THESIS

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TESTING MICROPLASTICS REMOVAL EFFICIENCY OF DIFFERENT FILTER MEDIA

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List of Abbreviations

EC - electrocoagulation

EF - electro-flotation

HDPE - High-density polyethylene

HPLC - High-performance liquid chromatography

LDPE - Low- density polyethylene

MP(s) - Microplastic(s)

MPPs - microplastic particles

NP(s) - Nanoplastics(s)

PA - Polyamide

PES - Polyester

PMMA - Polymethyl methacrylate

POPs - Persistent organic pollutants

PP - Polypropylene

PS - Polystyrene

PTE - Polyethylene terephthalate

PVC - Polyvinyl chloride

RAMP - Road-associated microplastic particles

TPE - Thermoplastic elastomers

TWP - Tyre-wear particles

WWTP - Wastewater treatment plant

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1. Introduction

Microplastics (MPs) have become a widespread environmental problem over the last few decades (Funck et al., 2021a). These tiny plastic particles are smaller than 5 millimeters in size and can come from a variety of sources, including the breakdown of larger plastic items, the shedding of synthetic fibers from clothing during laundering, and even from microbeads used in personal care products.

MPs can be found in the air, soil, waterways, and oceans, and they have harmful effects on wildlife, ecosystems, and human health (Funck et al., 2021a). The introduction of MPs into the environment can occur through a variety of pathways. For example, plastic waste can enter the environment through improper disposal, such as littering or dumping into bodies of water. Microbeads from personal care products can also enter the environment through wastewater treatment plants and end up in rivers, lakes, and oceans. Additionally, plastic particles can be released into the air during manufacturing process, use, and disposal of plastic products, and they can be carried by wind and deposited in soils and bodies ofwater (Brooks et al., 2018).

Recently, there has been a lot of attention in the common presence of MPs in various water matrices, including urban runoff, residential tap water, and wastewater treatment plants. Municipal wastewater is one of the wastewater matrices that has been investigated the most for the presence and removal of MPs. Several studies have reported that MPs are removed during conventional wastewater treatment systems, both with and without tertiary treatment processes. Although MPs have not been included in the design of wastewater treatment facilities (WWTPs), some MPs may be removed throughout various phases of the treatment process. MP removal from wastewater has been studied using a number of treatment methods, including membrane bioreactor, membrane disc filter, and sand filter. Despite being a potentially significant source of MPs in the environment, the removal of MPs in wastewater from the plastic sector has only been the subject of a small amount of research. According to reports, municipal WWTPs may reduce MPs by 79.3 to 99.9% when employing traditional techniques, such as primary and secondary treatment but not tertiary treatment (Umar et al., 2023).

Membrane filtration and the electrocoagulation-electro flotation process are common advanced treatment options for water and wastewater. Due to its high particle removal rates and advantages over conventional treatment techniques including adsorption, flotation, coagulation, and flocculation, electrocoagulation-electro-flotation (EC/EF) is gaining a lot of interest. While electrolysis occurs on the cathode, where flotation plays a significant role in pollutant removal, the process relies on the breakdown of the sacrificial anodes to release the active coagulant precursors into the solution (Akarsu et al., 2021).

Due to its low initial investment and ongoing running costs, filtration using sand filters is one of the technologies being researched. Prior research has already been done by some writers to determine how well it removes MPs from wastewater. However, no studies comparing the various process existing variables (such as the use of various substrate types or operational parameters that can be applied) to optimize the process and examine how they can affect the retention of MPs are available in the literature. Additionally, the majority of studies only describe how well these pollutants are removed rather than examining the mechanisms at play in the filter substrate that enable MP retention. Beyond only describing how effective this treatment method is, this study expands our knowledge of it. Because there isn’t much research of this kind in the literature, it is likely that there isn't much knowledge on technical and engineering issues. This is a crucial chance to fill this knowledge gap (Funck et al., 2021b; Mason et al., 2016).

Objectives

The main objective of this research was to evaluate the efficiency of removal of microplastics from water by using different filter media. We also evaluated the quality of Danube River water in terms of the presence of microplastics.

2. Literature review

2.1. Definition of microplastics

Plastic particles less than 5 mm in diameter are known as microplastics (MPs) (United Nations Environment Program, n.d.). This groundbreaking definition recognizes the tiny nature and magnitude of synthetic compounds but does not establish a lower size limit. Lower size limitations are often aligned with environmental sampling constraints and detection limits for analytical procedures. In order to distinguish between microscopic polymeric particles and those as tiny as 100 or 1000 nm, the term "nano plastics" (NPs) was coined (Figure 1). There is no agreed-upon definition, hence the current size-based terminology is ambiguous and nonstandard. In the scientific literature, small plastic particles (MPs) are referred to as MPs. There has been a broad variety of biological and physiological scales covered by the term "microplastic" in Figure 1. Because there are no defined particle size cut-offs, the terminology "MPs" would be used throughout the whole thesis to refer to tiny particles with a wide size range of 5 mm or less. An arbitrary < 1 µm size margin was established for NPs in specific (Maricela & Espinoza, 2019).

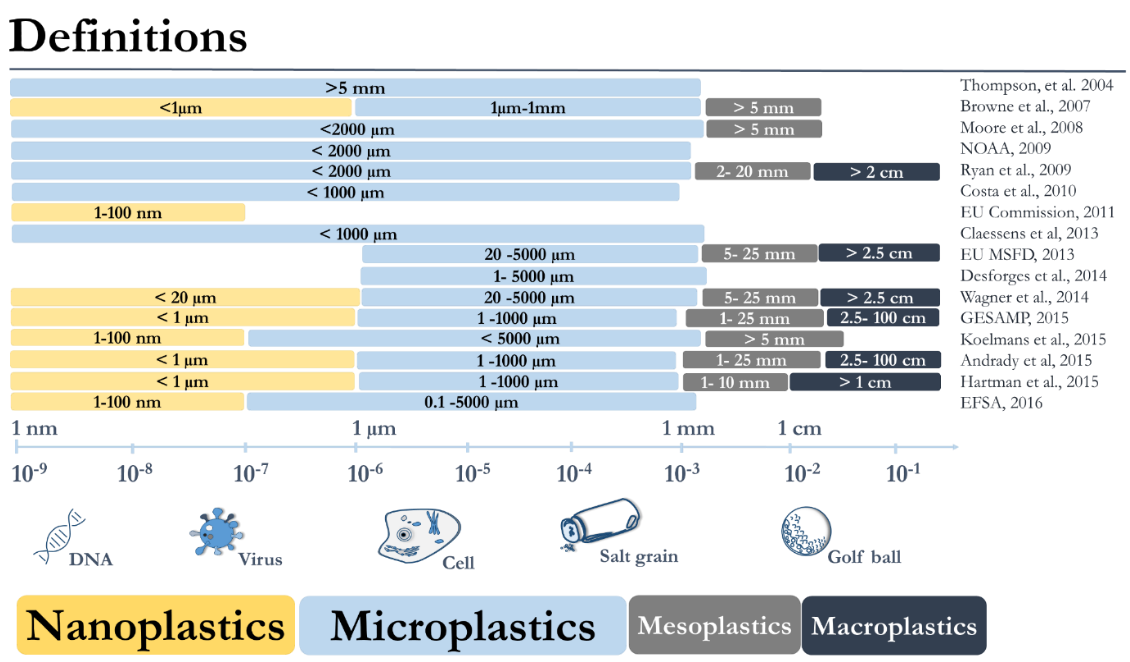

Figure 1. Shows general size-based nomenclature of microplastics (Maricela & Espinoza, 2019)

The word "MPs" incorporates not just a wide range of responsibilities but also a wide range of differences in terms of physical appearance, racial background, and origin. MPs or polymeric materials are plastic additives that are not restricted to a particular kind of copolymer or a certain pharmacological profile. Despite trade secrets preventing the formulation of plastics from being exposed, MPs are a fairly varied group of chemically diverse materials. Chemical compounds connected to plastic materials are predicted to have a wide range of structural and functional variety. There are main and secondary MPs depending on where they were born. Primal microplastic particles (MPPs) are created from scratch rather than being derived from the breakdown of larger plastic items. On the other hand, tend to be more uniformly formed and have a more stable morphology than secondary MPs. In terms of plastic pollution, primary MPs make up just a small percentage of all MPs in the natural environment, and they are expected to have a limited global impact owing to secondary MPs (Bjorkner, n.d.).

