactured for use as scrubbers for the removal of rust and paint [9], [31]
- Primary microplastics have been increasingly used as a vector for drugs in pharmaceutical industries [32]
- Virgin Plastic pellets and other plastic products such as plastic beads are used to make jewelry that have size less than 5mm are classified as primary microplastics.

2.1.2. Secondary microplastics. Secondary microplastics or daughter microplastics, come into existence due to the fragmentation of larger plastic debris [33]. This fragmentation is the result of the collective effects of physical, biological and chemical processes that cause loss of structural integrity of plastic (i.e. macroplastic) debris [34]. Prolonged exposure to solar ultraviolent (UV) radiation is the most significant mechanism which leads to the rapid fragmentation and degradation of plastic waste. Although fragmentation does occur in floating plastic debris in marine waters, the process is very slow, and hence, it can be concluded that the lowest rate of fragmentation takes place in marine water [35]. Rapid degradation of plastics, however, occurs in the coastal zones due to the exposure to UV radiation, high temperatures and high oxygen availability. Literature suggests that the majority of the microplactics found in the environment originate from secondary sources [14]. Studies have shown that direct pollution of microplastics in marine waters only contributes 20% of the plastic pollutants found in ocean waters [35]. Consequently, 80% of the microplastics contaminants in ocean waters originate from terrestrial sources.

Some common sources of secondary microplastics are as follows:

- Fragmentation of plastic debris discarded in the environment such as fishing nets, house hold items and other plastic waste [36] .
- Waste from laundry of synthetic fabrics. The composition of the plastic fibres produced during the process of washing clothes are mainly polyester, acrylic, and polyamide [37]. It is evident that microplastics' contamination in the effluents of laundries can reach 100 fibers per litre [38].
- Degradation of agricultural mulch films. Agricultural mulch films are used to cover agricultural lands to prevent weed growth and maintain stable soil temperature [39]. However, the improper disposal of these plastics, and degradation in harsh climatic conditions results in fragmentation and the formation of microplastics. [40].

2.2. Assessment of Microplastic Contamination

There is no specific concentration of microplastics in the literature at which a sample is considered polluted. Nonetheless, the presence of microplastics is generally undesirable. Hence, any level of concentration of microplastics in a sample is considered to be the contaminated by microplastics.

2.2.1. Microplastic contamination in terrestrial systems. Microplastic pollution was identified in many terrestrial systems including fresh- and salt- water bodies, drinking water networks, and releases water from wastewater treatment plants

(WWTPs). A recent study conducted in Europe, discovered 1000 - 4000 particles of microplastic per kg of dry mass sludge in landfill [41]. The existence of microplastics has additionally been accounted for in agricultural fields [41]. Furthermore, microplastic contamination was reported in drinking water. Orb Media, a non-profit organization, carried out experiments on drinking water samples from five continents and found that 83% of the drinking water samples were polluted by microplastics (Orb, 2017). Similarly, studies have demonstrated that 8 billion microbeads are discharged from WWTPs [42], which suggests that wastewater treatment plants do not treat for microplastics pollution. Moreover, WWTPs effluents are usually released into water bodies or reused for irrigation. This results in polluting these water systems and cultivatable grounds.

2.2.2. Microplastic contamination in marine systems. One of the disturbing concerns of the occurrence of microplastics in soil, portable and WWTP's effluents, is that microplastics are transported to fresh water systems through direct release or run-off, and eventually reach the marine environments [42].

Table 2.1: Overview of studies that have determined the concentration of microplastics in beach sediments and marine waters.

Microplastic found in Beach Sediments			**Microplastic found in Marine Water**		
Location	Abundance (iterms.kg^{-1} d.w)	Source	**Location**	Abundance (items.m^2)	**Source**
Russia	1.3–36.3	[45]	**Black Sea Waters**	600 -1200	[46]
Switzerland	0.3–90	[47]	**Northeast Pacific**	0.004 -0.19	[48]
Italy	112 and 234	[49]	**East Asian Sea**	3.7 ± 10.4	[50]
Belgium	92.8	[51]	**Southern California offshore**	3.92	[52]
United Kingdom	8	[53]	**Northeast Atlantic (Celtic sea)**	2.46	[54]
Romania	1000–5500	[55]	**Artic Polar Waters**	0.34 ± 0.31	[43]
Portugal	0.7–11	[56]	**Bohai Sea of China**	0.33 ± 0.36	[57]

Items = Number of microplastics; d.w. = dry weight of sediment

Research suggests that roughly 80% of the plastic debris found in marine condition originates from land-based sources [35]. Nonetheless, plastic can directly enter the marine ecosystems because of seaside tourism, recreational and commercial fishing activities [15]. Such plastic debris experiences fragmentations and exists as microplastics in marine ecosystems. Once they reach coastal waters, microplastics are transported by oceanic currents throughout the globe, where they prevail and accumulate. Consequently, microplastics are reported in remote areas such as polar regions that are far from sources of contamination [43]. Moreover, high density microplastics sink to the ocean bed where the absence of solar radiation leads to slower degradation. Hence, these microplastics prevail and pollute marine environments for longer durations [29], [44]. Microplastics have been found in beach sediments and costal environments. Table 2.1 gives a summary of few studies, showing the presence of microplastics in beach sediments and coastal waters.

2.3. Microplastics and Marine Fauna and Flora

Presence of microplastics in marine environments is known to have a negative impact on the fauna and flora thriving in these ecosystems. Microplastics can directly harm marine fauna on both physical and molecular levels by ingestion, entanglement, and suffocation [29]. Marine species have been found to be entangled in microplastic debris, mainly fishing gear, and are unable to escape. Some of the marine species documented to be affected by plastic entanglement include turtles, penguins, whales, dolphins, sharks, seals, sea lions, sea otters and fish [58]. The negative impacts of plastic entanglement on marine species are drowning, physical injuries, starvation, and possibly death.

Figure 2.1 2.1 depicts the death of a sea bird due to entanglement in microplastics (fishing gear).

Figure 2.1: Entanglement of seabird in microplastics [59]

Microplastics present in the marine waters have also been reported to be ingested by organisms from all trophic levels, ranging from microscopic organisms such as zooplankton taxa to large mammals such as sea turtles, sealions, seals and whales [9], [60]–[62]. Figure 2.2 shows the plastic debris recovered from loggerhead sea turtles. Additionally, higher density microplastics tend to sink to ocean beds. These have been reported to be ingested by benthic species which include oysters, blue mussels, barnacles and lobsters [63]. The negative impacts of ingestion of plastic include internal wounds, blocked digestive tracks, reduced food consumption, reduced reproductive capacity, drowning, limited predator avoidance, reduced quality of life, and vulnerability to diseases [64].

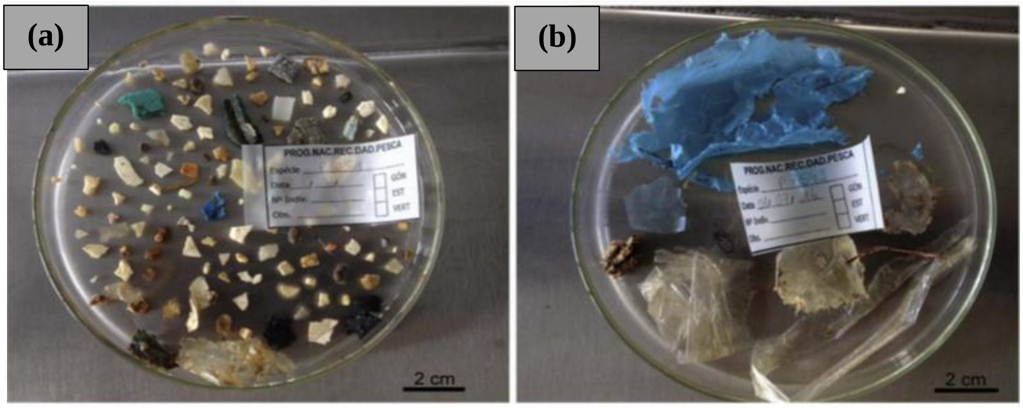


Figure 2.2: Plastic debris recovered from loggerhead sea turtles; (a) Microplastics in the intestine (b) Plastic sheets in the intestine [65]

Research also suggests that tertiary predators such as seabirds indirectly consume microplastics when they consume fish who have ingested microplastics [66], [67] Consequently, the presence of microplastics in the food chain has been documented to negatively impact marine fauna. Studies have found a positive relationship between reduced food consumption and feed of plastics in birds [68]. Hence, the presence of microplastics in marine water not only affects organisms but also indirectly, negatively affects tertiary organisms. Additionally, plastic debris has been identified in commercially sold seafood for human consumption [20]. Hence, fish consumption has been suggested to be an indirect source of microplastic consumption by humans.

In addition to marine fauna being negatively impacted by microplastic contamination, marine corals have also been harmed. Corals are a vital part of the marine ecosystem as they provide a living habitat to numerous fish species and other organisms [69]. The diet of corals includes phytoplankton, zooplankton and other small organisms, which have been identified to ingest microplastics. Hence, corals indirectly ingest microplastics which have been bioaccumulated in their food [70]. Furthermore, corals have also been reported to ingest microplastics, which resemble their prey. A research conducted in the Great Barrier Reef in Australia found out that corals ingested microplastics that affected the coral gut cavity; the research also concluded that microplastics constituted one of the factors which proved to be detrimental to corals' health [71]. The microplastic particle found in the corals is shown in Figure 2.3.

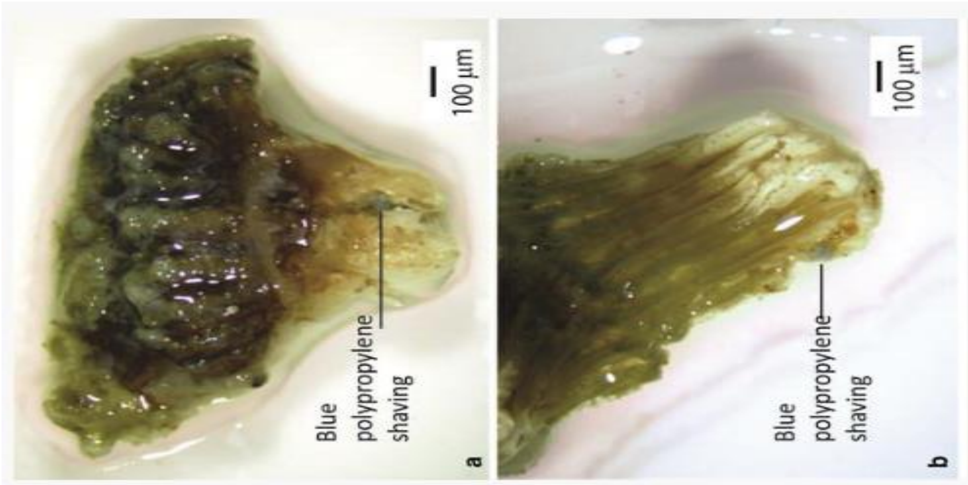


Figure 2.3: Microplastics present in the mouth and mesenteries of corals [71]

2.4. Adsorption of Heavy Metals on Microplastics

Presence of heavy metals in marine environments is expected [72]; However, their concentrations have increased at an alarming rate due to expansive growth in population, and urbanization as well as industrialization along coastal zones [73], [74]. Heavy metals are defined as metals which exhibit a specific density greater than 5 $g.cm^{-3}$ [75]. These metals include Copper (Cu), Cobalt (Co), Chromium (Cr), Cadmium (Cd), Iron (Fe), Zinc (Zn), Lead (Pb), Tin (Sn), Mercury (Hg), Manganese (Mn), Nickel (Ni), Molybdenum (Mo), Vanadium (V), Tungsten (W). Titanium (Ti), Nickel (Ni), Cerium (Ce), Pr (Praseodymium), Nd (Neodymium), and Palladium (Pd).

Heavy metals are essential to living organisms in very low concentrations. However, exposure to high concentrations can be detrimental [76]. The natural factors causing the heavy metals pollution in marine environments are continental runoff and atmospheric deposition [77]. Additionally, land-based human activities such as mining, smelting, agriculture, and other anthropogenic sources caused by industrialization and urbanization also add to the heavy metal contamination in marine environments [77],

[78]. Research has recently revealed that metal pollution originates from metal based antifouling paints, industrial waste and fuel combustion [79]. Moreover, in order to slow down the biofouling process, antifouling paints containing copper-based pigments are applied to ship hulls and several other fixed structures [80]–[82] Deterioration and diffusion of such antifouling paints were found to be a major source of heavy metal contamination in marine environment. A significant body of research has shown that such heavy metals, available in marine environment, adsorb on plastic debris, particularly, microplastics.

The interaction between metals and plastic has been ignored due to the fact that plastic is considered inert to metallic ions. However, studies suggesting that metallic losses to plastic containers during sample storage contradict this property of plastic [83], [84]. The mechanism of interaction between metallic ions and plastic debris is yet to be explored in academic literature [82]. Nonetheless, literature suggests that the formation of biofilms on microplastics increases the adsorption of heavy metals in comparison to virgin microplastics [85]. Furthermore, the increased surface area, due to cracks on aged microplastics, provides more surface for adsorption [86]. A study conducted in England examined 924 microplastics which were sampled from 2 beaches to determine the presence of heavy metals [87]. The heavy metals considered in this study were cadmium, lead, and bromine. The study found Cadmium and lead were detected in 6.9% and 7.5% of all microplastics, respectively. Furthermore, bromine was detected in 10.4% of the samples. Another study found variable amounts of Cr, Co, Ni, Cu, Zn, Cd and Pb on plastic pellets sampled from beaches in England [85]. Hence, heavy metals have been reported to be adsorbed by microplastics.

Chapter 3. Methodology

This chapter explains the sampling and experimental methodology adopted in order to achieve the objectives of this study. The study area, sampling locations, sampling procedure, and laboratory procedures for the extraction of microplastics are discussed in this chapter.

3.1. Study Area

The study was conducted in the city of Dubai, United Arab Emirates. Dubai being a coastal city with a coastline extending up to 520 Km, encompasses beautiful beaches. Sixteen sandy beaches were studied based on their accessibility to determine the presence and concentration of microplastics along the coastline of Dubai. The sampled beaches and the locations are shown in Figure 3.1.

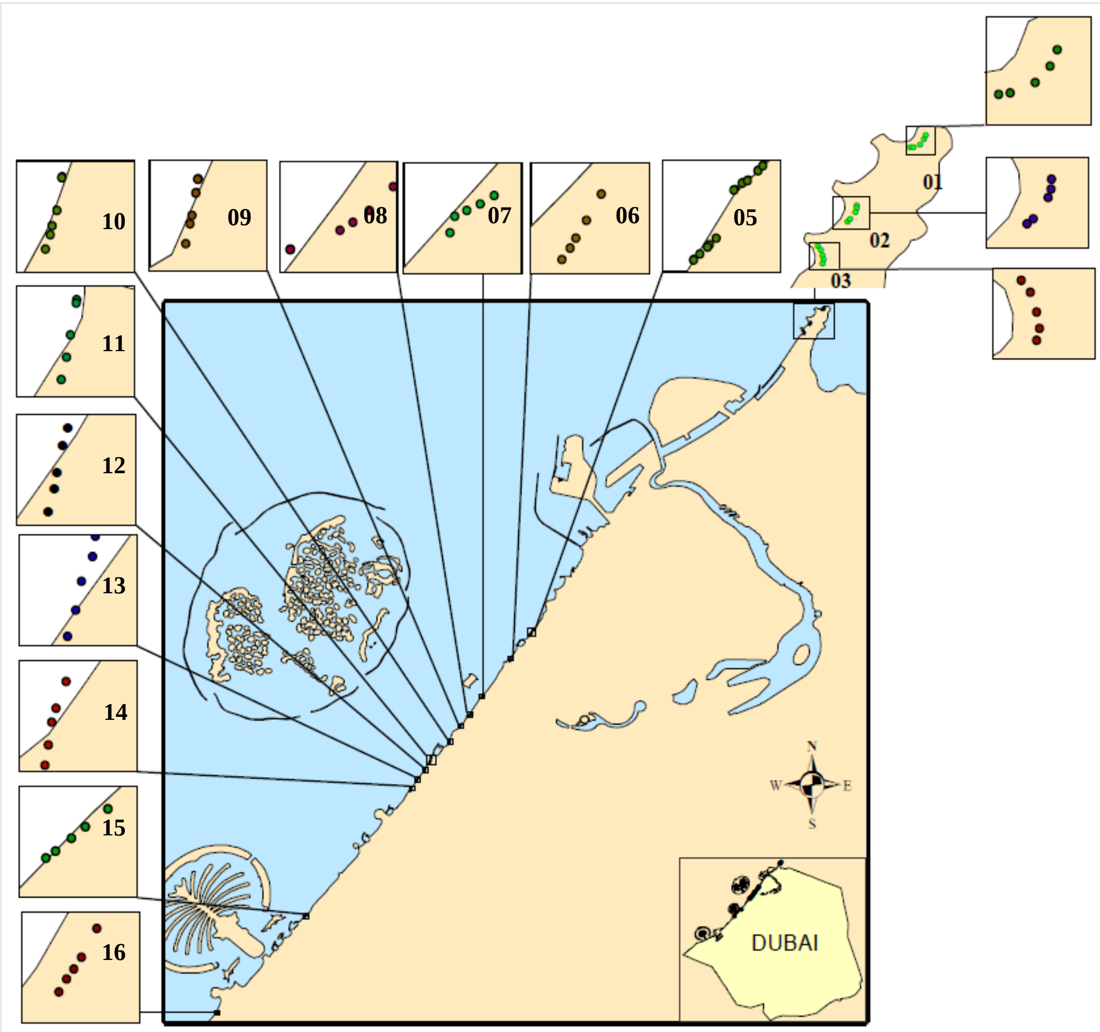


Figure 3.1: Locations map of study area and sampling locations

3.2. Sampling Method

The European Union's Marine Strategy Framework Directive (MSFD) suggests that 100 meters stretch on a beach is a practical sampling length to provide representative data for analysis [88]. However, the number of samples procured in this 100 m stretch determines the precision of the study. Academic research proposes that in order to have a confidence interval around the mean of 1 standard deviation, 3- 5 samples are required, depending on the targeted confidence interval [89]. Hence, taking this into consideration the cost and duration of the study, a sample size of 5 samples per 100m stretch was selected to reach one standard deviation at a confidence interval and a confidence level of 99%. The samples were collected using a 0.5m x 0.5 m, steel quadrant along the wrack lines (sometimes formed by several previous storms) (Figure 3.2) [45]. The majority of the samples were collected at this location as seaweeds and small shell fragments were found to accumulate at the wrack line, assuming that microplastics would concentrate at this location.

Figure 3.2: Sample collection along wrack lines

The dimension of the sampling quadrant was determined based on existing literature [56], [88], [90]–[92]. Approximately one cm of top wet sand samples were collected from the 0.25 m^2 quadrant using a clean stainless-steel spoon, and the sampling locations coordinates were recorded using an GPS device. Coordinates of the sampling locations are shown in the appendix section (Table A.). The sediment samples were placed in foil containers and were tightly sealed using stapler. The average dry weight of the samples was 751 grams. Plastic sampling equipment was strictly avoided to prevent plastic contamination of the samples. The samples were stored in a laboratory at room temperature before the extraction process of microplastics.

3.3. Microplastic Extraction Process

In the laboratory, the samples were emptied into metallic, oven safe bowls and oven dried at 60 °C for 48 hours. Research suggests a minimum drying time of 48 hours because samples take a minimum of 24 hours to dry. Hence, to ensure no variation among the samples, it is recommended that the samples get dried for 48 hours at 60 °C [89]. The dry weight of the samples was recorded before further testing. Consecutively, the samples were sieved using a 5mm sieve. The material retained in the sieve was discarded, and the material passing through the sieve was subjected to further analysis. Through visual inspection, microplastics in the sediments, passing through the sieve and visible to the naked eye, were removed and archived in sealed petri dishes for further analysis. Figure 3.3 shows the presence of microplastics visible during the sieving process.

Figure 3.3: Microplastics identified during sieving process

The remaining microplastics that were not detected through visual inspection were extracted from the retained materials through density separation. The sediments that passed through the sieves were transferred into glass beakers. Literature reports that sand or other sediments typically exhibit a density of 2.65 g. mL^{-1} [93]. Hence, the density separation process works on the principle that on adding a solution with density lower than that of sediments, the materials in the sediments which have density lower than that of the liquid will float to the surface and sediments will sink. Hence, the solution chosen for the present study, has density lower than 2.65 $g.mL^{-1}$. The specific density of some of the commonly found polymer types of microplastics are presented in Table 3.2. It is evident that the specific density of the solution employed during the density separation process is significantly higher than the specific density of these microplastics and lower than that of the marine sediments.

Table 3.2: Specific density of different plastic type [93]

Polymer Type	**Polymer Density ($mg.L^{-1}$)**
polyethylene	0.917−0.965
polypropylene	0.9−0.91
polystyrene	1.04−1.1
polyamide (nylon)	1.02−1.05
polyester	1.24−2.3
polyoximethylene	1.41−1.61
polyvinyl alcohol	1.19−1.31
polyvinyl chloride	1.16−1.58
poly methylacrylate	1.17−1.20
acrylic	1.09−1.20

Most studies employ saturated Sodium Chloride (NaCl) solution (density, d=1.2 $g.mL^{-1}$) for the density separation due to its low cost and nontoxic nature. However, it was decided not to use it in this study as it is ineffective in extracting denser microplastics containing polyvinyl chloride (d=1.16-1.58 $g.mL^{-1}$) or polyoxymethylene (d=1.41-1.61 $g.mL^{-1}$) [42]. Hence, potassium iodide (KI) was employed in this study despite its high cost and corrosive nature because the density of KI could go up to 1.7 $g.mL^{-1}$; making it possible to extract high density microplastics. Additionally, KI has been used in research for the density separation of microplastic from marine sediments [90]. The density separation was carried out using 5.4 M Potassium Iodide (KI) with density (d) of 1.62 $g.mL^{-1}$. 210 ml of 1.62 $g.mL^{-1}$ KI was added to 500 g (dry weight equivalent) of sediment in a 1000 mL glass beaker and was manually stirred for 2 minutes. The samples were then allowed to settle for 6-7 hours (Figure 3.4). Research suggests a minimum settling time of 5 hours for the samples to become clear and completely separate the microplastics from the sand particles [89]. Successively, the supernatant from the separation was vacuum filtered on a Sartorius©, MGC grade, Glass- Microfibre discs (pore size 1.2 μm). The filters from the previous step were archived in sealed petri dishes and dried in an oven at 60 °C [90]. Wet filters reflect light under a microscope which hinders the next experimental step, the microscopic examination of the filters. Digestion with hydrogen peroxide (H_2O_2) was not performed in this study for the removal of organic material as literature has shown that digestion is not effective in the removal of organic matter [94].

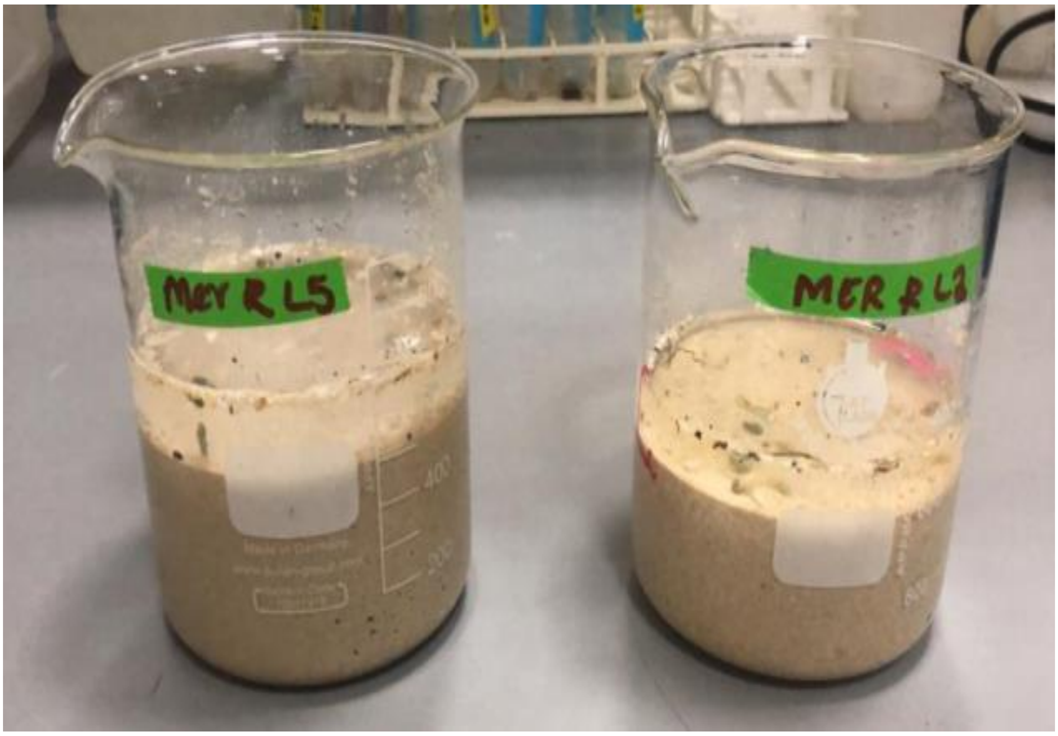


Figure 3.4: Settling process for extraction of microplastics from Sediments

In order to counter the exorbitant cost of KI, the solution was regenerated and reused. The KI filtrate, was stored and reused for subsequent density separations. Additionally, a novel technique was employed to extract the KI absorbed by the marine sediments. The KI which was absorbed by the sediments was extracted using a vacuum pump (Figure 3.5). Hence, a significant amount of KI was recovered and reused. However, this process is time- consuming and must be performed as soon as the vacuum filtration process is completed to counter evaporation and drying. Hence, the efficient use and reuse of KI made it feasible to use KI as a density separation medium.

Figure 3.5: Extraction of KI absorbed by the sediments after the density separation

3.4 Microscopic Examination

The criteria that were followed to identify microplastics under a 40X dissecting microscope are [93], [95]:

- No cellular or organic structures visible
- Fibers should be equally thick throughout their entire length
- Particles should exhibit clear and homogeneous color throughout

From Figure 3.6 a, it was observed that, in addition to the expected microplastics, the filter paper is covered with detritus and sand. Consequently, it was difficult to identify microplastics underneath these debris. Hence, to solve this problem, the detritus and sand laying on top of the filter paper were separated by transferring them to the cap of the petri dish (Figure 3.6 b). The two dishes were then transferred in to a container with a grid to aid in microscopic examination. The grid was placed over both the petri dishes containing the filter paper and debris (Figure 3.6 c). The grid comprising the dishes were examined under a dissecting microscope at 40X magnification to identify and further quantify the microplastics in the dishes (Figure 3.6 d) [96]. The filter papers were counted for microplastic along the grids by moving the dish left to right along a grid. On completion of a grid, the dish was moved to navigate one row down, and the dish was read from right to left as demonstrated by the red arrows (Figure 3.6 c). On identification of a microplastic, the grid was removed and the microplastic was removed using a tweezer, and archived. This process was repeated until the complete dish was covered. Moreover, this process was conducted separately for the dish with filter paper and the dish debris. The total number of microplastics found at each location was recorded. The total number of microplastics found in a location was the summation of the microplastic founds through visual inspection in the sieving stage (before density separation) and on the filters through microscopic examination (after density separation). The extraction process of microplastics from beach sediments is summarized in Figure 3.7. In addition to the microscopic examination, the physical attributes, color and shape of the microplastics were documented. The colors of microplastic identified were: blue, red, green, yellow, black, white, grey, orange, pink, and transparent. Furthermore, the shapes of microplastics were: fiber, string, pieces, and polystyrene spheres.

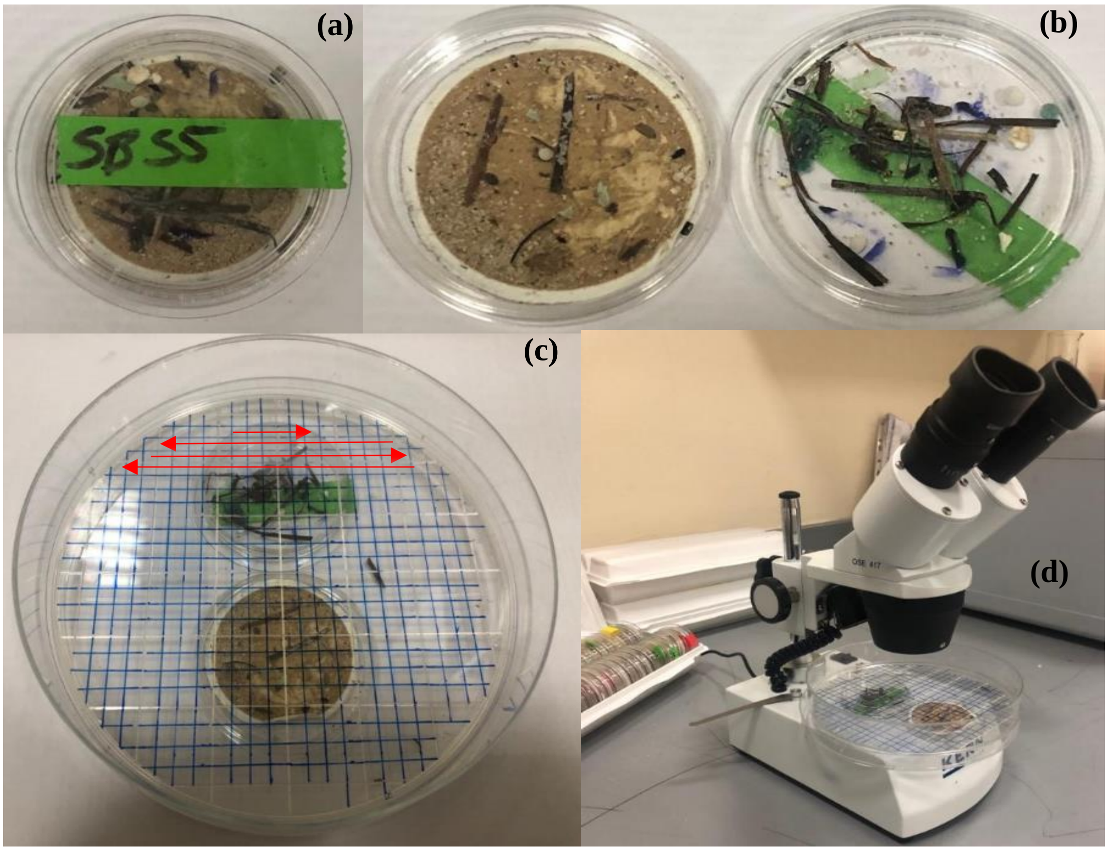


Figure 3.6: (a) Filter paper with detritus and sand, (b) Separation of detritus from filter paper, (c) examination procedure using grids, (d) microscopic examination

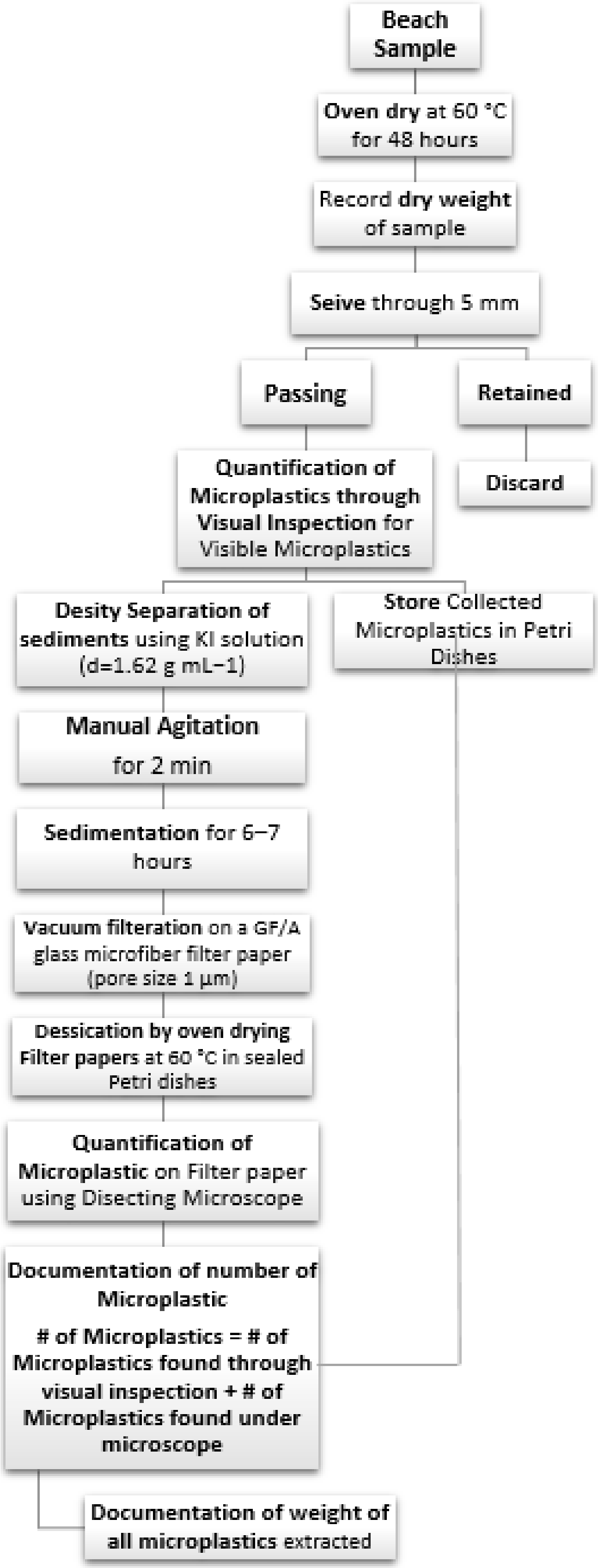


Figure 3.7: Flow diagram for the extraction of microplastics in beach sediments

3.5. Identification of Polymer Type

Fourier Transform Infrared (FT-IR) analysis was used for the identification of polymer type of fibers, strings, and polystyrene spheres which were found in the visual inspection stage. Due to its high accuracy, FT-IR is the most commonly used method for the identification of polymer type of microplastics found in marine sediments.

Different types of plastics are made up of distinct chemical bonds. FT-IR identifies these chemical bonds by providing a unique spectrum for a specific chemical bond. Hence, every polymer type exhibits a unique spectrum depending on the bond composition. These unique spectra have been documented in literature for different types of plastics. Therefore, the polymer type of microplastics can be identified by matching the spectrum obtained from the FT-IR analysis with the spectra documented in literature.

Microplastics found in the microscopic examination, i.e. invisible to the naked eyes, were not tested because FT-IR can only identify the polymer type of microplastics off size greater than 10-20 µm [97]. Additionally, due to the large amount of sand and organic matter on the filter paper, the filter papers could not be analyzed using the FT-IR to identify the polymer type of microscopic microplastics. In this research, samples were segregated in to possible polymer type categories on the basis of visual inspection and a subsample was selected from each category to undergo FT-IR analysis to identify polymer type. This method has been employed by other studies [98], [99]. Furthermore, visible microplastics which were extracted in the sieving process were used for this analysis to prevent contamination of microplastics during the density separation process.

3.6. Detection of Heavy Metal on the Extracted Microplastics

A representative sample (n=30) of microplastics was randomly selected from the microplastics extracted from each of the 16 beaches in Dubai and analyzed with a Horiba, model XGT 7200 X-ray analytical microscope to determine the heavy metals in the extracted microplastics. Hence, a total of 480 microplastics were tested. A Rhodium (Rh) anode was used in the X-ray tube, which may be operated at up to 50 kV and current up to 1 mA. Elements from sodium (Na) to uranium (U) were detected by means of Fluorescent X-ray detector which is an energy dispersive, Peltier cooled silicon drift detector (SDD). A mono glass capillary was utilized to generate a 1.2 mm

X-ray spot on the surface of each microplastic, and it was analyzed for 150 seconds. XRF has been used in research studies to detect heavy metals in soil samples, road dust, vegetation, fishes, and oysters [100]–[104]. Additionally, a study conducted in England utilized XRF spectrometry to identify heavy metals (Cd, Pb, and Br) on microplastics found in beach sediments [87]. Hence, XRF analysis was employed in this study for the detection of heavy metals in microplastics extracted from beach sediments. Furthermore, visible microplastics which were extracted in the sieving process were used for this analysis to prevent contamination of microplastics during the density separation process.

Chapter 4. Results and Discussion

This chapter presents and discusses the results of the analysis of the microplastics samples collected in this study from 16 beaches in Dubai. Furthermore, it discusses the coloration, shape and polymer type of the extracted microplastics. The chapter also evaluates the potential negative impact of color and shape of microplastic on marine fauna. In addition, the XRF analysis is presented and discussed to identify potential toxic metal components in the extracted microplastics.

4.1. Microplastic Quantities

Results demonstrated the presence of microplastics in all 16 sampled beaches. Furthermore, 100% of the five sampling points in each of the sampled beaches were found to be contaminated by microplastic debris. However, the levels of microplastic contamination were substantially variable throughout the sampled beaches and the five sampling points. The variability in the findings could be due to the dissimilarity in the content and weight of the sampled beach sediments from the 0.25 m^2 sampling frame. Some of the samples collected were observed to have higher contents of shells, pebbles, seaweed, and other debris in comparison to other beaches. Additionally, the weight and size of microplastics extracted from the beaches differed among the samples. Literature has shown that low density microplastics potentially weigh less in comparison to high density microplastics [93].