Size, form, and chemical composition are no longer the only variables considered when defining MPs in the last several years. Redefining environmental MPs as "a difficult and complicated, dynamic concoction of polymer composites and artificial sweeteners, to which biological matter and pathogens can subsequently bind to produce an "eco-corona, continuing to increase the density and number of particles and altering their biodistribution and toxicity" has been proposed as a way forward. MPs may be thought of as dynamic physicochemical and biological entities that are constantly changing and interacting with their surroundings. Because of the vast scope of its meaning, the word "MPs" is still somewhat ambiguous. MPs' interactions with environmental and physical systems, and their eventual destiny in the environment, remain uncertain because of this (Bhat, 1997; Bjorkner, n.d.).

Most synthetic polymers (Table 1.) are made of carbon and come from natural gas like oil and gas production, that’s why the name "plastic" is so broad. There are two primary kinds of plastics: thermoplastics and thermosets (United Nations Environment Program, n.d.). It is common to use thermoplastic elastomers (TPE), thermoplastic polyethylene terephthalate (PET), polyethylene terephthalate polyvinyl chloride (PVC), and polyamides (PA) in many applications. At room temperature, thermosets may be solids or liquids, but heating them causes chemical changes that make it impossible to remelt or mould them. Polyurethane, silicone, acrylic, and epoxy polymers are all examples of thermoset resins. Due to the great variety of uses, they may serve plastics are an excellent material for a wide range of products. Plastic polymers such as PE, PP, PS, and PVC are presently the most often utilized (PlasticsEurope Market Research Group, 2018).

Table 1: Density of different microplastic polymers and their use (PlasticsEurope Market Research Group, 2018)

SPI code	Properties	Applications
	Density: 1.38 g/cm^3 Strong and clear Resistant to heat	Beer bottles, water bottles, beverage bottles, textile fiber andcarpet fiber
	Density: 0.97 g/cm^3 Tensile strength of 5000 – 6000 psi Strong and stiff Moisture permeability to gas Easily forming. Resistance to chemicals Melting temperature of 130 – 137 °C Resistant to solvent below 60 °C	Retail bags, cereal bag liners, detergent bottles, compost bins, crates, milk containers
	Density: 1.40 g/cm^3 Tensile strength of 1500 – 3500 psi (flexible) and 6000 – 7500 psi (rigid PVC) Strong and clear Flexibility Versatility Resistance to chemicals, grease or oil Melting temperature of 75 – 105 °C Soluble in acetone and cyclohexanol but partially in toluene	Toys, shampoo bottles, plumbing pipes, construction pipes, construction flooring and fittings

SPI code	Properties	Applications
4 LDPE	Density: 0.92 g/cm^3 Tensile strength of 600 – 2300 psi Flexible and soft Ease of processing and sealing Barrier to moisture Melting temperature of 98 – 115 °C Resistant to solvent below 60 °C	Frozen food bags, bin bags, squeezable bottles, rubbish bins, plastic grocery bags
5 PP	Density: 0.90 g/cm^3 Tensile strength of 4500 – 5500 psi Strong and versatile Flexible Resistance to chemicals, grease or oil and heat Melting temperature of 175 °C Resistant to solvent below 80 °C	Medicine bottles, yoghurt containers, ketchup bottles, margarine containers
6 PS	Density: 1.05 g/cm^3 Tensile strength of 5000 – 7200 psi Versatile Rigid and brittle plastic Clear and light weight Styrofoam Thermal insulation Melting temperature of 100 °C	Meat tray, plastic cutlery, disposable cups, compact disc cases, egg cartons, packaging foam

SPI code	Properties	Applications
	Made with a resin other than the above mentioned or combination of resins	Baby bottles, automobile parts

More than half of the growth in plastic production between 1950 and 2017 came from the packaging business, which accounted for 348 x 106 metric. The rapid expansion in plastic manufacturing has been accompanied by an increase in plastic waste, particularly in the form of injection molded parts like low and high-density PE, PP, and PA fibers, and this trend looks to be accelerating. Plastics have lasted a long time, and so much of what is developed since mass production started is still in use. It is estimated that between 1950 and 2017, 6.3 x 109 metric tons of plastic garbage has been generated, and this amount is likely bigger currently than it was two years ago. It is estimated that between 60 and 90 fractions of all marine debris are created from the trash thrown in cemeteries and the environment, as reported by (Geyer et al., 2017).There is a chance that some of this garbage may end up in the seas (Program United Nations Environment (UNEP), 2018). The increasing manufacturing of plastic rubbish and the inability to properly dispose of this material has resulted in a worldwide calamity that might have devastating consequences.

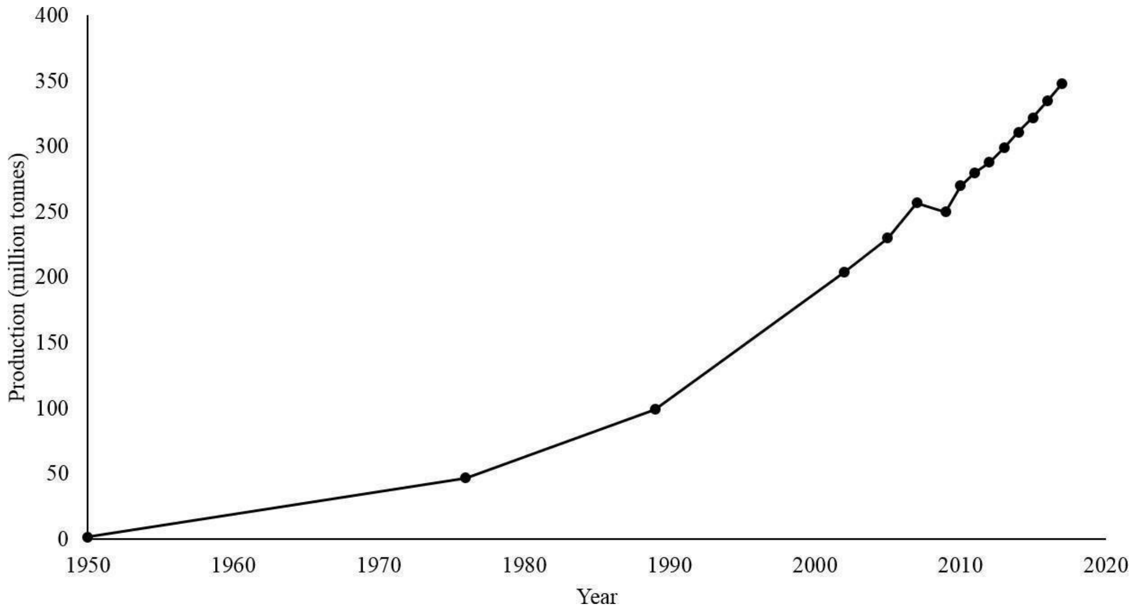

Figure 2. Shows the production of plastics in the world from 1950 to 2017 (PlasticsEurope Market Research Group, 2018)

Figure 2. showed the production of plastics across the world between 1950 and 2017 (data from Plastics Europe; excludes PET, PA, PP, and polyacrylic fibers; includes injection molded parts, polyurethanes, thermosetting polymers, elastomers, adhesives, coatings, and sealants; and polypropylene fibers). Plastic garbage may be created in a variety of ways and in a variety of forms. According to their size, plastic waste may be divided into microplastic, mesoplastic, and microplastics, however each category has a variety of subcategories Figure 1. More attention has been paid to MPs, which are the subject of this work, in recent years. MPs first focused on nanostructures and pre-production pellets. Components less than 5 mm in diameter are currently classified as MPs, while a precise size has not yet been agreed upon. According to the most recent studies, politicians are responsible for most of the world's plastic garbage. It is difficult to categorize microplastics since they are composed of so many diverse, highly changeable components (Geyer et al., 2017; Program United Nations Environment (UNEP), 2018).