Significant quantities of microplastics were extracted from sampled beach sediments. In order to assist with comparison of results with findings reported in literature, this paper presents the results in $mg.g^{-1}$ of dry sediment, $mg.m^{-2}$, $items.m^{-2}$, and $items.kg^{-1}$ of dry sediment. Table 4.1 presents the average, median, maximum, and minimum values of the measured microplastic in the beaches studied. The results obtained from the analysis of 80 samples procured from the wrack lines of 16 public beaches in Dubai demonstrate that the average weight of microplastic contamination is 0.33 mg. g^{-1} of sediment (or 953 $mg.m^{-2}$) and items of microplastic is 59.71 $items.kg^{-1}$ of sediment (or 165 $items.m^{-2}$). The number of microplastics (items.m-2, and items.kg-1 of dry sediment) and weight (mg. g-1 of dry sediment, mg.m-2) in each of the 80 sampling locations has been shown in the appendix (Table A.2). Also, a total of 3366 microplastics were found in the 80 beach sediments samples.

Table 4.1. Measured microplastic quantities in beach sediments

Sampled Beach		mg per gram of sediment	mg per m^2	Items per m^2	Items per kg
1	Mean ± Δ	0.30 ± 0.06	1229 ± 413	245 ± 106	51.71 ± 13.65
	Median	0.24	1086	196	44.44
	Min.–max.	0.21-0.50	522-2369	80-556	27.59-88.65
2	Mean ± Δ	0.09 ± 0.03	370 ± 147	152 ± 63	30.03 ± 10.20
	Median	0.09	348	112	29.00
	Min.–max.	0.02-0.15	120-777	68-384	13.83-59.43
3	Mean ± Δ	0.12 ± 0.05	385 ± 258	84 ± 21	31.06 ± 6.71
	Median	0.09	270	80	32.37
	Min.–max.	0.03-0.27	57-1213	32 - 128	15.84-45.87
4	Mean ± Δ	0.37 ± 0.17	789 ± 386	226 ± 73	91.04 ± 20.80
	Median	0.18	604	160	88.52
	Min.–max.	0.14 – 0.89	274 - 2000	148-476	54.24 – 147.28
5	Mean ± Δ	0.58 ± 0.28	1292 ± 756	337 ± 180	133.98 ± 67.48
	Median	0.27	653	200	107.53
	Min.–max.	0.22 - 1.46	386-3768	0-804	0.00 – 301.80
6	Mean ± Δ	0.09 ± 0.05	251±127	121 ± 8	41.74 ± 3.56
	Median	0.06	191	120	41.49
	Min.–max.	0.03-0.24	95-665	100-136	33.47 – 49.40
7	Mean ± Δ	0.20 ± 0.13	525 ± 278	170 ± 57	52.28 ± 10.91
	Median	0.11	352	120	47.04
	Min.–max.	0.04-0.64	139-1381	100-356	36.54 – 85.33
8	Mean ± Δ	0.06 ± 0.02	165 ± 58	97 ± 15	35.84 ± 4.60
	Median	0.06	175	104	38.36
	Min.–max.	0.02-0.12	41-302	52-120	21.45 – 42.00
9	Mean ± Δ	0.25 ± 0.10	430 ± 167	165 ± 54	94.72 ± 32.40
	Median	0.21	350	164	89.52
	Min.–max.	0.04-0.49	67-813	68-308	40.19 – 185.10
10	Mean ± Δ	0.27 ± 0.06	1348 ± 438	254 ± 43	53.20 ± 5.40
	Median	0.28	1100	212	55.87
	Min.–max.	0.15-0.41	598-2554	192-384	38.05-62.22
11	Mean ± Δ	0.31 ± 0.10	1063 ± 407	151 ± 38	44.73 ± 6.53
	Median	0.30	1075	108	39.28
	Min.–max.	0.10-0.53	288-2108	88-256	31.98-61.19
12	Mean ± Δ	0.11 ± 0.07	398 ± 283	26 ± 5	8.43 ± 1.54
	Median	0.07	156	20	9.06
	Min.–max.	0.02-0.35	86-1350	20-44	5.13-12.02
13	Mean ± Δ	0.48 ± 0.38	552 ± 376	186 ± 46	132.40 ± 44.44
	Median	0.25	243	204	137.36
	Min.–max.	0.02-1.74	35-1718	60-264	59.97-258.71
14	Mean ± Δ	1.44 ± 0.73	4242 ± 1971	130 ± 45	39.65 ± 11.08
	Median	1.09	2441	100	35.78
	Min.–max.	0.43-3.70	1640-10455	60-260	18.87 – 68.42
15	Mean ± Δ	0.23 ± 0.15	787 ± 615	176 ± 61	61.05 ± 12.64
	Median	0.17	511	144	63.37
	Min.–max.	0.02-0.68	44 - 2794	88-360	31.03 – 87.55
16	Mean ± Δ	0.42 ± 0.24	1050 ± 636	119 ± 26	46.58 ± 10.26
	Median	0.25	633	112	38.96
	Min.–max.	0.09 – 1.16	165-3012	72 - 188	26.54 – 72.42

The results are in accordance with findings reported in literature. Research examining microplastic contamination on five beaches on the Portuguese coastline reported an average microplastic density of 133.3 items.m^{-2} [56]. Furthermore, a study conducted in the beach sediments of 13 beaches in Russia reported a gross average value of 0.05–2.89 mg.g^{-1} of dry sediment [3]. However, a study conducted on 80 beaches in Qatar reported an average microplastic findings in marine sediments as 81 items.m^{-2} [14]. In addition, a study conducted in beaches in India reported the mean abundance of microplastic in sediments to be 68.83 items.m^{-2} [6]. These studies have reported mean microplastic abundance, which is lower than our findings. However, microplastic contamination, as reported in literature, varies with time and location of sampling. Additionally, the large number of microplastic was expected as the samples were procured from the wrack line which is known to have large amount of debris. Hence, variation in microplastic contamination in Dubai beach sediments reported in this study in comparison to other similar studies conducted in other countries is expected.

The weight and the number of extracted microplastics varied among the sampled beaches. From Figure 4.1 a, it is observed that the maximum weight of microplastic per gram of dry sediment (mg. g^{-1} of dry sediment) was found to be in beach 14. Similarly, the maximum weight of microplastic per square meter (mg.m^{-2}) was found in beach 14 as shown in from Figure 4.1 b. However, from Figure 4.2 a, it is observed that the maximum number of microplastic per square meter was observed in beach 15. Similarly, the maximum number of microplastic per kilogram of dry sediment (items.kg^{-1}) was observed in beach 15 as observed in Figure 4.2 b. Hence, it can be inferred from the results that the maximum number of microplastic were found in beach 15. Contrary to this, the total weight of the microplastics extracted was higher in beach 8. Additionally, From Figure 4.1 & Figure 4.2, it can be inferred that the minimum number of microplastic per square meter (items.m^{-2}) and per kg of dry sediment (items.kg^{-1}) was observed in beach 12. The variation in the weight and number of microplastics extracted among the 16 sampled beaches has been mapped and illustrated Figure 4.1 c & Figure 4.2 c.

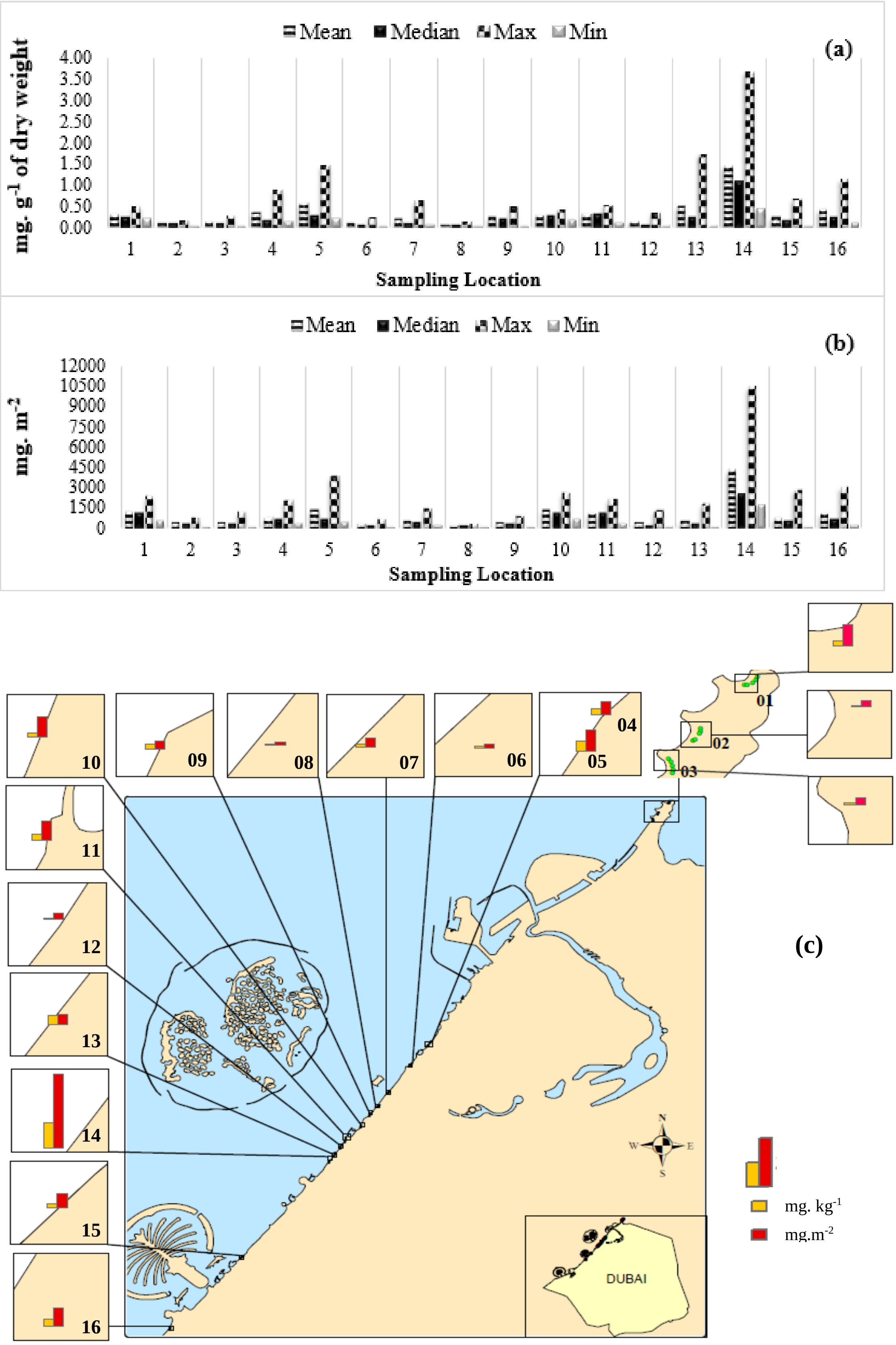


Figure 4.1: Distribution of weight of microplastics along the coast (from beach 1 to beach 16, according to the map in Figure 3.1) in (a) mg.m^{-2} (b) mg.kg^{-1} of dry sediment (c) Location map showing average mg.g^{-1} of dry sediment and mg.m^{-2}

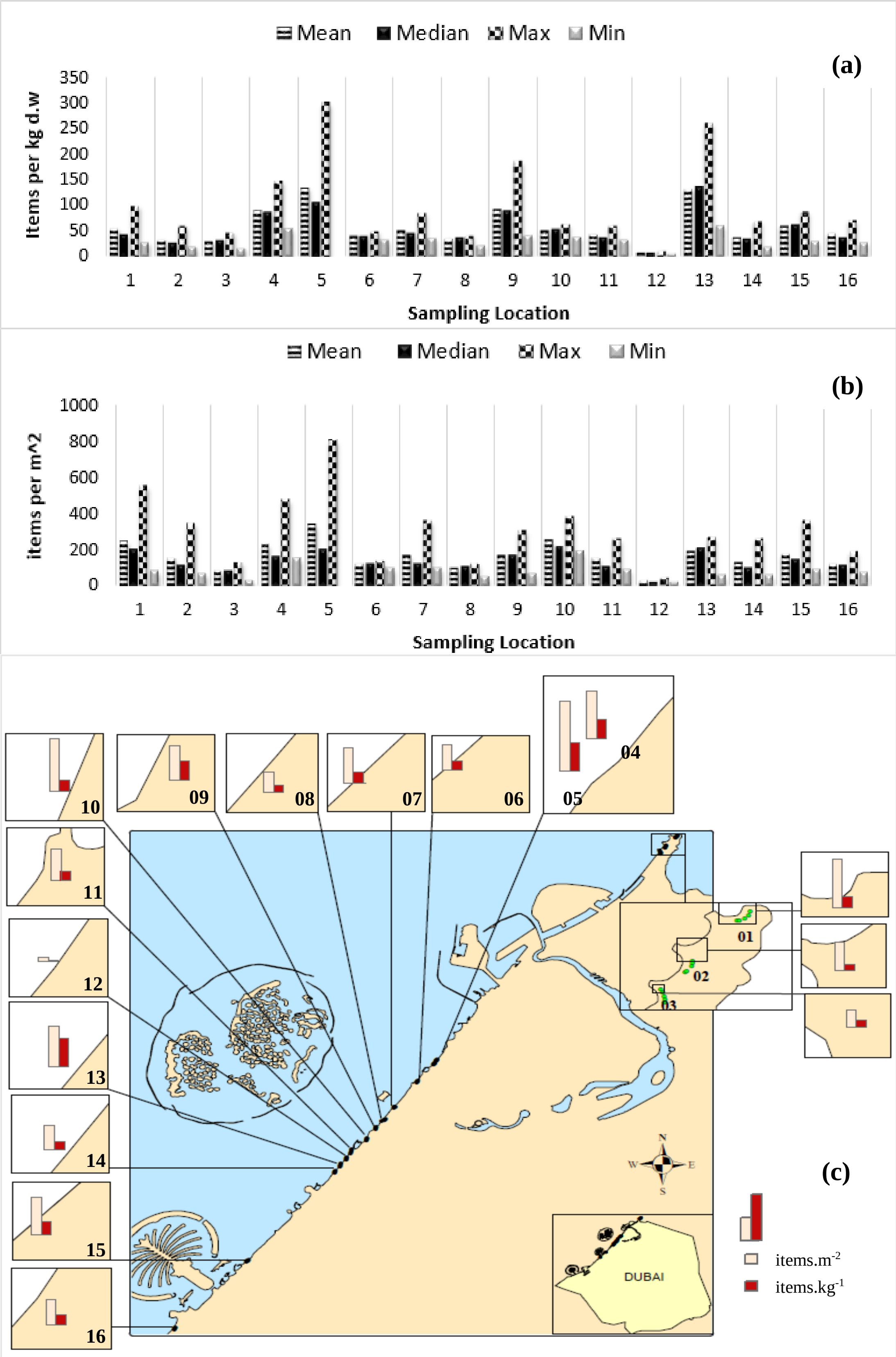


Figure 4.2: Distribution of number of microplastics along the coast (from beach 1 to beach 16, according to the map in Figure 3.) in (a) items.kg^{-1} of dry sediment (b) items.m^{-2} (c) Location Map showing average number of microplastics in items.m^{-2} and items.kg^{-1} of sediment

4.2. Microplastics Coloration

The extracted microplastics were studied under a 40X dissecting microscope, and the color was recorded and statistically analyzed. Research has found the color of microplastic is a factor that makes plastic intake enticing for marine organisms [23], [24]; hence, making it an important aspect to be studied. Additionally, coloration of the microplastics shows the synthetic nature of this contamination [105]. During the microscopic analysis, 10 colors were recorded, which are: blue, red, green, yellow, black, white, grey, orange, pink, and transparent. Samples of the extracted microplastics from each color category are shown in Figure 4.3

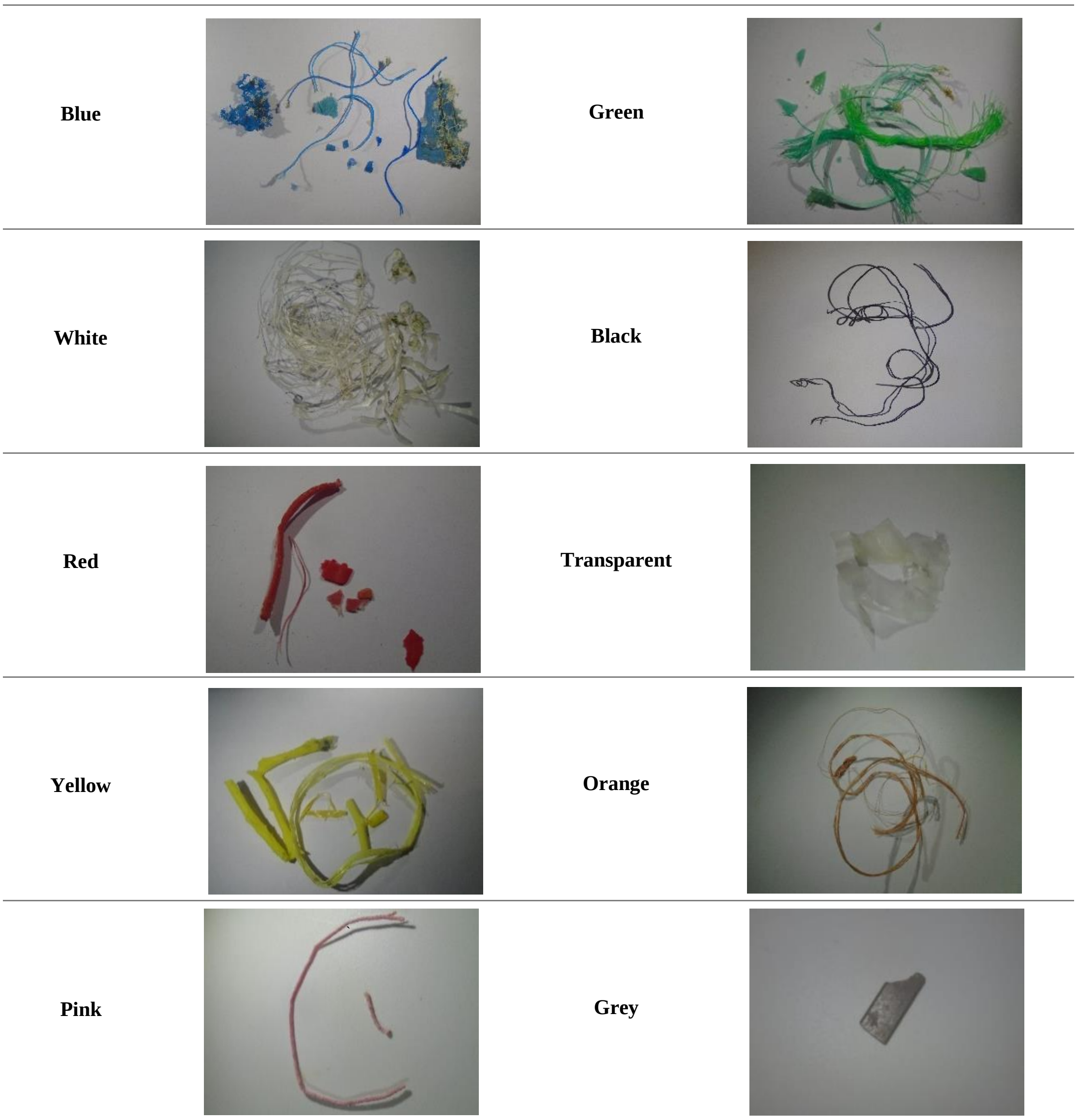


Figure 4.3: Sample coloration of microplastics extracted

Blue colored microplastics were the dominant type. The recorded number of microplastic in each color category in descending order of their abundance are as follows: blue > green > white > black > red > transparent > yellow >orange > pink = grey. As observed from Figure 4.4, blue microplastics were the most abundant in terms of number of microplastics (26.59%), followed by green (16.90%), white (16.73%), black (14.88%), and red (11.71%). Orange (1.28%), Grey (0.30%) and pink (0.30%) colored microplastics were sparsely found on exaction. On examination of the coloration of the microplastic, it is observed that the microplastic are fragments of macroplastic debris. However, small straws of yellow and white coloration were found with primary microplastics. The number of microplastics in each of the identified color category in the 80 sampled locations are presented in Table A.3.

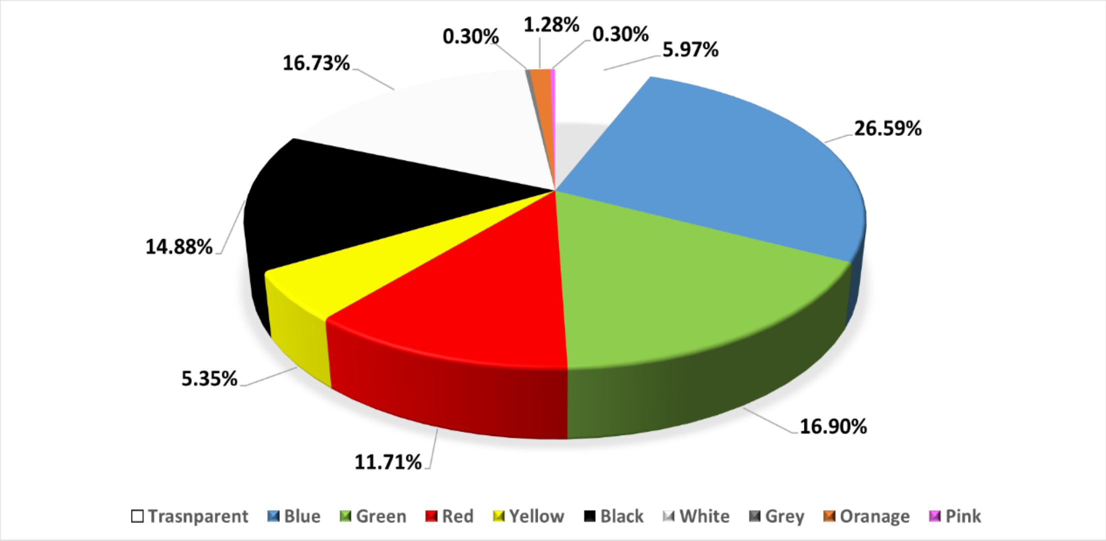


Figure 4.4: Proportion of different colors of microplastics extracted

The abundance in each identified color category in terms of items.m^{-2} and items.kg^{-1} of dry sediment is presented in the appendix in Table A.4 & Table A.5. The maximum items.m^{-2} was found to be 244 microplastics per square meter (items.m^{-2}) which belonged to the white color category. Furthermore, the maximum items.kg^{-1} was found to be 91.59 microplastics per kilogram of dry weight of sediment (items. kg^{-1}), which also belonged to the white color category. The abundance in each identified color category in terms of average items.m^{-2} and average items.kg^{-1} of dry sediment is presented in Table 4.2.

Table 4.2: Average microplastic abundance in beach sediments in Dubai in each of the identified color categories

Items per m^2										
	T	**B**	**G**	**R**	**Y**	**B_1**	**W**	**G_1**	**O**	**P**
1	23.20	69.60	53.60	15.20	12.00	4.80	59.20	4.00	2.40	0.80
2	13.60	40.00	37.60	7.20	8.80	12.00	30.40	0.00	0.80	1.60
3	4.00	25.60	15.20	4.00	1.60	8.80	24.80	0.00	0.00	0.00
4	4.00	60.00	38.40	14.40	48.00	24.80	29.60	1.60	4.00	0.80
5	3.60	24.00	23.60	3.20	4.20	10.40	25.20	0.40	2.40	1.00
6	7.20	16.00	24.00	24.80	12.00	25.60	8.00	0.80	2.40	0.00
7	7.20	57.60	12.80	24.00	3.20	40.80	23.20	0.00	1.60	0.00
8	2.40	37.60	20.80	16.00	4.00	13.60	2.40	0.00	0.00	0.00
9	3.20	54.40	20.80	16.80	1.60	58.40	9.60	0.00	0.00	0.00
10	24.00	68.00	52.00	28.00	8.00	20.00	52.80	0.00	0.80	0.00
11	8.00	40.00	25.60	21.60	11.20	20.80	24.00	0.00	0.00	0.00
12	2.40	4.80	5.60	0.00	0.00	0.00	12.80	0.00	0.00	0.00
13	0.00	33.60	6.40	68.80	5.60	51.20	15.20	0.00	5.60	0.00
14	0.80	24.80	3.20	32.80	4.00	28.00	32.00	0.00	4.00	0.00
15	44.80	47.20	15.20	21.60	4.80	34.40	6.40	0.00	1.60	0.00
16	1.60	40.80	29.60	7.20	2.40	16.00	19.20	0.00	1.60	0.80
Items per kg										
	T	**B**	**G**	**R**	**Y**	**B_1**	**W**	**G_1**	**O**	**P**
1	5.18	15.50	11.84	3.08	2.61	1.10	13.08	1.37	0.45	0.17
2	3.44	9.84	8.36	1.48	1.56	2.52	6.06	0.00	0.14	0.46
3	1.69	7.22	4.70	1.03	0.43	3.02	9.58	0.00	0.00	0.00
4	1.24	22.71	14.25	5.88	22.83	9.97	11.57	0.84	1.52	0.23
5	5.91	38.04	38.00	5.11	7.09	16.88	39.34	0.64	3.74	1.67
6	2.46	5.54	8.09	8.77	4.19	8.83	2.75	0.25	0.84	0.00
7	2.57	17.12	4.21	6.40	1.05	12.51	7.92	0.00	0.49	0.00
8	0.94	13.76	7.92	5.98	1.53	4.84	0.87	0.00	0.00	0.00
9	1.80	31.24	12.12	9.61	0.93	33.59	5.43	0.00	0.00	0.00
10	5.22	14.32	11.11	5.27	1.89	4.26	11.01	0.00	0.13	0.00
11	2.38	11.98	8.24	6.16	3.16	6.60	6.21	0.00	0.00	0.00
12	1.44	1.16	1.50	0.00	0.00	0.00	4.31	0.00	0.00	0.00
13	0.00	23.90	5.24	43.41	3.18	37.87	15.16	0.00	3.65	0.00
14	0.21	7.76	0.92	9.02	1.14	8.49	10.39	0.00	1.71	0.00
15	13.51	15.83	5.26	8.75	1.28	13.56	2.24	0.00	0.62	0.00
16	0.65	14.95	12.34	2.79	0.92	6.72	7.06	0.00	0.84	0.31

T = Transparent, B = Blue, G = Green, R = Red, Y = Yellow, B_1 = Black, W = White, G_1 = Grey, O = Orange, P = Pink

Blue and white microplastics which were abundantly found in the beaches are more likely to be ingested by marine fauna. Literature suggests that marine fauna ingests colored microplastic. The overwhelming presence of blue microplastics potentially poses a threat to the marine fauna. A study conducted in Chile found that the microplastics most frequently ingested by the southern king crab were mainly blue in color [106]. Furthermore, a study conducted in the western English Channel found that 83% of the microplastic ingested by fish larvae were also blue in color [25]. Additionally, research conducted in three ocean basins found that blue and black colored plastic was found to be more commonly ingested by marine turtles [107]. Furthermore, Seal scat samples were found to have black, clear, red and blue microplastics [27]. Research suggests that some of the commercially sold fish, which prey on zooplankton, are more prone to eating white, tan and yellow plastic microplastic which resembles their prey [23]. Hence, it is important to identify the beaches which are most prominently contaminated by colored microplastics that are likely to be ingested by marine fauna. Hence, the coloration of microplastics extracted from the 80 samples taken from Dubai beaches, not only proves its synthetic nature, but also shows that they are more likely to be ingested by marine fauna.

It is observed that on average, beach 1, beach 4, beach 5, beach 7, beach 9, and beach 10 have abundant amounts of blue colored microplastics (> 50 items.m^{-2}) (Figure 4.5a). In addition, white and green colored microplastics are more abundant in beach 1, beach 5, and beach 10 (> 50 items.m^{-2}). Red colored microplastics are more abundant (> 50 items.m^{-2}) in beach 13, and yellow colored microplastics are more abundant in beach 4. Black colored microplastic are more abundant (> 50 items.m^{-2}) in beach 13. Moreover, from Figure 4.6 a, it is observed that blue colored microplastics are more prominent in terms of number of microplastic per kilogram of dry sediment (>30 items.kg dry sediment) in beaches 5 and 9. Green and white microplastics were abundant (>30 items.kg dry sediment) in beach 5. Red colored microplastics were dominant (>30 items.kg dry sediment) in beach 13. Also, black color microplastics were more in beach 9. These findings are mapped in Figure 4.5 b & Figure 4.6 b to visually understand the variation in microplastic coloration along the coat of Dubai. Hence, this study suggests that authorities pay attention to the color variation along Dubai coast in order to understand the possible source(s) of these colored microplastics. This will aid in mitigating the harmful impact of colored microplastic on marine fauna in the area

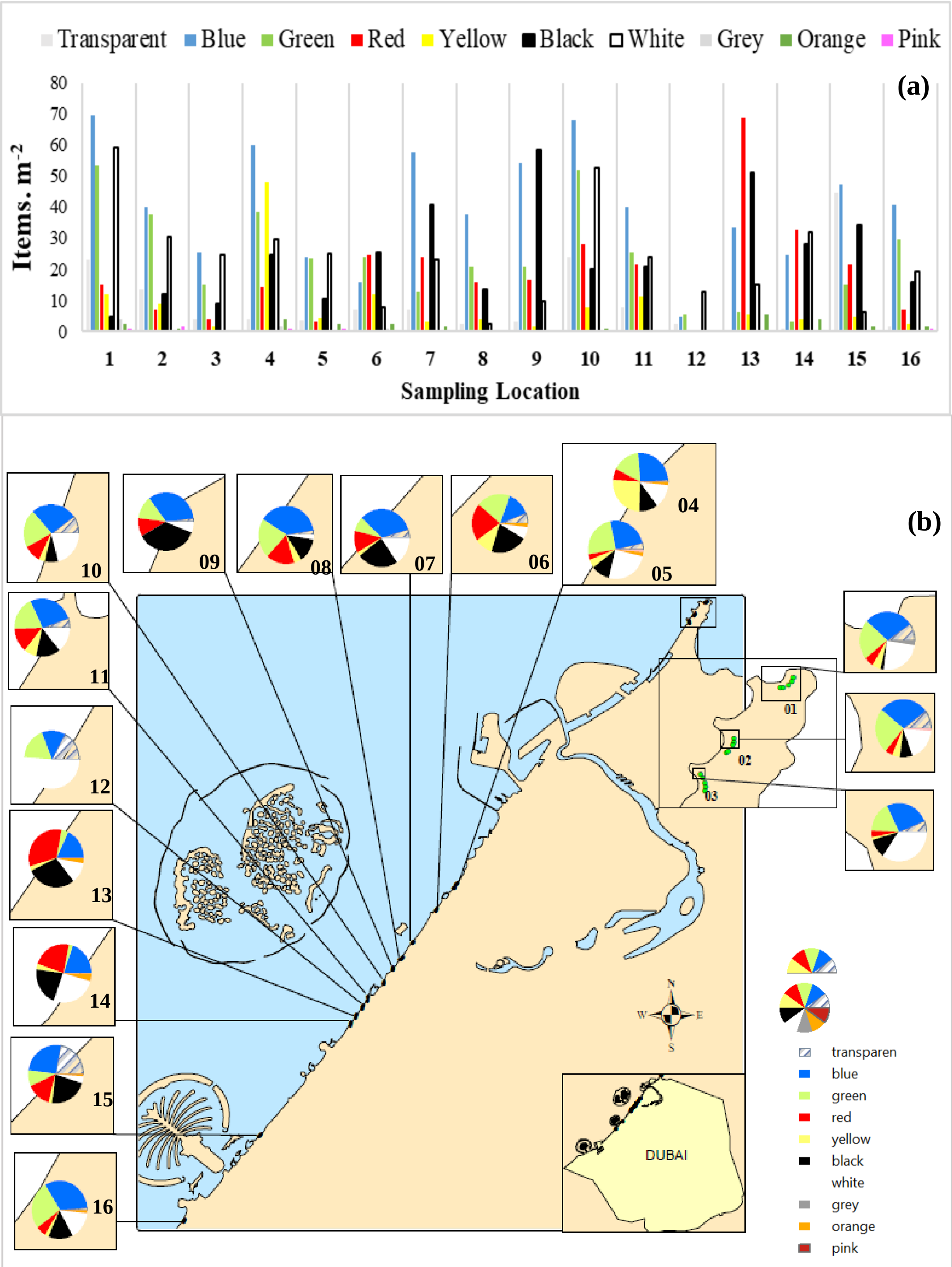


Figure 4.5: (a) Distribution of various colors of microplastics along the coast of Dubai (beach 1-beach 16, according to the map in Figure 3.1) in items.m^{-2} (b) Map showing average number of microplastics in items.m^{-2} in each color category in the sampled beaches. Items of microplastics signify the average number of microplastics in each color category

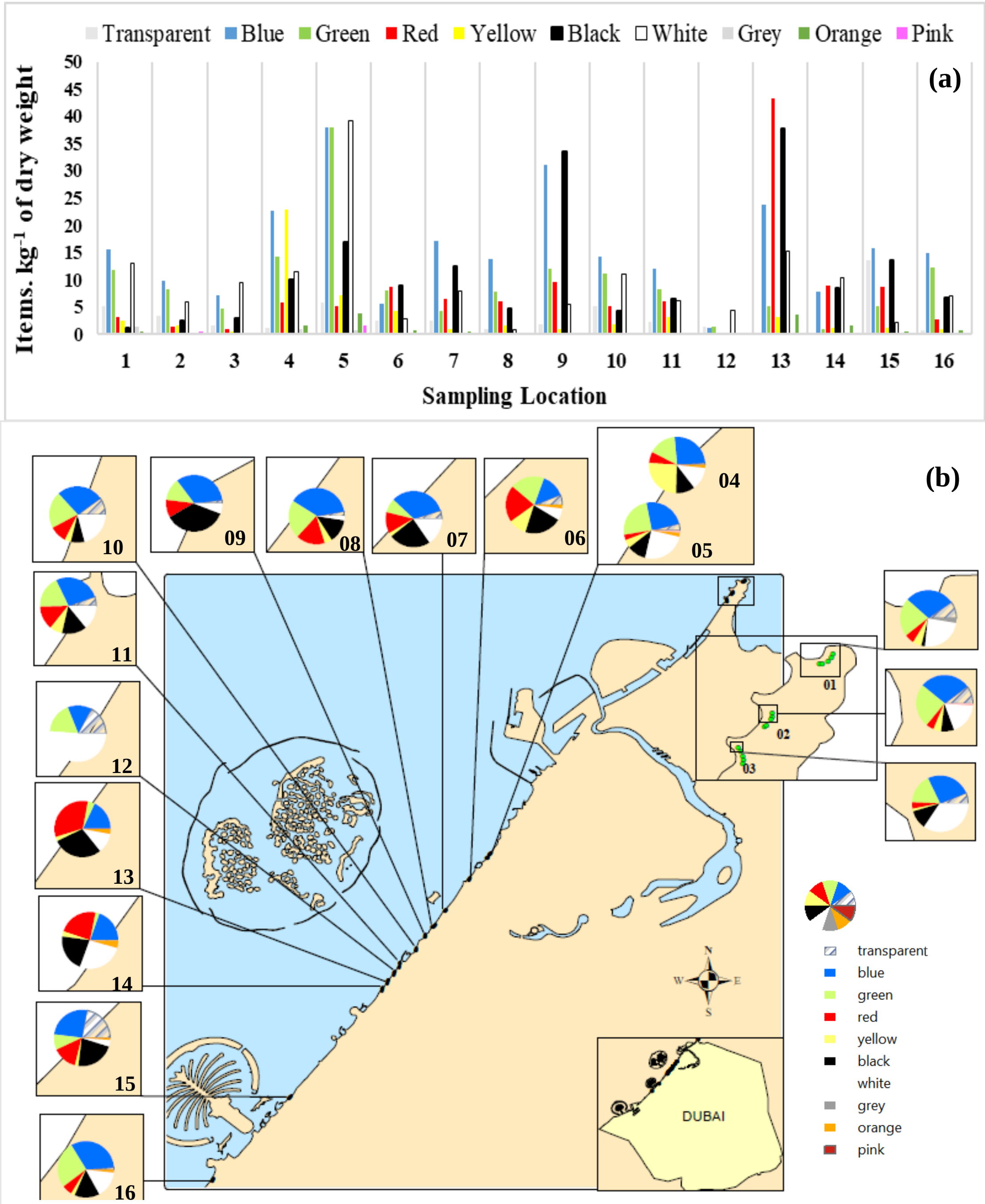


Figure 4.6: (a) Distribution of various colors of microplastics along the coast of Dubai (beach 1-beach 16, according to the map in Figure 3.1) in items.kg-1 (b) Map showing average weight of microplastics in items.kg-1 in each color category in the sampled beaches. Items of microplastics signify the average number of microplastics in each color category

4.3. Microplastic Shape

The shapes of the microplastics were documented in order to conduct statistical evaluation. Research has found that certain shapes of microplastics are more likely to be ingested by marine flora and fauna. Hence, studying the shapes of the microplastics in the beaches of Dubai will provide useful information on the negative impact microplastic contamination have on marine species thriving in the Arabian Sea. Additionally, physical attributes, such as the shape, can be a good indicator of the potential source of secondary microplastics. The Four shapes of microplastics observed were: fiber, string, pieces, and polystyrene spheres (Figure 4.7).