2.2.Sorption behaviors of microplastics and the influencing factors properties of microplastics

PE, PS, PVC, and PP are the microplastics that have been investigated in laboratories the most, followed by PA and PET. Because different forms of microplastics have different rubbery domains, polarities, and functional groups, they may have different sorption affinities for the same contaminants. The prevalence of rubbery microplastic domains is crucial for the sorption of organic substances. High mobility and high accessibility to some types of organic contaminants are both characteristics of the rubbery domains. PE contains a lot of rubbery domains among the microplastics in the laboratory. Researchers discovered that certain microplastics had higher sorption capabilities on PE than others, including PYR, PHE, lubricating oils, PCBs, PFOS, POSA, and 4, 4′-DDT. PP with lots of rubbery domains exhibited strong BTEX affinities.(Guo & Wang, 2019) Chemical compounds were distributed on microplastics in the following order: LDPE > HDPE > PP > PVC > PS. Additionally, interactions between microplastics and polar substances may be influenced by the polarity and unique groups of microplastics. For polar antibiotics CIP, TMP, AMX, and TC, for instance, the polar polymer PA with amide group exhibits higher sorption capabilities than other microplastics (Umar et al., 2023).

The process of sorption also heavily depends on size and degree of age. For the same types of microplastics, the sorption capacities rise as the particle size decreases, mostly because small particles have large specific surface areas. Additionally, larger particles have a longer sorption equilibrium period than smaller ones. Even though the particles are the same size, distinct types of microplastics may have varying specific surface areas. The sorption of organic molecules on microplastics revealed that the order of particle size was not followed. The impact of particle size is overshadowed by the nature of the microplastics and its particular surface area According to the supposition that every microplastic particle is the same size, the specific surface area is as follows:

$$\mathbf{S = S_{total}/\, m_{total} = nS_{part}/\, m_{total} = n\,(S_{sur} + S_{pore})/m_{total}} \qquad \text{Equation (1)}$$

Where n is the number of particles, Spart is the total surface area of one particle, S_{total} (m^2)

and m_{total} (g) are the total surface area and mass of all evaluated particles, and S (m^2/g) is the specific surface area. The entire area of a particle's surface and its internal pores are designated by the units Ssur (m^2) and Spore (m^2). Equation (1) shows the relationship between the specific area and the surface area and pore area.

Because of their huge specific surface area and high sorption affinities for pollutants, microplastics with rough surfaces, irregular shapes, and porous structures are likely to be found in the environment. Microplastics degrade due to the weathering/aging process, which results in morphological changes such the development of fractures and flakes on their surface (Hüffer et al., 2018). As a result of deterioration, microplastics' particular surface areas grow. Evidence suggests that compared to new microplastics, older microplastics exhibited higher sorption affinities for contaminants. Older microplastics may accumulate more pollutants in marine and coastal settings than the young microplastics investigated in labs; in some places, the quantities of pollutants are much greater than 10,000 g (Guo & Wang, 2019; X. Zhang et al., 2018).

2.3. Sources of Microplastics

Microscopic Plastic Detritus in the Environment Terrestrial creatures have been shown to contain microplastic particles, however, there has been very little study to support this claim. Reports of crows hooked in plastic and integrating it into their nesting have now been documented in California, USA. Although 85.2 percent of the anthropogenic waste identified in nests was plastic, the bulk of this material (meso- or macroplastic) was determined to be less than this size.

Birds in Shenzhen, China, ingested 62.6 percent of litter particles detected in their digestive systems as plastic fibers and shreds. There was an average of 6.22 pieces of plastic in the gastrointestinal system of ravens from central Florida, despite the fact that the majority of them were rayon, which is generally excluded from microplastic counts due to the fact that it is not a synthetic polymer. Avian species seem to have a high concentration of microplastics in their digestive tracts, as observed. Only one study of terrestrial motion resulting under field conditions has detected microplastics. Three Italian edible snail species (H. Aperta, H. Aspersa, and H. Pomatia) exhibited concentrations of 0.07-0.01 MPs/g in tissue. Microplastic intake by terrestrial creatures is presently unknown, however, several laboratory studies have indicated that a broad range of species consume microplastics and have investigated their impacts (Blair et al., 2017).

2.4. Pathways to Freshwater Environments

There are several routes in which microplastics enter freshwater systems, but the vast majority of them fall under the category of release pathways (Figure 3.). In freshwater ecosystems, there are only a few producers of microplastics, including in situ waste fragments, point discharge out from the plastics industry, and the generation of tiny polymeric pigment or plastic fragments by boats and other aquatic infrastructure. It is explained in detail in this section how pollutants are dispersed from 99 habitats as well as from litter and landfill leachate releases, urban drainage system discharges, road runoff, and wastewater treatment plant effluents (Blair et al., 2017).

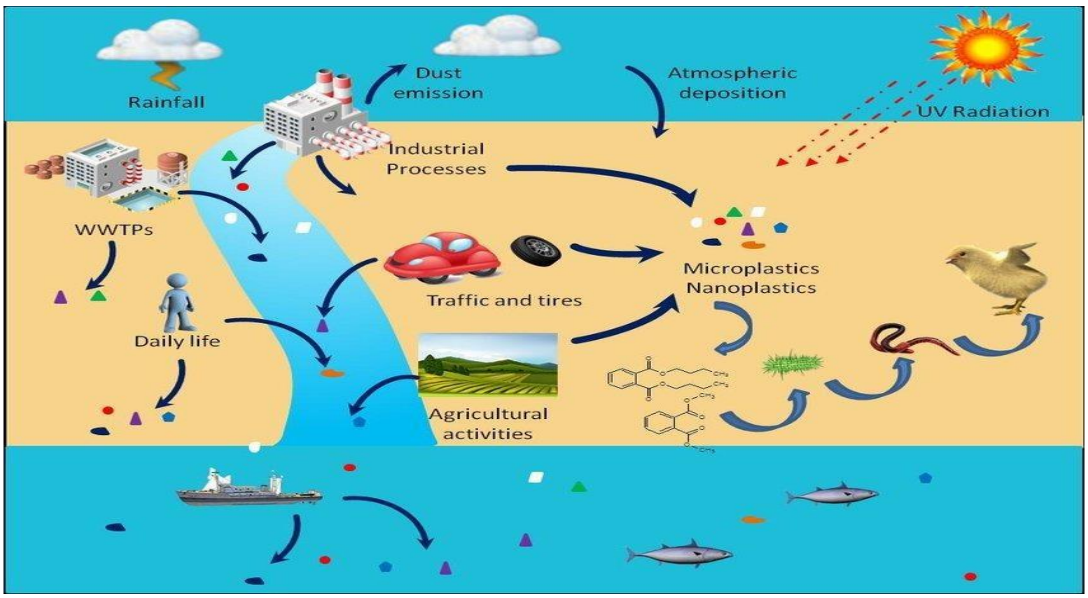

Figure 3: Shows different pathways of microplastics in environment (Kok, n.d.)

2.5. Transfer from agricultural Environment

Agricultural soils are becoming identified as a potential marine pollution receptacle, maybe even exceeding current ocean microplastic levels. In this regard, agricultural microplastic contamination is of special significance in terms of global patterns and cycles of plastic particles. Windthrow, inundation, types of events and leaching may all be used to transfer plastic particles from soil systems, depending on characteristics such as particle size, morphology, and zeta potential. Some of these processes have been validated experimentally in soil profiles by, but no effort has been made to quantify the number of suspended particles released from soils in agricultural contexts. Preliminary results show that water from a field in Norway that was changed with sludge was released in the form of sediment into a stream that was linked to the sedimentation pond. Microplastics may enter freshwater systems via agricultural soil, according to one study. It is imperative that further research be done to determine how microplastic contamination from agriculture affects bigger ecosystems (Nizzetto et al., 2016).