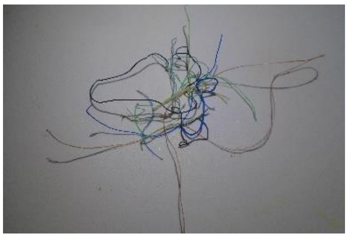
Fiber	
Strings	
Pieces	
Polystyrene Spheres	

Figure 4.7: Sample shapes of microplastics

Fibrous microplastics were more abundantly found in the beach sediments of Dubai in comparison to fragments, strings, and polystyrene spheres. The proportions of different shape categories of the extracted microplastics from the wrack lines of 16 public beaches in Dubai are shown in Figure 4.8. Among all the samples, fiber was the most prevalent microplastic shape in term of number of microplastic (63.87%). The second most found shape of microplastic was fragments (20.50%), followed by plastic strings (14.14%) and then polystyrene spheres (1.49%). The number of microplastics in each of the identified shape categories in the 80 sampled locations are presented in Table A.6.

These findings align with the findings reported in academic literature. A study conducted in marine sediments in 18 shores, across six continents reported that the most prevalent shape of microplastic was fibers [108]. Moreover, a study conducted on marine sediments along the Belgian coast also reported that majority of microplastic found were fibers. Furthermore, Polystyrene Balls were also found in the present study [51].

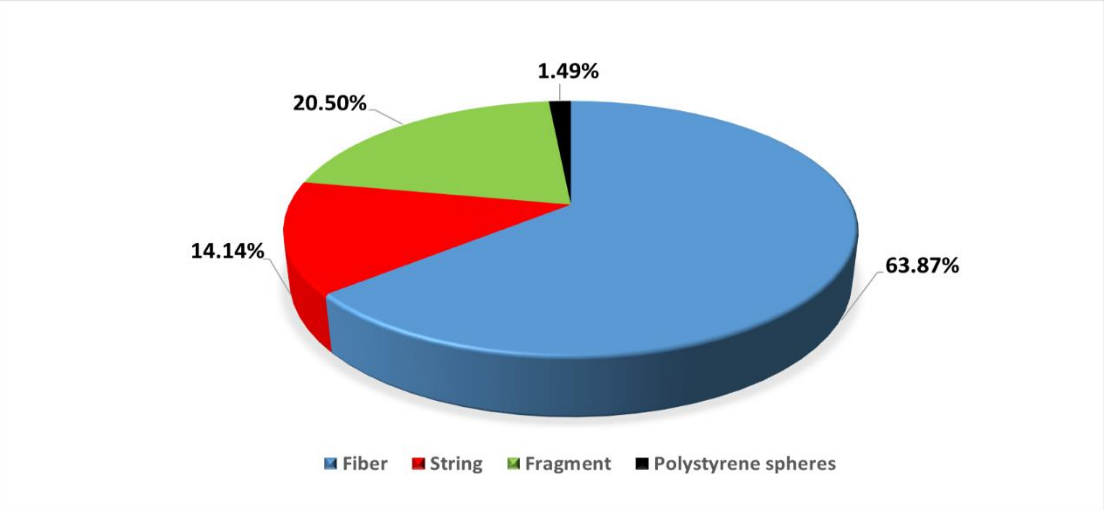


Figure 4.8: Proportion of different shapes of microplastics

The abundance in each identified color category in terms of items.m^{-2} and items.kg^{-1} of dry sediment is presented in the appendix in Table A.7 & Table A.8. On analysis, it was found that the maximum items.m^{-2} was 488 microplastics per square meter, which belonged to the fiber shape category. Furthermore, the maximum items.kg^{-1} was 189.99 microplastics per kilogram of dry weight of sediment, which also belonged to the fiber shape category. The average items.m^{-2} and average items.kg^{-1} of dry sediment in each of the four shape categories are presented in Table 4.3. Additionally, these findings are illustrated in Figure 4.9. The average number of fibrous microplastics per square meter (items.m^{-2}) was highest in beach 5. Similarly, the average number of fibrous of microplastics per kg dry weight of sediment (items.kg^{-1}) was found to be highest in beach 5. Furthermore, fragments of microplastic were abundant on average per square meter (items.m^{-2}) and per kg dry weight of sediment (items.kg^{-1}) in beach 15. In addition, strings of microplastic were abundant on average per square meter (items.m^{-2}) and per kg dry weight of sediment (items.kg^{-1}) in beach 5 and Polystyrene spheres where more abundant on average in beach 10.

Table 4.3: Average microplastic abundance in sediments of the beaches in Dubai categorized by Shape

Items per m^2				
Beach	**Fiber**	**String**	**Fragment**	**Polystyrene spheres**
1	103.20	55.20	81.60	4.80
2	76.00	30.40	44.00	1.60
3	40.00	19.20	23.20	1.60
4	173.60	20.80	28.00	3.20
5	249.60	102.40	38.40	1.60
6	76.00	11.20	30.40	3.20
7	126.40	16.80	23.20	4.00
8	75.20	1.60	19.20	0.80
9	139.20	8.00	17.60	0.00
10	160.80	34.40	46.40	12.00
11	93.60	26.40	31.20	0.00
12	8.80	11.20	4.80	0.80
13	147.20	13.60	24.80	0.80
14	85.60	19.20	24.80	0.00
15	85.60	2.40	86.40	1.60
16	79.20	8.00	28.00	4.00
Items per kg				
Beach	**Fiber**	**String**	**Fragment**	**Polystyrene spheres**
1	5.18	15.50	11.84	3.08
2	3.44	9.84	8.36	1.48
3	1.69	7.22	4.70	1.03
4	1.24	22.71	14.25	5.88
5	104.64	41.93	16.37	0.58
6	2.46	5.54	8.09	8.77
7	2.57	17.12	4.21	6.40
8	0.94	13.76	7.92	5.98
9	1.80	31.24	12.12	9.61
10	5.22	14.32	11.11	5.27
11	2.38	11.98	8.24	6.16
12	1.44	1.16	1.50	0.00
13	0.00	23.90	5.24	43.41
14	0.21	7.76	0.92	9.02
15	13.51	15.83	5.26	8.75
16	0.65	14.95	12.34	2.79

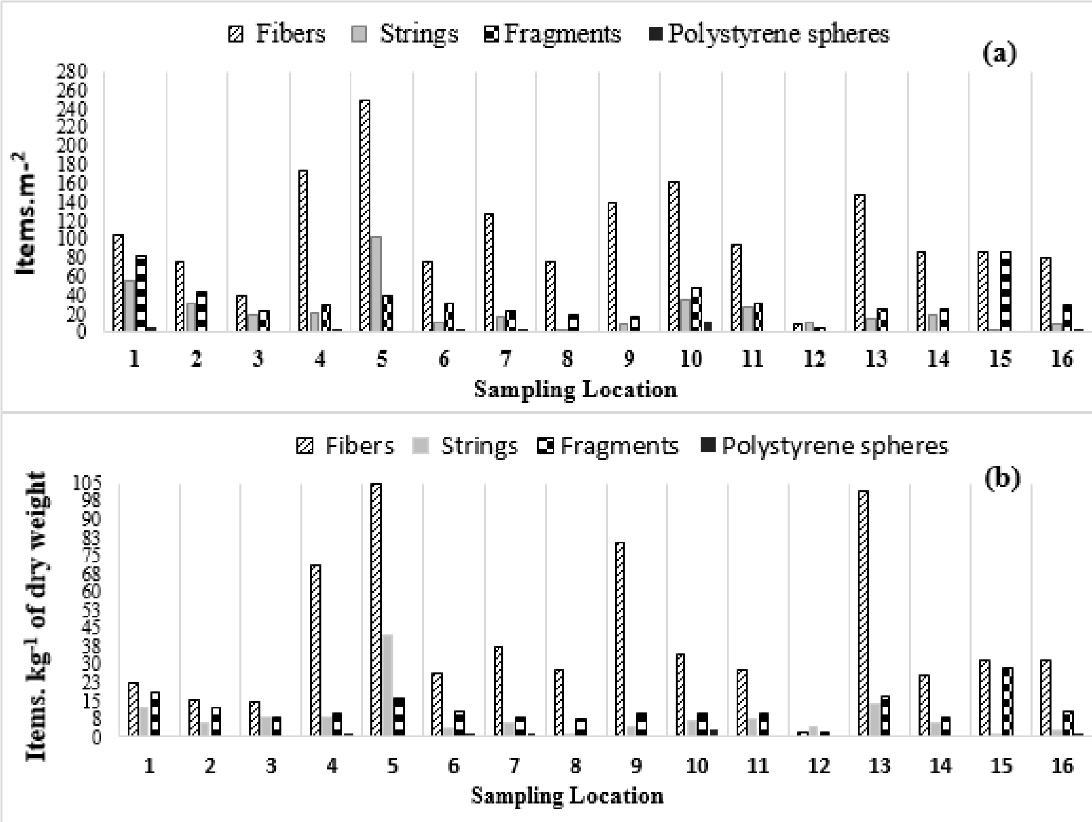


Figure 4.9: Distribution of Various Shape of Microplastics along the Coast of Dubai (beach 1-beach 16, according to the map in Figure 3.) in (a) items.m^{-2} (b) items.$kg^{-1}$of dry weight of sediment. Items of Microplastics Signify the Average Number of Microplastics in each Shape Category

There is evidence that different trophic levels of marine fauna have been ingesting these microplastic fibers, making their presence more injurious. A study conducted in the North East Pacific found that among the zooplankton community, one in 17 copepods, and one in 34 euphausiids ingested microplastics and 50–68% of these microplastic were fibers [109]. Additionally, a study conducted in the western English Channel found that 2.9% of fish larvae in the study area had ingested microplastics. Alarmingly 83% of these microplastics were fibrous [25]. A research studying the stomach and intestine contents of True's beaked whales found that 58% of the microplastics found in the stomach and 89% of the microplastics found in the intestine were fibers [26]. Additionally, research conducted in three ocean basins found that fibrous microplastics were more commonly ingested by marine turtles [107]. Hence it is important to identify the beaches which are dominantly contaminated by fibrous microplastics.

On evaluation of the results, it is observed that the number of fibrous microplastics per square meter (items.m^{-2}) is more than 100 in Beaches 1, 4, 5, 7, 9, 10 and 13. Additionally, Beaches 4, 5, 9 and 13 have been found to have more than 70 fibrous microplastics per kilogram of dry weight of sediment (items.kg^{-1} dry weight of sediment). Hence, the present study recommends that authorities pay close attention to these findings in order to understand the possible source(s) of fibrous microplastics. Authorities can then develop mitigation strategies that can help to control the factors causing this contamination in order to mitigate the harmful impact of fibrous microplastic.

4.4. Polymer Type

The synthetic origin of the dominant shapes of the extracted microplastics, fibers and strings, was determined using FT-IR analysis. As mentioned in the previous subsection, fibrous microplastics constituted of 63.87% of the total microplastics extracted from the sampled beach sediments and 14.14% of the samples were strings. Hence, taking in to consideration the constrain of time and cost, only these microplastics were tested to determine their polymer type. Moreover, FT-IR analysis was only conducted on fibers and strings that were large enough to handle using forceps; i.e. microscopic fibers and strings were not included in this analysis. Therefore, taking in to account this size constrain, the polymer types of 1396 microplastics (fibers and strings) were identified.

Two polymer types were found in the samples tested: polyethylene (PE), and polypropylene (PP). Therefore, less dense polymers, polypropylene ($d = 0.9-0.91$ mg.L^{-1}) and polyethylene ($d = 0.917-0.965$ mg.L^{-1}) are more prevalent in the area studied. As shown in Figure 4.10, 63.67% of the samples tested were identified to be PE and 32.94% were found to be PP. Additionally, it was observed that all colored fibers were PE and white colored strings and fibers were found to be PP. These findings have been corroborated by a research identifying the polymer type of fibers in marine sediments in Korea. The study identified colored fibers to be PE and white color strings to be PP copolymers [110].

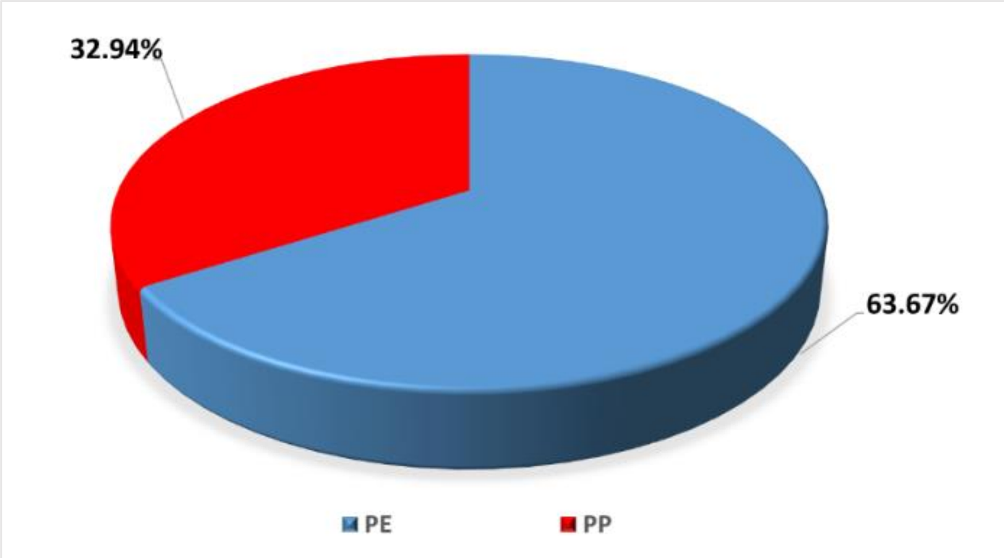


Figure 4.10: Proportion of polymer type of fibers and strings

The expected FT-IR spectra for (Figure 4.11a) and polypropylene (Figure 4.11 b) match with the spectra obtained on FT-IR analysis of the colored microplastics fibers (Figure 4.11 c) and white strings (Figure 4.11 d) has been shown in. However, it is observed that there are slight variations in the spectra between the reference spectra and the spectra obtained. These variations have been reported to be due to weathering of microplastics as shown in Figure 4.12 [111]. Nonetheless, the peaks at the adsorption bands used for identification which are shown in b were observed in the FT-IR spectra obtained.

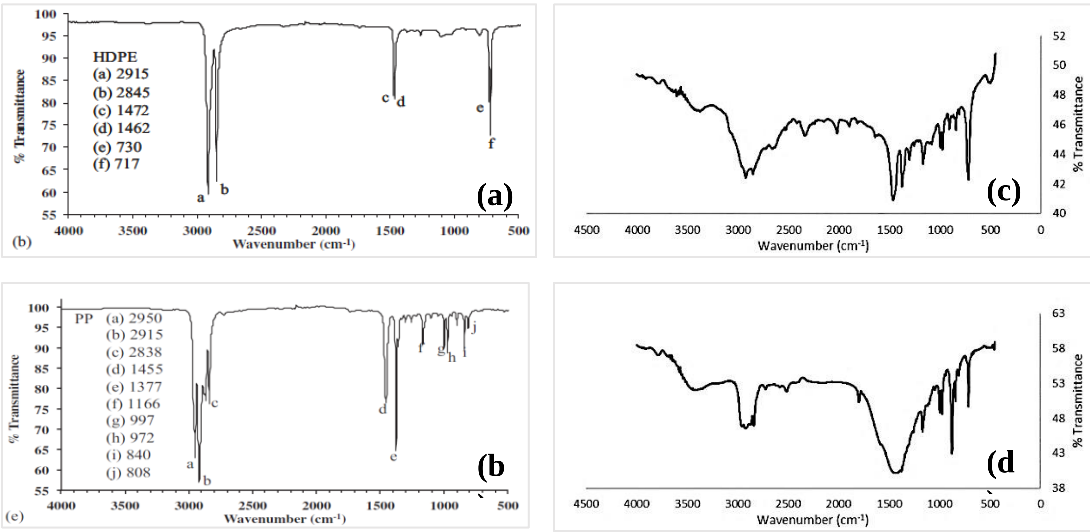


Figure 4.11: Reference spectra for (a) polyethylene [112], (b) polypropylene [112] and FT-IR spectra obtained for (c) colored fibers (d) white strings

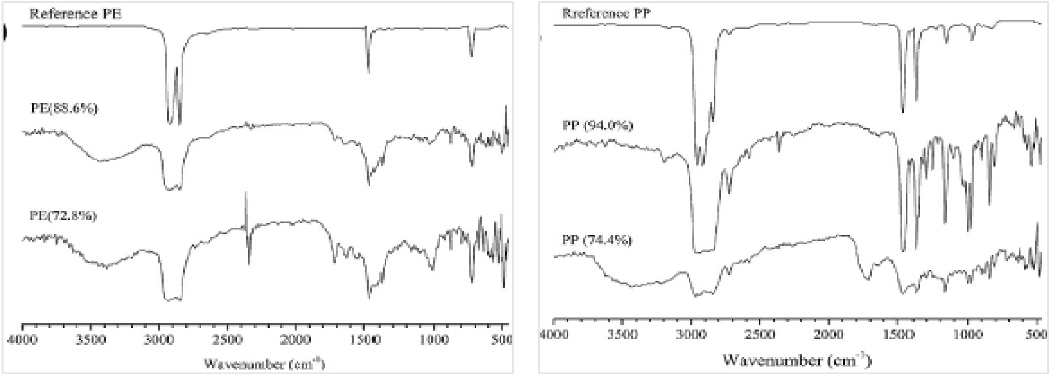


Figure 4.12: Variation in FT-IR spectra for PE and PP due to weathering of microplastics [111]

On analysis, it was found that the maximum items.m^{-2} was 488 microplastics per square meter, which belonged to the PE polymer category. Furthermore, the maximum items.kg^{-1} was 183.18 microplastics per kilogram of dry weight of sediment, which also belonged to the PE polymer category. The average items, items.m^{-2}, and average items.kg^{-1} of dry sediment in each of the two identified polymer type categories are presented in Table 4.4.

Table 4.4: Average microplastic abundance in sediments of the beaches in Dubai categorized by polymer type

	Items		**Items per m^2**		**Items per kg**	
Beach	**PE**	**PP**	**PE**	**PP**	**PE**	**PP**
1	16	14	65.60	55.20	15.09	12.30
2	13	8	52.00	30.40	10.14	6.06
3	4	5	16.00	19.20	4.64	8.24
4	23	5	91.20	20.80	33.48	8.29
5	51	26	202.40	102.40	82.30	41.93
6	7	3	28.80	11.20	9.80	3.70
7	9	4	34.40	16.80	11.10	5.59
8	7	0	28.80	1.60	10.84	0.55
9	9	2	36.80	8.00	21.45	4.46
10	17	9	67.20	34.40	14.97	6.94
11	4	7	14.40	26.40	4.21	7.15
12	2	3	8.80	11.20	2.28	3.95
13	2	3	6.40	13.60	5.00	13.79
14	2	5	8.80	19.20	2.99	5.87
15	4	1	16.00	2.40	4.88	0.70
16	15	2	58.40	8.00	22.20	2.72

One potential source of larger PE fibers is found to be HDPE ropes. Ropes are extensively used in marine environments in fishing activities and docking ships [110]. On further inspection of the larger fibers found in the beach sediments, it was observed that these were fragments of larger ropes. These ropes are manufactured by intertwining fibers to make thick ropes. Hence, due to the unwise disposal of these ropes in beaches and sea waters, they disintegrate and release microplastic fibers in marine environments. Additionally, the coloration of these larger fibers found in this study match with the coloration of the ropes sold commercially (Figure 4.13).

FT-IR analysis was conducted on ropes and colored fibers found in the beach sediment samples. It is observed that the spectra obtained for four different colored strings (shown in Figure 4.14 b, c, d, e. f) match with the spectra obtained for a rope (shown in Figure 4.14 a) extracted from the sampled beach sediments. Hence, it is verified that colored plastic fibers found in beach sediments are secondary microplastics which originate from ropes. The prevalence of fibrous microplastics could potentially result in a negative impact on marine fauna. Hence, this study urges authorities to consider strict regulatory policies to control of the use of synthetic ropes. Such strategies would help to limit, and in the long run, mitigate the fibrous microplastic contamination

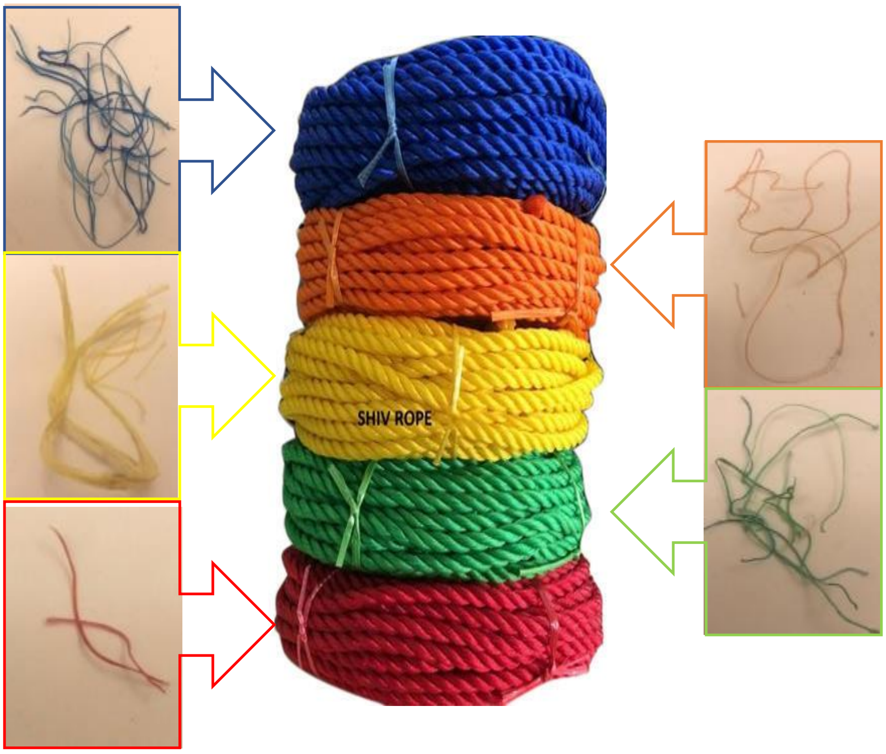


Figure 4.13: Coloration of plastic fibers extracted matched with commercially sold HDPE ropes

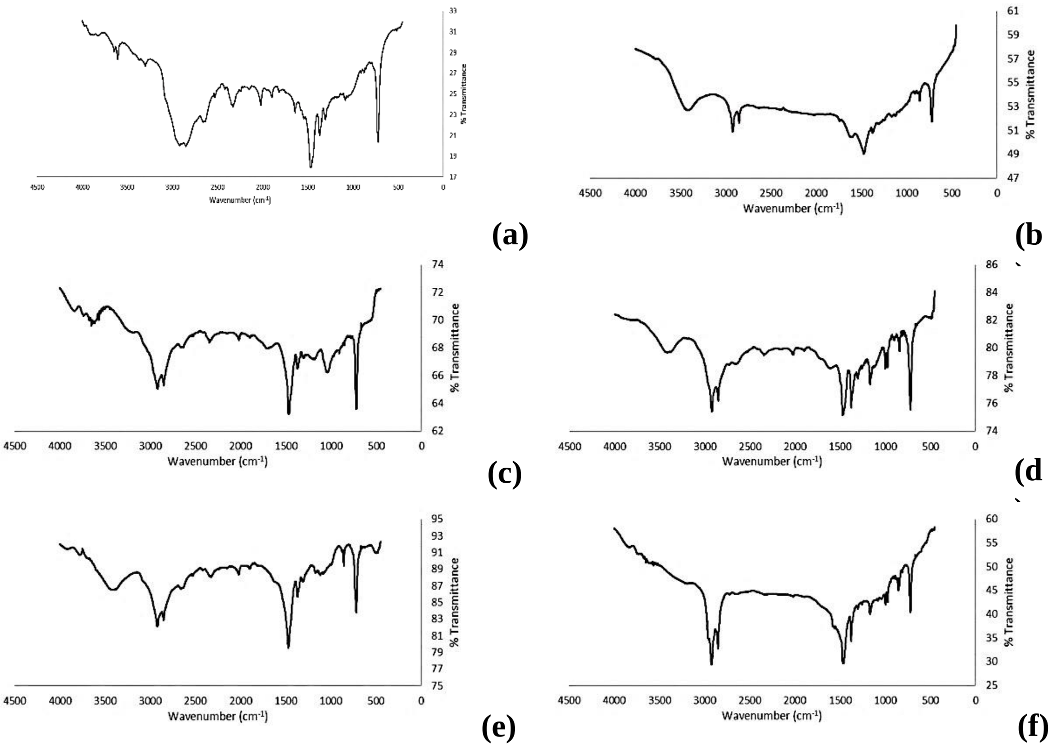


Figure 4.14: FT-IR spectrum produced from (a) rope (b) black fiber (c) blue fiber (d) orange fiber (e) yellow fiber (f) green fiber

4.5. Heavy Metals on Microplastics

The XRF analysis identified 14 heavy metals in the microplastics extracted from the beach sediments. The heavy metals identified are: Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Nickel (Ni), Copper (Cu), Zinc (Zn), Lead (Pb), Cerium (Ce), Pr (Praseodymium), Nd (Neodymium), Palladium (Pd), and cobalt (Co). From the 14 identified metals, Cr, Ni, Cu, Zn, and Pb are listed as priority pollutants by EPA. As observed from Figure 4.15, Iron was found in the most number of microplastics (25.11%), followed by Palladium (22.58 %), Nickel (14.86 %),Titanium (12.90 %), lead (7.02 %), Copper (6.45 %), and Zinc (5.12 %). Vanadium (1.20 %), Manganese (1.08%), Cerium (0.89%), neodymium (0.63%), Praseodymium (0.19 %), and Cobalt (0.06 %) were sparsely found.

Identification of beaches with abundant microplastics containing the heavy metals mentioned as priority pollutants by EPA is vital. The number of microplastics found in the 14 identified heavy metals have been presented in Table 4.5. Lead was found in all 30 microplastics tested from Beaches 1, 2, 6, 10, 11,13, 4, 15, and 16. Nickle was found in 25 microplastics tested from beach 2. Furthermore, beach 6 was found to have the highest number of microplastics containing Copper, i.e. 14 microplastics out of 30 were found to have Copper. Zinc was found in 11 microplastics out of the 30 tested in beach 7 and chromium was found in 7 microplastic out of the 30 in beach 11.

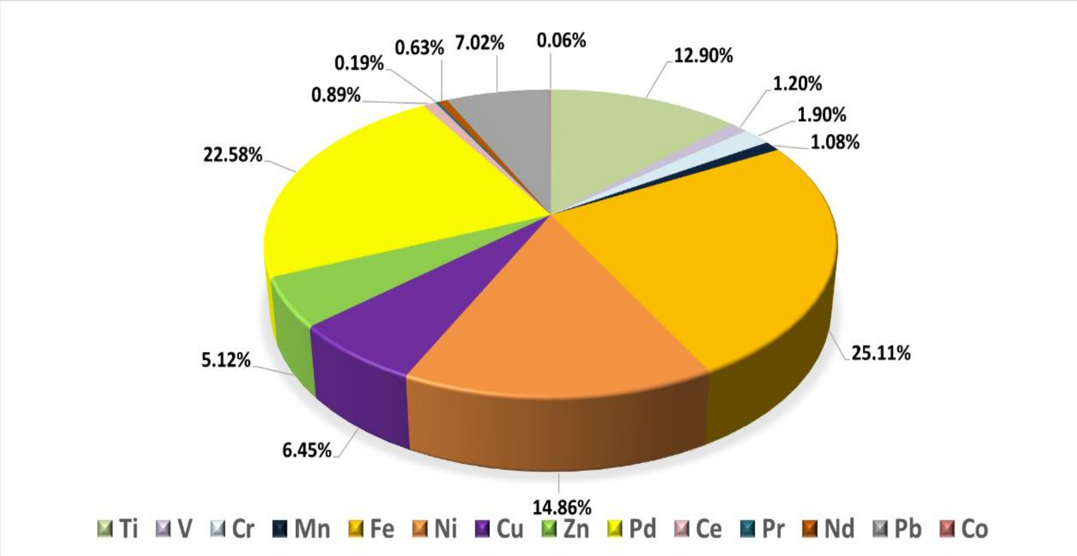


Figure 4.15: Proportion of Microplastics possessing the identified heavy metals

In addition to having information on the number of microplastics having heavy metals, it is important to understand the concentration of these heavy metals in these microplastics. The maximum and minimum percentage of heavy metal found in a microplastics from each of the 16 beaches are shown in Table 4.6. It is observed that the percentage of Ti is highest in the microplastics in comparison to the other heavy metals. The higher percentage of Ti in microplastics could be due to the addition of TiO_2 during the manufacturing process to serve as UV blockers or white pigment [113]. Additionally, research suggest degradation of microplastics could result in the release of TiO_2 [114]. Therefore, the presence of high concentration of Ti in the extracted microplastics from beach sediments could be detrimental as it could act as a potential source of Ti contamination in the beaches of Dubai. Furthermore, TiO_2 has been reported to be toxic to fishes [115]. Hence, the ingestion of these microplastic could result in the bioaccumulation of toxin in the food chain.

Table 4.5: Number of microplastics found in each of the identified heavy metals

Beach	Ti	V	Cr	Mn	Fe	Ni	Cu
1	17.0 (56.7 %)	1.0 (3.3 %)	3.0 (10 %)	1.0 (3.3 %)	23.0 (76.7 %)	23.0 (76.7 %)	7.0 (23.3 %)
2	12.0 (40.0 %)	0.0 (0.0 %)	3.0 (10.0 %)	0.0 (0.0%)	28.0 (93.3 %)	25.0 (83.3%)	2.0 (6.7 %)
3	15.0 (50.0 %)	1.0 (3.3 %)	0.0 (0.0 %)	1.0 (3.3 %)	25.0 (83.3 %)	23.0 (76.7 %)	3.0 (10.0 %)
4	6.0 (20.0 %)	0.0 (0.0 %)	1.0 (3.3 %)	1.0 (3.3 %)	26.0 (86.7 %)	10.0 (33.3 %)	9.0 (30.0 %)
5	13.0 (43.3 %)	0.0 (0.0 %)	0.0 (0.0 %)	1.0 (3.3 %)	27.0 (90.0 %)	14.0 (46.7 %)	2.0 (6.7 %)
6	15.0 (50.0 %)	0.0 (0.0 %)	1.0 (3.3 %)	3.0 (10.0 %)	27.0 (90.0 %)	22.0 (73.3 %)	14.0 (46.7 %)
7	16.0 (53.3 %)	2.0 (6.7%)	5.0 (16.7%)	3.0 (10.0%)	24.0 (80.0%)	8.0 (26.7 %)	7.0 (23.3 %)
8	9.0 (30.0 %)	2.0 0 (6.7%)	1.0 (3.3 %)	2.0 (6.7 %)	30.0 (100%)	23.0 (76.7 %)	10.0 (33.3%)
9	8.0 (26.7 %)	0.0 (0.0 %)	2.0 (6.7 %)	0.0 (0.0 %)	26.0 (86.7 %)	15.0 (50.0 %)	7.0 (23.3 %)
10	13.0 (43.3 %)	0.0 (0.0 %)	1.0 (3.3 %)	1.0 (3.3 %)	27.0 (90.0 %)	17.0 (56.7 %)	5.0 (16.7 %)
11	19.0 (63.3 %)	1.0 (3.3 %)	7.0 (23.3 %)	0.0 (0.0 %)	30.0 (100%)	1.0 (3.3 %)	7.0 (23.3 %)
12	8.0 (26.7 %)	0.0 (0.0 %)	0.0 (0.0 %)	1.0 (3.3 %)	18.0 (60 %)	15.0 (50.0%)	3.0 (10.0 %)
13	3.0 (10.0 %)	1.0 (3.3 %)	0.0 (0.0 %)	0.0 (0.0 %)	14.0 (14.7 %)	18.0 (60.0 %)	2.0 (6.7 %)
14	15.0 (50.0 %)	2.0 (6.7%)	1.0 (3.3 %)	1.0 (3.3 %)	26.0 (86.7 %)	0.0 (0.0 %)	4.0 (13.3 %)
15	23.0 (76.7 %)	7.0 (23.3 %)	1.0 (3.3 %)	1.0 (3.3 %)	27.0 (90.0 %)	4.0 (13.3 %)	10.0 (33.3 %)
16	14.0 (46.7 %)	0.0 (0.0 %)	3.0 (10.0 %)	0.0 (0.0 %)	23.0 (76.7 %)	17.0 (56.7 %)	9.0 (30.0 %)

Beach	Zn	Pd	Ce	Pr	Nd	Pb	Co
1	5.0 (16.7 %)	30.0 (100.0 %)	0.0 (0.0 %)	1.0 (3.3 %)	1.0 (3.3 %)	10.0 (33.3 %)	0.0 (0.0 %)
2	3.0 (10.0 %)	30.0 (100.0 %)	3.0 (10.0 %)	1.0 (3.3 %)	1.0 (3.3 %)	16.0 (53.3 %)	0.0 (0.0 %)
3	2.0 (6.7 %)	29.0 (96.7 %)	3.0 (10.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	11.0 (36.7 %)	0.0 (0.0 %)
4	3.0 (10.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	3.0 (10.0 %)	0.0 (0.0 %)
5	0.0 (0.0 %)	1.0 (3.3 %)	0.0 (0.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	6.0 (20.0 %)
6	5.0 (16.7 %)	30.0 (100.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	1.0 (3.3 %)	10.0 (33.3%)	0.0 (0.0 %)
7	11.0 (36.7 %)	0.0 (0.0 %)	1.0 (3.3 %)	0.0 (0.0 %)	2.0 (6.7 %)	1.0 (3.3 %)	0 (0.0 %)
8	2.0 (6.7 %)	29.0 (96.7 %)	0.0 (0.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	11.0 (36.7 %)	0 (0.0 %)
9	2.0 (6.7 %)	1.0 (3.3 %)	0.0 (0.0 %)	0.0 (0.0 %)	2.0 (6.7 %)	2.0 (6.7 %)	0 (0.0 %)
10	4.0 (13.3 %)	30.0 (100%)	0.0 (0.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	3.0 (10.0 %)	0.0 (0.0 %)
11	10.0 (33.3%)	30.0 (100%)	2.0 (6.7%)	1.0 (3.3 %)	1.0 (3.3 %)	8.0 (26.7 %)	0.0 (0.0 %)
12	0.0 (0.0 %)	29.0 (96.7 %)	0.0 (0.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	0.0 (0.0 %)
13	10.0 (33.3%)	30.0 (100%)	0.0 (0.0 %)	0.0 (0.0 %)	1.0 (3.3 %)	5.0 (16.7 %)	0.0 (0.0 %)
14	8.0 (26.7 %)	30.0 (100%)	2.0 (6.7%)	0.0 (0.0 %)	2.0 (6.7 %)	11.0 (36.7 %)	0.0 (0.0 %)
15	8.0 (26.7 %)	30.0 (100%)	2.0 (6.7%)	0.0 (0.0 %)	1.0 (3.3 %)	4.0 (13.3 %)	2.0 (6.7%)
16	7.0 (23.3 %)	30.0 (100%)	3.0 (10.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	10.0 (33.3%)	0.0 (0.0 %)

%= (Number of Micro plastic/30)*100

Table 4.6: Metal concentrations (%) carried by Microplastics in Beach Sediments

		Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Pd	Ce	Pr	Nd	Pb	Co
1	Max	76.3	1.2	0.6	0.5	4.1	0.8	0.6	2.4	5.0	0.0	0.6	0.7	6.0	0.0
	Min	0.0	1.2	0.2	0.5	0.1	0.0	0.0	0.3	0.1	0.0	0.6	0.7	0.0	0.0
2	Max	24.7	0.0	7.9	0.0	7.3	0.7	0.8	1.6	4.7	21.2	1.6	3.6	8.8	0.0
	Min	0.2	0.0	1.7	0.0	0.1	0.0	0.1	0.8	0.2	1.4	1.6	3.6	0.0	0.0
3	Max	49.3	0.8	0.0	0.1	4.6	2.4	0.8	0.5	31.6	20.4	0.0	0.0	1.4	0.0
	Min	0.2	0.8	0.2	0.1	0.1	0.0	0.0	0.1	0.1	1.4	0.6	0.7	0.0	00
4	Max	6.2	0.0	0.2	0.2	4.3	0.8	1.7	7.6	0.0	0.0	0.0	0.0	0.0	0.0
	Min	0.5	0.0	0.2	0.2	0.2	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
5	Max	54.9	0.0	0.0	0.4	2.3	0.7	0.7	0.0	1.2	0.0	0.0	0.0	0.0	0.1
	Min	0.2	0.0	0.0	0.4	0.4	0.1	0.1	0.0	1.2	0.0	0.0	0.0	0.0	0.0
6	Max	15.3	0.0	0.4	1.2	6.3	0.5	1.6	1.2	3.2	0.0	0.0	3.4	0.1	15.3
	Min	0.3	0.0	0.4	0.9	0.4	0.1	0.1	0.1	0.4	0.0	0.0	3.4	0.0	0.3
7	Max	38.6	0.4	4.5	0.6	6.4	1.1	0.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0
	Min	0.2	0.3	0.8	0.2	0.7	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	Max	64.3	1.1	0.0	0.2	6.9	0.6	0.4	0.9	4.5	0.0	0.0	0.0	0.3	64.3
	Min	0.4	0.8	0.0	0.1	0.3	0.0	0.1	0.1	0.3	0.0	0.0	0.0	0.0	0.4
9	Max	19.3	0.0	6.2	0.0	9.3	0.6	1.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
	Min	0.7	0.0	0.8	0.0	0.3	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
10	Max	65.3	0.0	12.0	0.1	2.6	0.8	0.7	1.4	7.8	0.0	0.0	0.0	18.6	65.3
	Min	1.3	0.0	12.0	0.1	0.2	0.1	0.1	0.1	0.2	0.0	0.0	0.0	0.0	1.3
11	Max	36.9	0.6	5.9	0.0	3.1	0.1	0.8	0.9	2.2	6.0	3.5	2.7	6.7	0.0
	Min	1.1	0.6	0.3	0.0	0.3	0.1	0.1	0.0	0.2	4.9	3.5	2.7	0.0	0.0
12	Max	11.4	0.0	0.0	0.2	3.3	0.9	0.9	0.0	4.6	0.0	0.0	0.0	0.0	0.0
	Min	0.3	0.0	0.0	0.2	0.6	0.2	0.2	0.0	0.5	0.0	0.0	0.0	0.0	0.0
13	Max	44.1	2.7	0.0	0.0	7.3	0.6	0.4	1.1	9.5	0.0	0.0	8.9	0.3	0.0
	Min	0.6	2.7	0.0	0.0	0.2	0.1	0.2	0.2	0.4	0.0	0.0	8.9	0.0	0.0
14	Max	70.4	2.2	8.0	2.4	3.1	0.0	0.4	1.2	2.9	14.9	0.0	0.2	18.3	0.0
	Min	0.3	1.8	8.0	2.4	0.1	0.0	0.1	0.1	0.1	14.7	0.0	0.2	0.0	0.0
15	Max	76.4	0.7	0.4	0.1	3.7	0.8	0.5	4.5	3.5	2.8	0.0	4.7	0.5	1.1
	Min	0.4	0.0	0.4	0.1	0.3	0.0	0.1	0.1	0.2	1.9	0.0	4.7	0.0	1.1
16	Max	19.7	0.0	1.0	0.0	30.5	0.7	4.0	0.7	7.1	3.6	0.0	0.0	3.0	0.0
	Min	0.1	0.0	0.8	0.0	0.2	0.0	0.0	0.1	0.2	0.9	0.0	0.0	0.0	0.0

Chapter 5. Conclusion

The increased documentation of microplastic contamination in beach sediments throughout the globe and the lack of studies reporting microplastic pollution in beaches along the coast of Dubai created a need to investigate this contamination.