2.6. Transfer from Urban Environments

2.6.1. Leaching and Littering of Plastic waste

It has been estimated that using inappropriate disposal of plastic garbage to measure marine contamination. Municipal environmental sanitation efforts may result in the generation of the trash either deliberately or accidentally (Kum et al., 2005). This debris may already contain microplastic particles, or it may act as a source of microplastic particles by trying to break down significantly bigger plastic waste into tiny bits. Both possibilities are possible. Corrosion, oxidation, and weathering are all processes that disintegrate and physiologically alter polymeric polymers and may contribute to fragmentation. The effect on water is predicted to be significant.

Landfill leachate is another method through which this kind of microplastic contamination is discharged into the environment. Leachate from China's solid waste landfills was found to have between 0.42 and 24.6 particles of L-1 in two peer-reviewed studies. The decrease in particles recorded by earlier landfill systems has been connected to an increase in plastic usage and disposal in recent years. Microplastics may be transported by leachate discharges to neighboring soils or freshwater sources (Su et al., 2019).

2.6.2. Urban Drainage

Precipitation storm water management systems are a critical connection between urban and freshwater environments. Numerous research projects have been carried out to better understand this process and devise technical methods to reduce or avoid the discharge of big plastic debris into rivers. Particles from urban drainage are more likely to get into freshwater systems (Su et al., 2019). Though combined sewage overflows have been recognized as a substantial source of microplastics into freshwater systems by many studies, relatively little study has tried to quantify the amount of release and examine microplastic composition (Kum et al., 2005).

Identifies sewage treatment and Combined sewer overflows as one of the eight primary land-based sources of microplastic pollution, emphasizing the critical role they are supposed to be playing as a conduit for particulate from metropolitan areas. Many urban drainage systems are equipped with CSOs, which allow untreated wastewater to be discharged directly into the environment in times of high precipitation. Sampled three CSOs during a storm occurrence in Paris, France. Some 190,000 L-1 synthetic fibers were detected, and 3100 L-1 synthetic pieces were reported. During severe weather, there is a high concentration of microplastics discharged into rivers. Microplastics have also been found in storm water ponds. Various metro regions' runoff and particulate matter is collected and retained by these sand and gravel filtration systems. When it comes to transmitting microplastic to freshwater systems, it is not clear how big of a role these systems play in that process yet (Jeftic et al., 2009).

2.6.3. Wastewater treatment plant (WWTP) Effluents

Wastewater treatment facilities typically discharge the treated effluents into receiving bodies of water (WWTPs) (Program United Nations Environment (UNEP), 2018). As a result, it is possible that microplastics will be dispersed into nearby freshwater environments. Wastewater treatment processes remove a major amount of them and send them to the sludge phase (64.4-99.9 percent). Despite this, the remaining 20% of WWTP discharges are expected to represent a major release pathway for microplastics throughout time. This outflow has been estimated by various studies recently. Despite the fact that major WWTPs handle millions of liters of wastewater each day, the concentration range of microplastic in treated effluents frequently falls below 1 particle per liter of wastewater treated. According to a single WWTP in the United States emits about four million pieces of plastic per day on average. This investigation's lowest detection size limit was 125 µm (Horton & Dixon, 2018).

Studies after this one reveal considerably bigger levels of the lowest size fraction (100 fibers L-1). A broad range of treatment methods are used by WWTPs across the world, with capture rates ranging between 0 to 99.9 percent. Depending on the range of particles and morphologies, it is expected that the efficiency of various cleaning processes would differ. Microplastics of the fibrous kind, which have been shown to be the most difficult to remove from storm water owing to their tendency to curl and flex, are especially important in this respect. When microplastics are present, it may make it more difficult to remove them since their existence can negatively affect the efficacy of wastewater treatment (Zettler et al., 2013). Microplastics generated by WWTPs may be underestimated if a smaller proportion is not included in studies because treatment processes may be less likely to collect them. In order to accurately measure the amount of plastic emitted by WWTP effluent, more work is needed (Z. Zhang & Chen, 2020).

2.6.4. Road runoff

The surfaces of roads are artificial, subject to high levels of mechanical wear from car tyres, and emit a variety of contaminants from vehicle exhaust, tyres, the road surface, and other debris. Roads are complex anthropogenic ecosystems. High amounts of particles and a variety of heavy metals (such as zinc, copper, cadmium, and nickel) as well as organic pollutants (such as polycyclic aromatic hydrocarbons, organophosphates, octyl phenols, and phthalates) are typical characteristics of runoff from road environments. The presence of polymer-containing particles in road runoff, which has been recognized as one of the major sources of microplastic particles in the environment, has rekindled interest in this area in recent years (Baensch-Baltruschat et al., 2020). Although these estimates are based on emission factors and need to be supported by peer-reviewed experimental or environmental evidence, car tyre wear and tear particles are thought to be the single largest source of microplastics in several nations, including Norway, Sweden, and Denmark. Similar calculations utilizing emission factors have been made in China, where it is estimated that tyres constitute the principal source of about 55% of all primary microplastic emissions (X. Zhang et al., 2018).

The scientists determined that the discharge in China is 400 times greater compared to Denmark and 85 times higher compared to Norway in terms of emissions. We refer to the particles in this review as "road-associated microplastic particles" (RAMP). Road-wear particles from bitumen modified with polymers (RWPPMB), tyre-wear particles (TWP), and road-wear particles from road markings make up RAMP (RWPRM). The tyre and road wear particle (TRWP) terminology, which is used in numerous other research, varies from RAMP in that RAMP exclusively includes particles with plastic components, whereas TRWP may also contain particles without plastic components (Baensch-Baltruschat et al., 2020).

2.7. Fluxes of microplastic in ecological Compartments

Recent years have seen a dramatic increase in the study of microplastics and the spread of microplastics across the ocean basins and deep-sea layers, as well as the improvement of microplastics in river systems and lakes, the spread of microplastics through broadcast spillover, and transport to the ocean. At least a few attempts have been made to synthesize the current situation with climate microplastics, as well as to conduct extensive surveys and provide an overall overview. This section just briefly touches on plastic pollution and cites pertinent research that has already been published (Bank Editor, n.d.; United Nations Environment Program, n.d.).

2.8. Microplastics and Earthly Biological systems

Except for marine fishing, all plastic is produced and used on land. Despite this, Earth's climate has received relatively little attention in data analysis on plastic and microplastic contamination. For example, marine complex systems are a far cry from this. In addition to traffic and vehicle tyre scrapes homegrown and domestic initiatives like beauty products and cleaning agents, synthetic fibers from clothing and resource shampooing and coatings, plastic comes from a wide variety of sources. There are many factors that contribute to climate change, including direct littering, as well as improper waste management practices, such as modern mishaps and waste delivery from landfill venues. Even consuming plastics, whether on purpose or by accident, may release plastic particles into the atmosphere and general environment, which can then be carried into neighboring waterways by uncontrolled removal through ingestion or through ordinary wildfires. The removal of packing and transportation ropes or the application of sewage sludge to horticulture grounds may also result in plastics being released into the atmosphere during agricultural operations. According to (Nizzetto et al., 2016), applying sewage ooze to rural soils in Europe annually introduces 125–850 tons of microplastic per million people. When the input from reckless trash and littering is coupled with the plastic stock held in earthbound settings, it will either produce major accumulation or act as a source for other ecological compartments in the ecosystem. Wet affidavits are more common in urban regions and locations where plastic particles are resuspended in soil, according to research (Horton & Dixon, 2018).