In order to achieve the objectives of this study, samples of beach sediments were collected from 16 beaches in Dubai. Five samples were collected from each beach along 100 meters stretch using a 0.5 x 0.5 m steel quadrant. Microplastics were extracted from the samples by means of the density separation process. The separation medium was KI (d=1.62 g/mL). Microplastics were identified under a 40X dissecting microscope. The total number, weight, color, and shape of the extracted microplastics were recorded and analyzed.

The results showed that marine sediments in Dubai contained significant number of microplastics of different colors and shapes. The results obtained from the analysis of 80 samples procured from the wrack lines of 16 public beaches in Dubai demonstrate that the average weight of microplastic contamination is 0.33 mg. g^{-1} of sediment (or 953 $mg.m^{-2}$) and items of microplastic is 59.71 $items.kg^{-1}$ of sediment (or 165 $items.m^{-2}$).

Certain color and shape of microplastics have been reported to be more likely to be ingested by marine fauna. Hence, the coloration and shape of the extracted microplastics were documented and analyzed. In this study, 10 microplastic colorations were recorded: blue, red, green, yellow, black, white, grey, orange, pink, and transparent. Blue colored microplastics were dominant in the extracted microplastics in terms of number of particles (items). White colored microplastics were more dominant in terms of number of microplastics per meter square ($items.m^{-2}$) and number of microplastics per kg of dry sediment (items. kg^{-1}). Blue colored microplastics have been reported to be dominantly ingested by King crabs, fish larvae, marine turtles, and seals. Furthermore, studies have shown that white colored microplastics are ingested by zooplankton community due to resemblance to their prey [23]. Moreover, four shapes of microplastics were observed: fiber, string, pieces, and polystyrene spheres. Fibrous microplastics were more abundantly found in the beach sediments of Dubai in terms of number of microplastics (items), number of microplastics per square meter ($items.m^{-2}$), and number of microplastics per kilogram of dry sediment (items. kg^{-1}). This study has found that beaches 1, 4, 5, 7, 9, 10, and 13 are predominantly contaminated with blue and white colored microplastics as well as fibrous microplastics. Hence, the study recommends that authorities pay close attention to these findings in order to understand the possible source(s) of colored and fibrous microplastics in these beaches and organize clean up drives to reduce the negative impact of these microplastics on marine fauna.

FT-IR analysis was used to determine the synthetic origin of the dominant forms of extracted microplastics, fibers and strings. In addition, FT-IR analysis was performed only on fibers and strings that were sufficiently large to handle using forceps; i.e. microscopic fibers and strings were not included in this analysis. Therefore, the polymer types of 1396 microplastics (fibers and strings) were identified. In the samples tested, two polymer types were found: polyethylene (PE) and polypropylene (PP). 63.67% of the samples tested were PE and 32.94% of the samples were PP. Additionally, it was observed that all colored fibers were PE and white colored strings and fibers were found to be PP. Furthermore, this research found that the major source of fibrous microplastics in beaches in Dubai is HDPE ropes. Hence, the present study urges authorities to limit the production and usage of such ropes.

XRF analysis showed the presence of 14 heavy metals on the extracted microplastics. A representative sample of 30 microplastics was selected from the microplastics extracted from the beach sediments of each of the 16 beaches. Hence, in total, 480 microplastics were analyzed through XRF analysis to determine the heavy metals contained by these microplastics. The heavy metals identified are: Titanium (Ti), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Nickel (Ni), Copper (Cu), Zinc (Zn), Lead (Pb), Cerium (Ce), Pr (Praseodymium), Nd (Neodymium), Palladium (Pd), and Cobalt (Co). EPA lists Cr, Ni, Cu, Zn, and Pb as priority pollutants from the 14 identified metals. Iron was found in the most number of microplastics (25.11%), followed by Palladium (22.58 %), Nickel (14.86 %), Titanium (12.90 %), Lead (7.02 %), copper (6.45 %), and Zinc (5.12 %). Vanadium (1.20 %), Manganese (1.08%), Cerium (0.89%), Neodymium (0.63%), Praseodymium (0.19 %), and Cobalt (0.06 %) were sparsely found. In addition, the percentage of Ti in microplastics is found to be the highest compared to the other heavy metals. The higher percentage of Ti in microplastics may be due to the addition of TiO_2 to serve as UV blockers or white pigment during the manufacturing process.

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Appendix A

Table A.1: Longitude and latitude coordinates of sampled locations

Beach	Location	Longitude	Latitude	Beach	Location	Longitude	Latitude
1	Location 1	25.3264419	55.35102546	2	Location 1	25.32245462	55.34721241
	Location 2	25.32646779	55.35124334		Location 2	25.32221293	55.34719968
	Location 3	25.32666079	55.35172452		Location 3	25.32199122	55.34712241
	Location 4	25.32696698	55.35201075		Location 4	25.32133767	55.34656788
	Location 5	25.32726954	55.35215094		Location 5	25.32146206	55.34673458
3	Location 1	25.31961991	55.34444186	4	Location 1	25.2158698	55.24792907
	Location 2	25.31937757	55.34463618		Location 2	25.21603086	55.24812247
	Location 3	25.31897097	55.34476827		Location 3	25.21609476	55.24824725
	Location 4	25.31864029	55.34482856		Location 4	25.2163175	55.24849389
	Location 5	25.31839400	55.34476405		Location 5	25.21643522	55.24861448
5	Location 1	25.21476556	55.24749929	6	Location 1	25.20538067	55.2397362
	Location 2	25.21461894	55.24734882		Location 2	25.20551947	55.23984312
	Location 3	25.21455889	55.24729568		Location 3	25.20563929	55.23991221
	Location 4	25.21439295	55.24712042		Location 4	25.20585901	55.24004644
	Location 5	25.21425821	55.24696265		Location 5	25.20618316	55.24023454
7	Location 1	25.19274646	55.22987610	8	Location 1	25.186530389	55.225402728
	Location 2	25.19300277	55.22995541		Location 2	25.186647344	55.225606539
	Location 3	25.19309315	55.23014855		Location 3	25.186833072	55.225867189
	Location 4	25.19319106	55.23035784		Location 4	25.18719679	55.226251644
	Location 5	25.19331738	55.23057649		Location 5	25.186231511	55.224613206`
9	Location 1	25.18327398	55.22219933	10	Location 1	25.17787398	55.21836463
	Location 2	25.18306600	55.22216702		Location 2	25.17736958	55.21828431
	Location 3	25.18272082	55.22210771		Location 3	25.17712982	55.21821297
	Location 4	25.18259028	55.22207535		Location 4	25.17699419	55.21818148
	Location 5	25.18228412	55.2220063		Location 5	25.17677289	55.21810322
11	Location 1	25.17210693	55.21175382	12	Location 1	25.17787398	55.21836463
	Location 2	25.17202448	55.21174152		Location 2	25.17736958	55.21828431
	Location 3	25.17118761	55.21158532		Location 3	25.17712982	55.21821297
	Location 4	25.17061036	55.21147647		Location 4	25.17699419	55.21818148
	Location 5	25.17002277	55.21133228		Location 5	25.17677289	55.21810322
13	Location 1	25.16363266	55.20655254	14	Location 1	25.1617037	55.20468166
	Location 2	25.16403401	55.20668764		Location 2	25.16129291	55.20452297
	Location 3	25.16448014	55.20677976		Location 3	25.16108027	55.20445235
	Location 4	25.16486419	55.20695436		Location 4	25.16072774	55.2044046
	Location 5	25.16517302	55.20699454		Location 5	25.16041281	55.20434545
15	Location 1	25.11677787	55.16640027	16	Location 1	25.08333912	55.13528749
	Location 2	25.11688337	55.16654599		Location 2	25.08353847	55.13541047
	Location 3	25.11708424	55.16680422		Location 3	25.08369048	55.13552662
	Location 4	25.11725623	55.16702435		Location 4	25.08387417	55.13564516
	Location 5	25.11753408	55.16738395		Location 5	25.08431144	55.13588821

Table A.2: Measured microplastic quantities in beach sediments from each of the sampling location

Beach	Sample #	mg.g^{-1}	mg .m^{-2}	Items.Kg^{-1}	Items.m-^{2}	Beach	Sample #	mg.g^{-1}	mg .m^{-2}	Items.Kg^{-1}	Items.m-^{2}
1	1	0.41	2554	62	384	2	1	0.03	57	32	72
	2	0.15	598	49	192		2	0.06	115	16	32
	3	0.28	967	61	212		3	0.15	270	46	80
	4	0.22	110	56	280		4	0.27	1213	28	128
	5	0.29	1519	38	200		5	0.09	271	35	108
3	1	0.09	402	24	112	4	1	0.21	1179	99	556
	2	0.13	777	60	348		2	0.22	1086	39	196
	3	0.02	120	19	104		3	0.34	987	28	80
	4	0.15	348	29	68		4	0.24	522	44	96
	5	0.06	200	37	128		5	0.50	2369	62	296
5	1	0.53	2108	53	208	6	1	0.02	86	6	24
	2	0.25	600	39	96		2	0.07	295	10	44
	3	0.10	288	38	108		3	0.06	104	12	20
	4	0.30	1244	61	256		4	0.07	156	9	20
	5	0.39	1075	32	88		5	0.35	1350	5	20
7	1	0.30	568	137	264	8	1	3.70	10455	35	100
	2	0.02	35	144	204		2	1.09	2441	36	80
	3	0.08	196	60	148		3	0.63	2335	40	148
	4	1.74	1718	259	256		4	0.43	1640	68	260
	5	0.25	243	62	60		5	1.36	4338	19	60
9	1	0.04	67	90	164	10	1	0.02	41	37	100
	2	0.40	651	66	108		2	0.05	115	42	104
	3	0.14	266	93	176		3	0.06	175	38	120
	4	0.21	350	40	68		4	0.12	302	21	52
	5	0.49	813	185	308		5	0.07	193	41	108
11	1	0.07	210	41	120	12	1	0.04	139	47	156
	2	0.03	8895	33	100		2	0.11	352	37	120
	3	0.06	191	43	136		3	0.09	233	37	100
	4	0.24	665	41	116		4	0.64	1381	56	120
	5	0.04	96	49	132		5	0.12	520	85	356
13	1	0.16	314	65	124	14	1	0.16	274	89	148
	2	0.09	165	39	72		2	0.89	2000	67	152
	3	1.16	3012	72	188		3	0.18	572	147	476
	4	0.25	953	27	100		4	0.46	757	98	160
	5	0.42	1580	30	112		5	0.14	494	54	192
15	1	0.22	637	25	72	16	1	0.02	44	31	88
	2	1.46	3768	236	608		2	0.05	107	58	124
	3	0.71	1886	302	804		3	0.68	2794	88	360
	4	0.27	668	0	0		4	0.25	646	63	164
	5	0.22	405	108	200		5	0.17	376	66	144

Table A.3: Number of microplastics (items) in each color category

B #	S #	T	B	G	R	Y	B_1	W	G_1	O	P	B #	S #	T	B	G	R	Y	B_1	W	G_1	O	P
	1	14	35	32	12	4	0	40	0	2	0		1		11	4	4	1	20	1	0	0	0
	2	5	19	15	1	2	2	5	0	0	0		2	0	12	6	1	1	6	1	0	0	0
1	3	1	5	3	2	2	1	3	3	0	0	9	3	2	17	4	5	0	11	5	0	0	0
	4	3	7	6	0	0	0	7	1	0	0		4	0	8	3	2	0	3	1	0	0	0
	5	6	21	11	4	7	3	19	1	1	1		5	2	20	9	9	0	33	4	0	0	0
	1	1	10	5	1	1	1	9	0	0	0		1	9	18	19	17	1	6	25	0	1	0
	2	4	18	21	3	9	7	24	0	1	0		2	13	11	9	1	1	0	13	0	0	0
2	3	2	8	7	3	1	4	1	0	0	0	10	3	2	13	14	3	4	7	10	0	0	0
	4	1	11	3	0	0	1	1	0	0	0		4	5	28	12	6	3	5	11	0	0	0
	5	9	3	11	2	0	2	3	0	0	2		5	1	15	11	8	1	7	7	0	0	0
	1	0	9	0	3	0	3	3	0	0	0		1	6	17	9	3	6	2	9	0	0	0
	2	0	1	1	1	0	1	4	0	0	0		2	0	7	3	5	3	4	2	0	0	0
3	3	2	3	2	0	0	3	10	0	0	0	11	3	0	4	14	3	0	5	1	0	0	0
	4	0	10	9	1	1	3	8	0	0	0		4	0	13	3	16	5	9	18	0	0	0
	5	3	9	7	0	1	1	6	0	0	0		5	4	9	3	0	0	6	0	0	0	0
	1	0	2	0	1	1	2	18	0	1	0		1	0	1	3	0	0	0	2	0	0	0
	2	0	6	0	1	0	5	4	0	4	0		2	0	3	2	0	0	0	6	0	0	0
4	3	0	8	0	19	3	7	0	0	0	0	12	3	3	0	0	0	0	0	2	0	0	0
	4	1	11	2	18	1	16	16	0	0	0		4	0	0	1	0	0	0	4	0	0	0
	5	0	4	2	2	0	5	2	0	0	0		5	0	2	1	0	0	0	2	0	0	0
	1	0	4	1	5	1	4	2	0	1	0		1	0	11	2	37	2	12	0	0	2	0
	2	3	40	36	1	6	16	44	1	1	4		2	0	8	2	10	1	24	1	0	5	0
5	3	0	54	55	1	5	17	61	0	8	0	13	3	0	8	0	19	3	7	0	0	0	0
	4	14	11	11	7	4	7	13	1	1	14		4	0	11	2	18	1	16	16	0	0	0
	5	1	11	15	2	5	8	6	0	1	1		5	0	4	2	2	0	5	2	0	0	0
	1	5	4	3	1	7	10	0	0	0	0		1	0	2	0	1	1	2	18	0	1	0
	2	3	2	3	7	0	8	1	0	1	0		2	0	6	0	1	0	5	4	0	4	0
6	3	0	5	14	4	2	4	4	1	0	0	14	3	0	8	0	19	3	7	0	0	0	0
	4	1	4	6	6	3	5	2	0	2	0		4	1	11	2	18	1	16	16	0	0	0
	5	0	5	4	13	3	5	3	0	0	0		5	0	4	2	2	0	5	2	0	0	0
	1	1	16	4	7	0	7	4	0	0	0		1	1	3	0	2	0	16	0	0	0	0
	2	3	9	3	0	2	5	8	0	0	0		2	11	7	4	3	0	6	0	0	0	0
7	3	1	6	6	3	0	5	3	0	1	0	15	3	40	29	10	1	5	2	3	0	0	0
	4	3	8	1	0	1	9	8	0	0	0		4	2	10	0	14	1	9	3	0	2	0
	5	1	33	2	20	1	25	6	0	1	0		5	2	10	5	7	0	10	2	0	0	0
	1	1	15	4	0	1	3	1	0	0	0		1	0	8	8	1	0	7	5	0	2	0
	2	2	7	13	0	1	2	1	0	0	0		2	1	5	8	0	0	2	2	0	0	0
8	3	0	12	5	3	1	8	1	0	0	0	16	3	0	14	11	7	3	6	5	0	0	1
	4	0	4	2	3	2	2	0	0	0	0		4	0	13	4	0	0	2	6	0	0	0
	5	0	9	2	14	0	2	0	0	0	0		5	1	11	6	1	0	3	6	0	0	0

T = Transparent, B = Blue, G = Green, R = Red, Y = Yellow, B1 = Black, W = White, G1 = Grey, O = Orange, P = Pink

Table A.4: Number of microplastics per square meter (items.m^{-2}) in each color category

B #	S #	T	B	G	R	Y	B_1	W	G_1	O	P	B #	T	B	G	R	Y	B_1	W	G_1	O	P
	1	36	12	44	8	0	8	12	0	0	8		0	16	8	8	0	20	8	0	0	0
	2	56	140	128	48	16	0	160	0	8	0		0	44	16	16	4	80	4	0	0	0
1	3	20	76	60	4	8	8	20	0	0	0	**9**	0	48	24	4	4	24	4	0	0	0
	4	4	20	12	8	8	4	12	12	0	0		8	68	16	20	0	44	20	0	0	0
	5	12	28	24	0	0	0	28	4	0	0		0	32	12	8	0	12	4	0	0	0
	1	0	0	0	0	0	0	0	0	0	0		36	72	76	68	4	24	100	0	4	0
	2	4	40	20	4	4	4	36	0	0	0		52	44	36	4	4	0	52	0	0	0
2	3	16	72	84	12	36	28	96	0	4	0	**10**	8	52	56	12	16	28	40	0	0	0
	4	8	32	28	12	4	16	4	0	0	0		20	112	48	24	12	20	44	0	0	0
	5	4	44	12	0	0	4	4	0	0	0		4	60	44	32	4	28	28	0	0	0
	1	0	36	0	12	0	12	12	0	0	0		24	84	44	16	28	12	76	4	4	4
	2	0	4	4	4	0	4	16	0	0	0		24	68	36	12	24	8	36	0	0	0
3	3	8	12	8	0	0	12	40	0	0	0	**11**	0	28	12	20	12	16	8	0	0	0
	4	0	40	36	4	4	12	32	0	0	0		0	16	56	12	0	20	4	0	0	0
	5	12	36	28	0	4	4	24	0	0	0		0	52	12	64	20	36	72	0	0	0
	1	4	44	24	4	0	12	24	0	0	0		16	36	12	0	0	24	0	0	0	0
	2	0	28	32	8	68	8	4	0	0	0		0	4	12	0	0	0	8	0	0	0
4	3	0	8	12	0	76	16	32	4	4	0	**12**	0	12	8	0	0	0	24	0	0	0
	4	20	156	88	48	32	68	64	0	0	0		12	0	0	0	0	0	8	0	0	0
	5	0	44	8	16	36	24	24	4	4	0		0	0	4	0	0	0	16	0	0	0
	1	0	64	52	0	28	8	24	0	12	4		0	8	4	0	0	0	8	0	0	0
	2	0	16	4	20	4	16	8	0	4	0		0	44	8	148	8	48	0	0	8	0
5	3	12	160	144	4	24	64	176	4	4	16	**13**	0	32	8	40	4	96	4	0	20	0
	4	56	44	44	28	16	28	52	4	4	0		0	32	0	76	12	28	0	0	0	0
	5	4	44	60	8	20	32	24	0	4	4		0	44	8	72	4	64	64	0	0	0
	1	0	36	8	56	0	8	0	0	0	0		0	16	8	8	0	20	8	0	0	0
	2	20	16	12	4	28	40	0	0	0	0		0	8	0	4	4	8	72	0	4	0
6	3	12	8	12	28	0	32	4	0	4	0	**14**	0	24	0	4	0	20	16	0	16	0
	4	0	20	56	16	8	16	16	4	0	0		0	32	0	76	12	28	0	0	0	0
	5	4	16	24	24	12	20	8	0	8	0		4	44	8	72	4	64	64	0	0	0
	1	0	20	16	52	12	20	12	0	0	0		4	12	0	8	0	64	0	0	0	0
	2	4	64	16	28	0	28	16	0	0	0		44	28	16	12	0	24	0	0	0	0
7	3	12	36	12	0	8	20	32	0	0	0	**15**	160	116	40	4	20	8	12	0	0	0
	4	4	24	24	12	0	20	12	0	4	0		8	40	0	56	4	36	12	0	8	0
	5	12	32	4	0	4	36	32	0	0	0		8	40	20	28	0	40	8	0	0	0
	1	8	80	36	36	0	132	16	0	0	0		4	132	8	80	4	100	24	0	4	0
	2	4	60	16	0	4	12	4	0	0	0		0	32	32	4	0	28	20	0	8	0
8	3	8	28	52	0	4	8	4	0	0	0	**16**	4	20	32	0	0	8	8	0	0	0
	4	0	48	20	12	4	32	4	0	0	0		0	56	44	28	12	24	20	0	0	4
	5	0	16	8	12	8	8	0	0	0	0		0	52	16	0	0	8	24	0	0	0

Table A.5: Number of microplastics per kilogram dry weight of sediment (items.kg^{-1}) in each color category

B #	S #	T	B	G	R	Y	B_1	W	G_1	O	P	B #	S #	T	B	G	R	Y	B_1	W	G_1	O	P
	1	14	35	32	12	4	0	40	0	2	0		1		11	4	4	1	20	1	0	0	0
	2	5	19	15	1	2	2	5	0	0	0		2	0	12	6	1	1	6	1	0	0	0
1	3	1	5	3	2	2	1	3	3	0	0	9	3	2	17	4	5	0	11	5	0	0	0
	4	3	7	6	0	0	0	7	1	0	0		4	0	8	3	2	0	3	1	0	0	0
	5	6	21	11	4	7	3	19	1	1	1		5	2	20	9	9	0	33	4	0	0	0
	1	1	10	5	1	1	1	9	0	0	0		1	9	18	19	17	1	6	25	0	1	0
	2	4	18	21	3	9	7	24	0	1	0		2	13	11	9	1	1	0	13	0	0	0
2	3	2	8	7	3	1	4	1	0	0	0	10	3	2	13	14	3	4	7	10	0	0	0
	4	1	11	3	0	0	1	1	0	0	0		4	5	28	12	6	3	5	11	0	0	0
	5	9	3	11	2	0	2	3	0	0	2		5	1	15	11	8	1	7	7	0	0	0
	1	0	9	0	3	0	3	3	0	0	0		1	6	17	9	3	6	2	9	0	0	0
	2	0	1	1	1	0	1	4	0	0	0		2	0	7	3	5	3	4	2	0	0	0
3	3	2	3	2	0	0	3	10	0	0	0	11	3	0	4	14	3	0	5	1	0	0	0
	4	0	10	9	1	1	3	8	0	0	0		4	0	13	3	16	5	9	18	0	0	0
	5	3	9	7	0	1	1	6	0	0	0		5	4	9	3	0	0	6	0	0	0	0
	1	0	7	8	2	17	2	1	0	0	0		1	0	1	3	0	0	0	2	0	0	0
	2	0	2	3	0	19	4	8	1	1	0		2	0	3	2	0	0	0	6	0	0	0
4	3	5	39	22	12	8	17	16	0	0	0	12	3	3	0	0	0	0	0	2	0	0	0
	4	0	11	2	4	9	6	6	1	1	0		4	0	0	1	0	0	0	4	0	0	0
	5	0	16	13	0	7	2	6	0	3	1		5	0	2	1	0	0	0	2	0	0	0
	1	0	4	1	5	1	4	2	0	1	0		1	0	11	2	37	2	12	0	0	2	0
	2	3	40	36	1	6	16	44	1	1	4		2	0	8	2	10	1	24	1	0	5	0
5	3	0	54	55	1	5	17	61	0	8	0	13	3	0	8	0	19	3	7	0	0	0	0
	4	23	18	18	11	7	11	21	2	2	0		4	0	11	2	18	1	16	16	0	0	0
	5	1	11	15	2	5	8	6	0	1	1		5	0	4	2	2	0	5	2	0	0	0
	1	1	5	4	3	1	7	10	0	0	0		1	0	2	0	1	1	2	18	0	1	0
	2	2	3	2	3	7	0	8	1	0	1		2	0	6	0	1	0	5	4	0	4	0
6	3	3	0	5	14	4	2	4	4	1	0	14	3	0	8	0	19	3	7	0	0	0	0
	4	4	1	4	6	6	3	5	2	0	2		4	1	11	2	18	1	16	16	0	0	0
	5	5	0	5	4	13	3	5	3	0	0		5	0	4	2	2	0	5	2	0	0	0
	1	1	1	16	4	7	0	7	4	0	0		1	1	3	0	2	0	16	0	0	0	0
	2	2	3	9	3	0	2	5	8	0	0		2	11	7	4	3	0	6	0	0	0	0
7	3	3	1	6	6	3	0	5	3	0	1	15	3	40	29	10	1	5	2	3	0	0	0
	4	4	3	8	1	0	1	9	8	0	0		4	2	10	0	14	1	9	3	0	2	0
	5	5	1	33	2	20	1	25	6	0	1		5	2	10	5	7	0	10	2	0	0	0
	1	1	15	4	0	1	3	1	0	0	0		1	0	8	8	1	0	7	5	0	2	0
	2	2	7	13	0	1	2	1	0	0	0		2	1	5	8	0	0	2	2	0	0	0
8	3	0	12	5	3	1	8	1	0	0	0	16	3	0	14	11	7	3	6	5	0	0	1
	4	0	4	2	3	2	2	0	0	0	0		4	0	13	4	0	0	2	6	0	0	0
	5	0	9	2	14	0	2	0	0	0	0		5	1	11	6	1	0	3	6	0	0	0

T = Transparent, B = Blue, G = Green, R = Red, Y = Yellow, B1 = Black, W = White, G1 = Grey, O = Orange, P = Pink

Table A.6: Number of microplastics (items) in each shape category

Beach	Location	Fiber	String	Fragment	Styrofoam Balls	Beach	Location	Fiber	String	Fragment	Styrofoam Balls
	1	52	38	47	2		1	37	1	3	0
	2	25	4	19	1		2	23	0	4	0
1	3	5	3	12	0	**9**	3	33	5	6	0
	4	10	7	7	0		4	15	1	1	0
	5	37	17	17	3		5	66	3	8	0
	1	16	9	3	0		1	50	19	27	0
	2	52	24	9	2		2	20	3	16	9
2	3	12	1	13	0	**10**	3	40	8	4	1
	4	1	1	15	0		4	51	6	8	5
	5	14	3	15	0		5	40	7	3	0
	1	14	2	2	0		1	18	4	8	0
	2	2	3	3	0		2	21	9	22	0
3	3	6	10	4	0	**11**	3	17	4	3	0
	4	17	7	8	0		4	24	1	2	0
	5	11	2	12	2		5	45	18	1	0
	1	33	2	2	0		1	10	1	11	0
	2	29	7	1	1		2	4	2	0	0
4	3	85	10	24	0	**12**	3	4	4	2	1
	4	31	3	3	3		4	0	2	3	0
	5	39	4	5	0		5	1	4	0	0
	1	13	1	3	1		1	2	2	1	0
	2	97	43	11	1		2	61	0	5	0
5	3	122	60	19	0	**13**	3	37	0	13	1
	4	40	18	11	0		4	30	0	7	0
	5	40	6	4	0		5	47	15	2	0
	1	18	4	8	0		1	9	2	4	0
	2	13	1	11	0		2	6	4	15	0
6	3	23	8	3	0	**14**	3	15	3	2	0
	4	15	0	12	2		4	30	0	7	0
	5	26	1	4	2		5	47	15	3	0
	1	33	4	2	0		1	20	0	2	0
	2	17	5	6	2		2	13	0	18	0
7	3	16	2	6	1	**15**	3	27	2	61	0
	4	15	5	9	1		4	26	1	14	0
	5	77	5	6	1		5	21	0	13	2
	1	12	1	12	0		1	18	1	10	2
	2	18	0	7	1		2	15	0	2	1
8	3	27	1	2	0	**16**	3	35	4	8	0
	4	11	0	2	0		4	12	3	9	1
	5	26	0	1	0		5	19	2	6	1

Table A.7: Number of microplastics per square meter (items.m^{-2}) in each shape category

Beach	Location	Fiber	String	Fragment	Styrofoam Balls	Beach	Location	Fiber	String	Fragment	Styrofoam Balls
1	1	208	152	188	8	**9**	1	148	4	12	0
	2	100	16	76	4		2	92	0	16	0
	3	20	12	48	0		3	132	20	24	0
	4	40	28	28	0		4	60	4	4	0
	5	148	68	68	12		5	264	12	32	0
2	1	64	36	12	0	**10**	1	200	76	108	0
	2	208	96	36	8		2	80	12	64	36
	3	48	4	52	0		3	160	32	16	4
	4	4	4	60	0		4	204	24	32	20
	5	56	12	60	0		5	160	28	12	0
3	1	56	8	8	0	**11**	1	84	36	88	0
	2	8	12	12	0		2	68	16	12	0
	3	24	40	16	0		3	96	4	8	0
	4	68	28	32	0		4	180	72	4	0
	5	44	8	48	8		5	40	4	44	0
4	1	132	8	8	0	**12**	1	16	8	0	0
	2	116	28	4	4		2	16	16	8	4
	3	340	40	96	0		3	0	8	12	0
	4	124	12	12	12		4	4	16	0	0
	5	156	16	20	0		5	8	8	4	0
5	1	52	4	12	4	**13**	1	244	0	20	0
	2	388	172	44	4		2	148	0	52	4
	3	488	240	76	0		3	120	0	28	0
	4	160	72	44	0		4	188	60	8	0
	5	160	24	16	0		5	36	8	16	0
6	1	72	16	32	0	**14**	1	24	16	60	0
	2	52	4	44	0		2	60	12	8	0
	3	92	32	12	0		3	120	0	28	0
	4	60	0	48	8		4	188	60	12	0
	5	104	4	16	8		5	36	8	16	0
7	1	132	16	8	0	**15**	1	80	0	8	0
	2	68	20	24	8		2	52	0	72	0
	3	64	8	24	4		3	108	8	244	0
	4	60	20	36	4		4	104	4	56	0
	5	308	20	24	4		5	84	0	52	8
8	1	48	4	48	0	**16**	1	72	4	40	8
	2	72	0	28	4		2	60	0	8	4
	3	108	4	8	0		3	140	16	32	0
	4	44	0	8	0		4	48	12	36	4
	5	104	0	4	0		5	76	8	24	4

Table A.8: Number of microplastics per kilogram dry weight of sediment (items.kg-1) in each shape category

Beach	Sample #	Fiber	String	Fragment	Styrofoam Balls	Beach	Location	Fiber	String	Fragment	Styrofoam Balls
1	1	36.88	26.95	33.33	1.42	**9**	1	80.79	2.18	6.55	0.00
	2	20.03	3.21	15.22	0.80		2	56.37	0.00	9.80	0.00
	3	6.90	4.14	16.55	0.00		3	69.47	10.53	12.63	0.00
	4	18.52	12.96	12.96	0.00		4	35.46	2.36	2.36	0.00
	5	30.99	14.24	14.24	2.51		5	158.65	7.21	19.23	0.00
2	1	13.83	7.78	2.59	0.00	**10**	1	32.40	12.31	17.50	0.00
	2	35.94	16.59	6.22	1.38		2	20.28	3.04	16.23	9.13
	3	8.62	0.72	9.34	0.00		3	46.19	9.24	4.62	1.15
	4	1.72	1.72	25.77	0.00		4	40.70	4.79	6.38	3.99
	5	16.24	3.48	17.40	0.00		5	30.44	5.33	2.28	0.00
3	1	25.18	3.60	3.60	0.00	**11**	1	21.30	9.13	22.31	0.00
	2	3.96	5.94	5.94	0.00		2	27.82	6.55	4.91	0.00
	3	13.76	22.94	9.17	0.00		3	34.19	1.42	2.85	0.00
	4	14.99	6.17	7.05	0.00		4	43.02	17.21	0.96	0.00
	5	14.16	2.57	15.44	2.57		5	14.53	1.45	15.99	0.00
4	1	78.95	4.78	4.78	0.00	**12**	1	3.79	1.90	0.00	0.00
	2	51.42	12.41	1.77	1.77		2	3.73	3.73	1.86	0.93
	3	105.20	12.38	29.70	0.00		3	0.00	4.81	7.21	0.00
	4	75.79	7.33	7.33	7.33		4	1.81	7.25	0.00	0.00
	5	44.07	4.52	5.65	0.00		5	2.05	2.05	1.03	0.00
5	1	17.74	1.36	4.09	1.36	**13**	1	126.96	0.00	10.41	0.00
	2	150.62	66.77	17.08	1.55		2	104.13	0.00	36.59	2.81
	3	183.18	90.09	28.53	0.00		3	48.62	0.00	11.35	0.00
	4	85.65	38.54	23.55	0.00		4	189.99	60.64	8.08	0.00
	5	86.02	12.90	8.60	0.00		5	37.45	8.32	16.65	0.00
6	1	24.76	5.50	11.00	0.00	**14**	1	8.49	5.66	21.22	0.00
	2	17.40	1.34	14.73	0.00		2	26.83	5.37	3.58	0.00
	3	29.15	10.14	3.80	0.00		3	32.29	0.00	7.53	0.00
	4	21.46	0.00	17.17	2.86		4	49.47	15.79	3.16	0.00
	5	38.92	1.50	5.99	2.99		5	11.32	2.52	5.03	0.00
7	1	39.81	4.83	2.41	0.00	**15**	1	28.21	0.00	2.82	0.00
	2	20.71	6.09	7.31	2.44		2	24.21	0.00	33.52	0.00
	3	23.49	2.94	8.81	1.47		3	26.26	1.95	59.34	0.00
	4	27.88	9.29	16.73	1.86		4	40.19	1.55	21.64	0.00
	5	73.83	4.79	5.75	0.96		5	38.25	0.00	23.68	3.64
8	1	17.60	1.47	17.60	0.00	**16**	1	37.74	2.10	20.96	4.19
	2	29.08	0.00	11.31	1.62		2	32.47	0.00	4.33	2.16
	3	34.53	1.28	2.56	0.00		3	53.93	6.16	12.33	0.00
	4	18.15	0.00	3.30	0.00		4	12.74	3.18	9.55	1.06
	5	39.22	0.00	1.51	0.00		5	20.34	2.14	6.42	1.07

Vita

Huda Aslam was born in 1995, in Karnataka, India. She received her primary and secondary education at the Indian High School, Dubai, UAE. Subsequently, she completed her Bachelor of Science Degree in Civil Engineering with honours, cum Laude, at the American University of Sharjah in 2017. The research topic she worked on during her undergraduate degree was the use of Non-Destructive Techniques (NDT) for the detection of leaks in portable water systems. The NDT's employed during the research were Ground Penetrating Radar (GPR), Spectrometers, and IR (Infrared Camera).

On receiving a Graduate Teaching Assistantship from at the American University of Sharjah in 2017, she joined the Civil Engineering master's program special concentration in Environmental Engineering. As a graduate teaching assistant, she worked as a laboratory assistant and grader for the environmental engineering laboratory. During his master's study, she was the first author in two conference papers. The research titled "Use of Spectrometer for Detection of leaks in Water Distribution System" was presented in CCWI 2018 Joint Conference, Ontario, Canada. Additionally, the study titled "Detection of Leaks in Water Distribution System using Non-Destructive Techniques" was presented in ICFEE 2018, Phuket, Thailand. The research area selected by her during her postgraduate degree (Microplastic contamination in Marine Sediments) and the course work chosen during her undergraduate as well as her postgraduate degree ignited a strong liking towards the field of environmental sciences and engineering.

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