2.9. Microplastic and Freshwater Environments

There are a number of factors that contribute to the difficulty in explaining the issue of microplastic contamination in marine freshwater microbiological systems, which include trenches, streams, rivers and estuaries, as well as short-lived but highly long-lasting wetland areas and lakes. Many freshwater environments may contribute to plastic contamination in a variety of ways. It may be derived from the wind, barometric pressure and surface runoff from the surrounding region, as well as from improper garbage disposal and inadequate garbage collection (Zhang & Chen, 2020). According to, storms are a significant cause of microplastic contamination in marine environments. General duty overflow increased at least 40-fold during and immediately after a storm occurrence.

One of the most significant determinants in the quantity of natural microplastics found in inland surface waters is precipitation, according to experts. There were theories that rainfall would transport plastic (both full-scale and microscale) from land to sea (United Nations Environment Program, n.d.) but this did not directly cause an increase in plastic details. Instead, surface spillover from downpours was responsible for the increase. As found, torrential rain effluents and urban indirect effects are frequently unchecked and unfiltered, and this allows microplastics from degraded tyre wear and street painting, as well as microplastics from litter, to be washed into the adjacent amphibian frameworks. After being rescued, plastic may either break down and spread or become caught in the silt and clog up the waterways (Horton & Dixon, 2018).

2.10. Microplastics and Marine biological system

Aside from discarded fishing gear, the principal sources of microplastic pollution in marine natural systems are overflowing landfills and contemporary plastic trash. Several important publications, such as (Horton & Dixon, 2018). In addition to fishing, aquaponics, tourism, and indeed the marine industry, salty areas where humans participate in coastal activities are contaminated with microplastics. Plastic and microplastic pollution may be traced back to its sources, destiny, transit, and impacts throughout a wide range of sizes. In addition to other important aspects, such as biofouling and biofilm formation and the delivery or adsorption of optional foreign bodies, the intertidal zone has a rare combination of physicochemical conditions, sea geographical distribution, tension, and water segment elements that regulate microplastics (Sharma & Chatterjee, 2017).

Additionally, microplastics may be made from a wide range of polymers, have a wide range of subatomic structures, and come in a wide range of sizes, shapes, and thicknesses. Because of these and other aspects, they are also regarded as a confusing concoction of contaminants. Microplastics have a variety of properties that influence their dispersion, lightness and sinking, fate, and transit within marine ecosystems. These properties also control their bioavailability and trophic transaction with marine biota. Sea surface microplastics may be transported by marine snow into deep maritime and mesopelagic zones, where they may be more bioavailable to benthic organisms. For example, marine snow is the frequent settling of naturally occurring particles from the highest reaches of the water column.

It was projected that 99.8% of the plastic pollution that started in the 1950s had fallen into the sea surface layer by 2016, with an additional 9.4 million tones sinking per year as a result of reenactments of amphibian pollution. Microplastics are widely known to be carried to the seabed via vertical settling from the top, but it is presently assumed that ocean depths and global atmospheric fluxes are also major manifestations of spatial utilization, fate, and transport dynamics. At least two keys, interconnected elements are concerned about the prevalence of microplastic in the ocean. Fish, particularly those that eat microplastics that are floating in the ocean, may absorb and spread hazardous chemicals from the microplastics they consume. This research was conducted by Smith and colleagues. Marine microplastics are regularly discovered in large concentrations, and they may be swallowed by marine organisms. Another major concern is the potential damage to human health presented by microplastic contamination, both directly and indirectly (Zhang & Chen, 2020).

In spite of the fact that microplastic holes have been proved to adversely affect biota, various basic vulnerabilities connected to their complex toxicological profiles still persist, and generally speaking, a major percentage of the issue has still to be remedied. As a result, the link between fish security and microplastics and harmful mixtures like bisphenol A remains unclear, despite several ongoing study. These findings underscore the need for a more comprehensive examination of the link between fish health, human exhibit safety, contaminants, and overall food security, as shown by these findings (Sharma & Chatterjee, 2017).

2.11. How microplastics behave after entering in the environment

The fact that microplastics are frequently consumed and that their sizes are remarkably similar to those of the food consumed by aquatic biota is one of the main worries about them. Numerous creatures from various trophic levels, including zooplankton, copepods, bivalves, mussels, shrimp, fish, seabirds, and whales, have been found to consume microplastics. When it comes to being consumed, microplastics' various characteristics are taken into account. Both their densities, which determine whether they sink or float, and the species that are most likely to consume them are influenced by their size (Auta et al., 2017).

Because PS, PE, and PP float and have a specific density lower than that of water, organisms grazing on surface waters are more likely to consume these substances. As opposed to less thick plastics, like PET and PVC, which tend to sink and are mostly found in sediment and are more likely to be consumed by benthic creatures. Biofouling is another element that has recently been shown to contribute to the chemoreceptive cue-induced ingestion of microplastic particles. On the surface of microplastics, it has been discovered that a biofilm develops after a specific length of time. These biofilms break down and release a particular dimethyl sulfide odor that makes them smell like food, attracting organisms and tricking them into believing that microplastics are actually nutritive (Carbery et al., 2018).

The global decline of coral reefs is a significant aspect of microplastic pollution. “The phenomenon known as bleaching has been linked to a number of various causes, most notably an increase in ocean temperature, or global warming, but also to sun irradiance and illnesses. Microplastics have also recently been added to the list of offenders. The deterioration of zooxanthellae, which ultimately causes the coral to become detached from itself, can be characterized as the mechanism of bleaching. In other words, it is the corals' whitening as a result of the loss of the symbiotic algae and/or pigments that gave them their color. The interactions between microplastics and corals were the subject of an intriguing investigation. Six small polyp corals from the species Acropora, Pocillopora, and Porites were subjected to a 4000 particle per liter concentration of polyethylene over a 4-week period. All the species displayed feeding behaviors like ingestion and egestion. More importantly, 5 of the 6 specimens contained bleaching and tissue necrosis (Rhodes, 2018).

2.12. Ecological Effects

MNP’s natural impacts on freshwater habitats have been studied, although sparingly (Horton & Dixon, 2018). Because of its tiny size, MNP may be digested by seagoing creatures more rapidly than bigger particles, sometimes being misunderstood for food and causing severe real-world impacts because of their consumption. When people consume MNP, they are at risk of choking, digestive system compromises, organ damage and eventually passing away. Evidence from marine studies shows that all performed audits. MNP consumption by freshwater organisms has been demonstrated to be comparable to that of marine fauna, however, there is still a lack of evidence of fish and bird species taking up the substance in lakes.

As an added benefit, MNP is capable of binding toxic substances that might linger in the environment, such as persistent organic pollutants (POPs). Water contamination fixations may be exacerbated by the desorption of POPs and other assembling extra chemicals, which can enhance the vulnerability of bigger parts to corruption. While there is a paucity of data on microplastics ability to absorb and drain persistent organic pollutants like POPs, much of the information on their toxicity comes from laboratories and marine tests, with just a few studies focusing on freshwaters. While MNP surfaces may facilitate microbial colonization and the formation of biofilms, they must also take into consideration the mobility of clever microorganisms and invasive species (Zettler et al., 2013).

The fourth choice might be critical for WWTP, as it could alter the treatment processes and increase the quantity of WWT bacteria that travels from these offices to groundwater (PlasticsEurope Market Research Group, 2018; Zhang & Chen, 2020). It is usual for MPs to infiltrate the networks of amphibian food and reach the highest levels of consumer decision-makers in the marine environment. Many aquatic creatures, including fish, oysters, and mussels, have been shown to contain microscopic pieces of plastic (Program United Nations Environment (UNEP), 2018).

More than a quarter of fish products on the market were discovered to contain plastic shards, according to some estimates. Considering that fish is a common component in many weight-loss plans, this finding has sparked worry about the impact MPs may have on human health, food safety, and availability. Many people are worried about fish containing anthropogenic particles, which, if consumed, may lead to human openness. Mussels and clams, which may be able to amass 15 MPs in digestible animal parts via water filtering, have been the primary focus of this point of view. For fish, on the other hand, this does not seem to be of much consequence, not only because detailed MP overflow in wild-caught fish is similarly tiny, but also because the majority of fish species are wiped off before they are eaten. Although MPs' involvement in transporting and collecting contaminants into the eatable tissues of commercial animals has been debated, additional general health and food handling problems for fish consumption have surfaced throughout these talks.

Additionally, food quality security concerns have evolved as a result of direct physical and indirect synthetic openness. The permeability of fish to plastic-related compounds may impact the nature or acceptability of fish for human consumption, it has been postulated. Synthetic openness may speed up enzymatic degradation, a significant element in the nature of commercial oily fish (PlasticsEurope Market Research Group, 2018; Program United Nations Environment (UNEP), 2018). Filets undergo lipid oxidation, which alters their surface and variety as well as promoting aldehyde arrangement, resulting in a more foul smell and odor. Cytotoxic and genotoxic compounds may be more widely dispersed under certain conditions. Fish's lower oxidative stability reduces their marketability and value, which might have consequences for food safety and human health. Shockingly, several food items and beverages that are meant for human consumption have been found to contain MPs. This has fueled public concern and piqued media interest in this matter. Concerns about the possible health dangers connected with the high frequency of MPs in amphibian food chains have prompted sophisticated evaluations and analyses in the legal and current fields. In order to fully understand the possible consequences of synthetic divergence into consumer products, additional research is needed (Zettler et al., 2013).

2.13. Impacts of Microplastics on the Soil Biophysical Environment

If pollution results in alterations to the soil environment, microplastics pose a possible harm to the soil biota. According to empirical calculations, 32% of all plastic produced is available to the environment in continental systems (De Souza MacHado et al., 2018), and other writers contend that soils may hold more microplastic waste than marine basins. Terrestrial contamination may be caused by a range of human activities and environmental factors, including compost used as an agricultural fertilizer, contaminated water courses, plastic mulches, and atmospheric precipitation. With a baseline level of up to 0.002% of soil dry weight, microplastics have been discovered in soils from nonurban natural reserves, including mountainous and populated locations (Steinmetz et al., 2016).

Microplastics can be efficiently integrated into the soil matrix after reaching the soil surface by a variety of processes, including bioturbation, soil management techniques, and water percolation. Currently, it is impossible to correctly predict this contaminant's ultimate destiny in soils. However, it is fair to assume a near-permanent and growing microplastic terrestrial pollution at time scales relevant to human life and pollution management. There have been reports of microplastic weight concentrations as high as 7% in heavily contaminated topsoils. To the best of our knowledge, no research has been done on the potential changes in soil biophysical parameters brought on by microplastic pollution (De Souza MacHado et al., 2018).

Microplastic terrestrial pollution's non-natural features and endurance may designate these particles as environmental change drivers. As a result, it is critical to explore the effects of this contaminant on the natural interactions between soil particles and biota. The current study investigates the ability of microplastics to disrupt the inherent biophysical features of the soil environment. We present results on the effects on basic soil physical characteristics, soil structure, and microbial function using classic and well-established proxies of soil health and function. We examine the environmental significance of such unique microplastic influences on soil properties, commenting on the limits of this preliminary evaluation, and highlighting future research needed to test the potential broad implications of the current findings in a global change context (De Souza MacHado et al., 2018).

2.14. Public Perception

Marine plastic pollution has been a hot environmental concern in recent years, affecting both the general public and scientific sectors. According to the findings of a 15-country survey, the European public is increasingly concerned about the impacts of plastic pollution on marine ecosystems and public health, and they support the need for additional research in this area. (Rhodes CJ 2018). In light of the increased public awareness of marine plastic pollution, media outlets and broadcasting behemoths such as the BBC have advocated for a reduction in everyday reliance on single-use plastics, with the effects of plastics on marine fauna featured in documentaries such as the BBC's Blue Planet II. Blue Planet II was seen by 14 million people globally and is widely regarded as a watershed moment in changing consumer attitudes against plastic.

This underlines the importance of trustworthy media communication in tackling environmental challenges, but it also highlights the necessity for more widespread media coverage of the plastic pollution disaster. Following the recent media attention, the public launched a number of successful efforts to raise pressure on large firms to eliminate single-use plastic, one of which was McDonald's plastic straw ban in 2018. The straw ban demonstrated that a combination of scientific evidence, media attention, and public pressure is sufficient to hold huge corporations like McDonald's accountable for unnecessary waste. Furthermore, global movements to prohibit the use of micro-sized plastic particles in cosmetics have emerged, as public and scientific attention has switched to the presence and implications of microscopic plastic particles in the marine environment (Cunningham, n.d.).

3. Methods of the studies

3.1. Materials

Sand of different diameters is collected from different construction sites and gardens. Silica gel was obtained from MERCK chemicals Budapest, Hungary and vermiculite was purchased from Brinkmann vermiculite, Budapest, Hungary. Polyethylene Terephthalate bottles were used to generate microplastics. MN 619 G filter paper was purchased from Macherey-Nagel, Germany.

3.2. Collection of sand and physical analysis

Sand samples (Figure 4.) were collected from different gardens and construction sites in Kiskunhalas, Hungary. The samples were collected in paper bags and transferred to the laboratory on the same day.

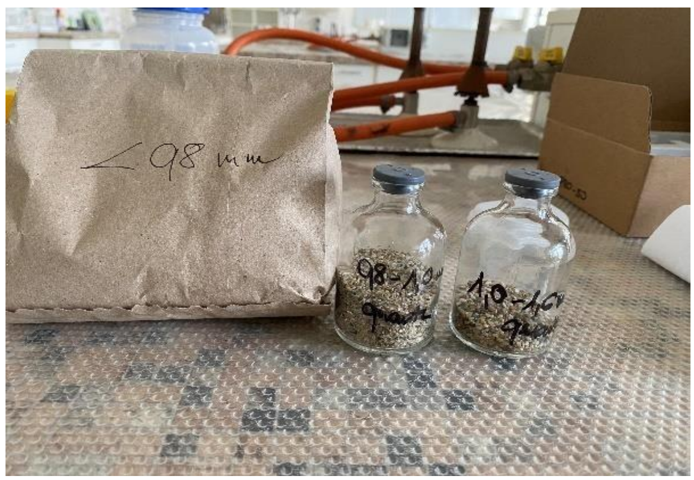

Figure 4: Collected sand of different diameters from gardens and construction site

The sand was dried in oven at 105 ℃ to remove the moisture. After drying the unwanted material was removed from sand through sieving. Later on, different size sieves were used to characterize the size fraction of sands. The particle size range of both category sands is given in Table 2.

Table 2: Diameters of different sand and other media used in the experiment

No.	Sand category	Diameters
I.	Coarse sand 1	<0.8 mm
II.	Coarse sand 2	0.8 – 1.0 mm
III.	Very Coarse sand 3	1.0 – 1.6 mm
IV.	Silica gel	1.0 – 1.6 mm
V.	Vermiculite	1.0 – 1.6 mm

3.3. Experimentation

3.3.1. Experiment 1

To evaluate the effectiveness of different filtration media e.g., different diameter sand, vermiculite and silica gel to remove the microplastics from water a laboratory experiment was conducted (Figure 5.). For this purpose, HPLC pump (Jasco, PU 980, The Netherlands) attached to a steel column was used. The column specifications were diameter =3 cm, length= 13 cm and the volume =91.84 cm^3. Different masses of filter media and PET microplastics were added into the stainless-steel column (Table 3). After filling the column with the required material, both ends were sealed with caps. Distilled water pumped from the upper part of the column by using HPLC pump. The flow rate of the water was maintained at 0.5 mL per minute and the pressure was kept constant.

At the bottom part of the column a funnel with filter paper was attached and the bottom part of the funnel was placed in a 50 mL beaker. The beaker and the funnel were covered with aluminum foil to avoid external moisture. Before using the filter, paper was also dried in oven at 105 ℃ to remove the moisture contents. The filtration process was carried out for 35 minutes for each sample. After that the filter paper was removed carefully from funnel and placed in a petri dish. The petri dish was then placed in oven at 65 ℃ until the constant weight was achieved. After complete drying the difference in the mass of filter paper was calculated and it was supposed that the increase in the mass of the filter paper after filtration was due to the presence of microplastics.

To confirm the presence of microplastics, visual evaluation was carried out by using microscope (btc, BIM 312T) equipped with lens WF 10x and a camera (Toupcam). The pictures were taken on a laptop using the software ToupView.

Figure 5: Experimental setup, sample collection and visualization

Table 3: Fraction of different filter media and microplastics used to fill the column.

Material	Size (In mm)	$m_{material}$ [g]	m_{MP} [mg]	$m_{original\ filter\ paper}$ [g]	$m_{filter\ paper\ (after\ filtration)}$ [g]
Coarse sand 1	<0.8	9.9041	22.1	0.4943	0.4943
Coarse sand 2	0.8-1.0	12.2507	16.1	0.4973	0.4998
Coarse sand 3	1.0-1.6	12.3351	21.4	0.4959	0.4991
Vermiculite	1.0-1.6	12.4268	20.1	0.4961	0.4991
Silica gel	1.0-1.6	11.7651	19.3	0.4949	0.4977

3.4. Experiment 2

3.4.1. Water sampling

To evaluate the quality of Danube River water in terms of the presence of microplastics different filtration media e.g., different diameter sand, vermiculite and silica gel were used in a laboratory study. The Danube River water was collected following an appropriate water sampling procedure in Budapest Hungary (47.517211, 19.045293) shown in (Figure 6).

Figure 6: Google Map of sample taking place

The water from the Danube River was collected in glass bottles. The bottles were washed by using the river water several times to avoid any pre-existing contamination. The water was collected from the point where the flow was normal by attaching a glass bottle to the stick. The samples were transferred to the laboratory on the same day. The sample was split before testing. NaCl was added to the first half (the density should be about 1.2 g cm^3) and shaken on a magnetic stirrer at 200 rpm. It was then poured into a separating funnel and separated by density (Figure 7).

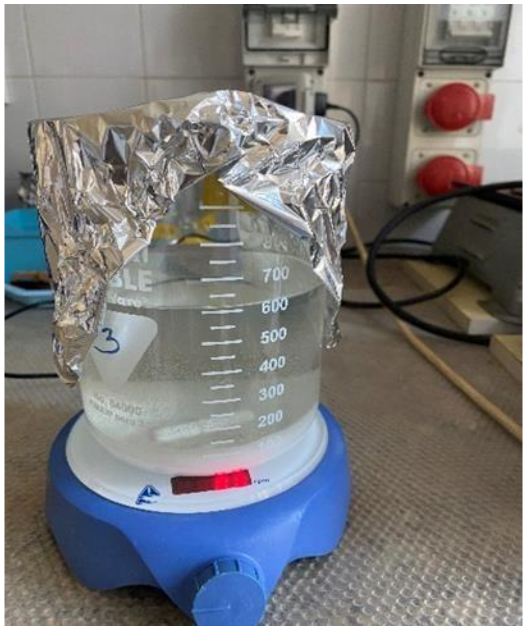

Figure 7: Magnetic stirring of Danube River water before microplastic detection.

The HPLC pump (Jasco, PU 980, The Netherlands) attached to a steel column was used. The column specifications were diameter =3 cm, length= 13 cm and the volume =91.84 cm^3. Different masses of filter media were added into the stainless-steel column. After filling the column with the required material, both ends were sealed with caps. The Danube water (second half) pumped from the upper part of the column by using HPLC pump. The flow rate of the water was maintained at 0.5 mL per minute and the pressure was kept constant. At the bottom part of the column a funnel with filter paper was attached and the bottom part of the funnel was placed in a 50 mL beaker. The beaker and the funnel were covered with aluminum foil to avoid external moisture. Before using the filter, paper was also dried in oven at 105 ℃ to remove the moisture contents. The filtration process was carried out for 35 minutes for each sample. After that the filter paper was removed carefully from funnel and placed in a petri dish. The petri dish was then placed in oven at 65 ℃ until the constant weight was achieved. After complete drying the difference in the mass of filter paper was calculated and it was supposed that the increase in the mass of the filter paper after filtration was due to the presence of microplastics.

To confirm the presence of microplastics, visual evaluation was carried out by using microscope (btc, BIM 312T) equipped with lens WF 10x and a camera (Toupcam). The pictures were taken on a laptop using the software ToupView.

3.5. Data collection and analysis

The data was collected and stored in excel sheets and later on analyzed to evaluate the significance of the obtained results.

4. Results and evaluation of results

From the first experiment after collecting and analyzing data, it was observed that the different filter media significantly retained the microplastics and only a small fraction of MPs was passed through the filter column (Figure 8). The size of the filter media had a significant influence on the proportion of retained MPs. The sand with small diameter retained all the MPs and no MPs were found on the filter paper. The sand with diameter 0.8-1.0 mm retained about 84.47% or (13.6 mg) of MPs, while sand with diameter 1.0-1.6 mm retained around 85.05% or (18.2 mg) of MPs and around 15% of MPs were passed through the column. Another filter media vermiculite with a particle diameter 1.0-1.6 mm retained around 85.07% of MPs which is equivalent to the coarse sand with particle diameter 1.0-1.6 mm (Table 4.).

This variation in the retained proportion of MPs is because of the variable size of the filter media. The smaller size sand with particle diameter <0.8 mm retained 100% of MPs because the after filling it in the column the pore size for the filtration of water remained very small and almost all the microplastics retained inside the column. While in case of coarse sands with diameter >0.8 mm around 14-15% of MPs passed through the column and found on the filter paper that could because of the higher size porosity of coarse sand when filled inside the columns and allowed the passage of a portion of MPs through it.

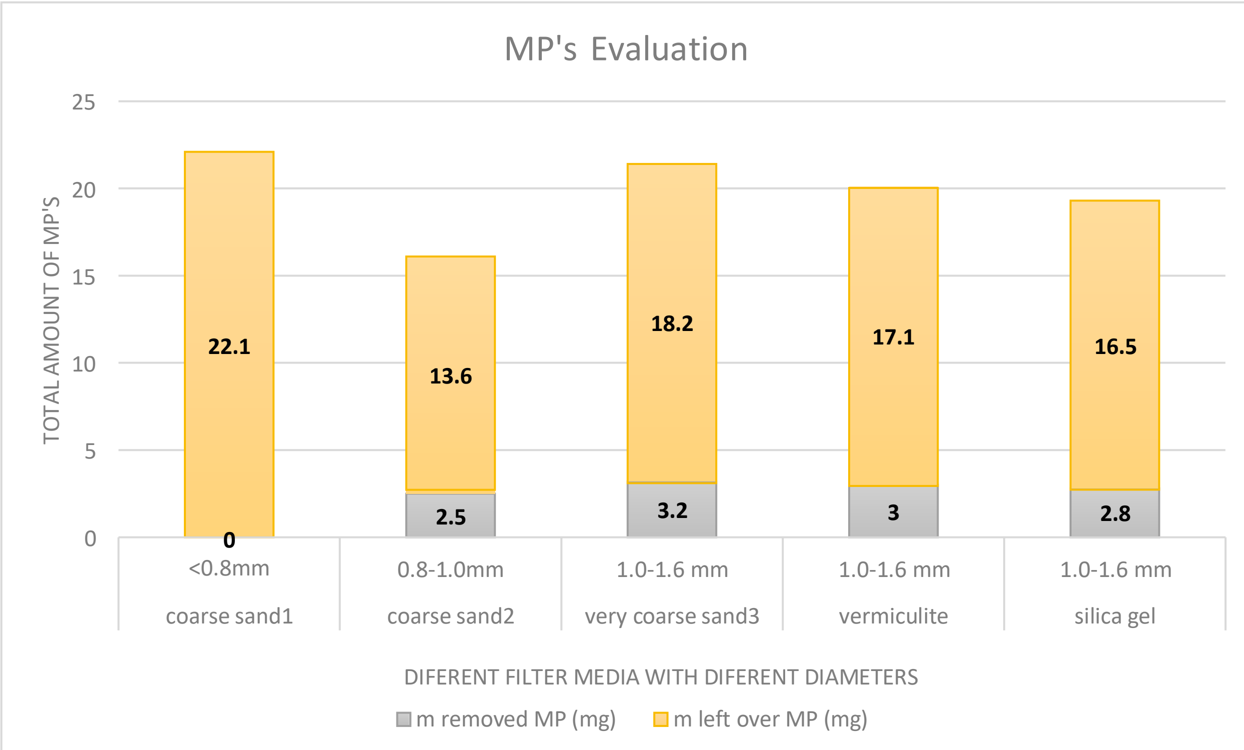

Figure 8: Retention of microplastics by different filter media

Table 4: Details of the data obtained after the first experiment

Material	Size (in mm)	$m_{material}$ [g]	m_{MP} [mg]	$m_{original\ filter\ paper}$ [g]	$m_{filter\ paper\ (after\ filtration)}$ [g]	$m_{removed\ MP}$ [mg]	$m_{removed\ MP}$ %	$m_{left\ over\ MP}$ [mg]	$m_{left\ over\ MP}$ %
Coarse sand 1	<0.8	9.9041	22.1	0.4943	0.4943	0	0.00	22.1	100
Coarse sand 2	0.8-1.0	12.2507	16.1	0.4973	0.4998	2.5	15.53	13.6	84.47
Coarse sand 3	1.0-1.6	12.3351	21.4	0.4959	0.4991	3.2	14.95	18.2	85.05
Vermiculite	1.0-1.6	12.4268	20.1	0.4961	0.4991	3.0	14.93	17.1	85.07
Silica gel	1.0-1.6	11.7651	19.3	0.4949	0.4977	2.8	14.51	16.5	85.49

The particles of MPs passed through the columns were seen by using a microscope (Figure 9.) for the confirmation. It was observed that the MPs passed through the column were of smaller size and most of the larger size microplastics were retained inside the column. It was concluded that the size of the filter media and the size of the MPs both matter when it comes to the retention efficiency of filter media.

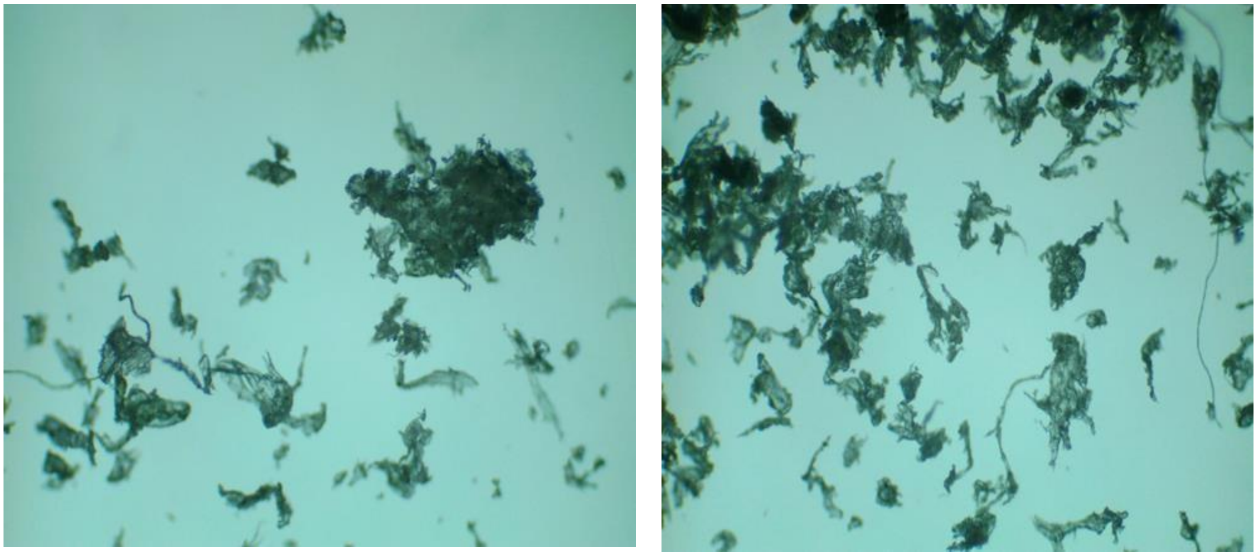

Figure 9: Visualization of PET passed through the filter column under microscope

In the second experiment we evaluated the quality of Danube River water in terms of the presence of MPs. Unfortunately there are MPs in Danube River We but we could not detect the occurrence of MPs in the Danube water (further investigations are needed) and found only a few plant (Figure 10.) remains.

Figure 10: Plant material found in Danube River water

5. Conclusions and recommendations

Currently the MPs are one of the biggest health concerns either that of humans, animals or soil health. A hazard number of MPs have been detected in different places where it is hard to believe that the MPs would have been present. Water is considered as one of the main destinations of MPs as most of the sources of MPs end up in water ways and that leads to the transportation of MPs far away from its place of origin. By keeping the importance of MPs, we evaluated different filter media to retain the MPs from water and leads to clean water. It was concluded that in terms of the retention of MPs the size of the filter media along with the size of the MPs play a significant role. It was observed that smaller size filter media retained a significant proportion of MPs in the columns while a smaller portion of MPs was still passed through the columns and after visualization under microscope it was concluded that the passed MPs were of smaller size. From the second study concluded that the presence of microplastics in the water of the Danube in the Budapest area cannot be detected and further investigations are needed.

To develop standard sampling and analysis procedures for microplastics in marine and coastal ecosystems. Microplastic abundance, distribution, and characteristics in global habitats require statistical monitoring and assessment using defined methodologies or criteria. To investigate the interactions of microplastics with a broader spectrum of contaminants (for example, radioactive heavy metals and antibiotics). To assess the dangers of microplastics to marine species and humans. In this regard, studies to evaluate microplastics as vectors for transporting contaminants, particularly harmful pollutants, across food webs are required. Biodegradable plastics are another intriguing option. Biodegradable plastics are composed of polymers such as cellulose and starch, which can be transformed into CO_2 and CH_4 by microbial action and integrated into the microbial biomass. This can be done both aerobically and anaerobically.

Conditions that are anaerobic. The entire process is comprised of many steps: first, we see microbial colonization of the plastic surface, followed by extracellular enzymatic depolymerization, and last, the uptake of those polymer fragments into the microbial cells, which mineralize them via a respiration process. However, while biodegradable plastics break down quickly in compost, they may not degrade in the natural environment.

Indeed, contrary to the prevalent belief that biodegradable plastics can disintegrate in the environment, increasing the risk of polluting nature, their 36 degradability is dependent on a number of variables that must be met in commercial compost settings. Biodegradable plastics must be composted for 180 days at a temperature of roughly 58 C to decompose > 90%, which is rarely attained in the natural environment.

6. Summary

Microplastics are little plastic particles with a diameter of less than five millimeters (0.2 inch). They are classified into two types: primary and secondary. Primary microplastics are microscopic particles and microfibers emitted by commercial products such as cosmetics, clothing, and other textiles, as well as fishing nets. Secondary microplastics are particles that form when bigger plastic items, such as water bottles, degrade. Exposure to external elements such as sunlight and ocean waves might promote this breakdown. Researchers discovered that secondary microplastics account for the vast majority of microplastics. Microplastics have been found in every nook and cranny of the environment, including the air, soil, and water. Drinking water, oceans, freshwater, and polar water have all been reported to contain high levels of these hazardous particles.

Microplastic contamination has been discovered in natural freshwater systems around the world, including wetlands, lakes, and rivers. Microplastics have been discovered in high quantities in Lake Superior in North America, Swiss lakes in Europe, and Lake Taihu in China. Their concentration, however, varies surface water in lakes in China and Saudi Arabia has been found to be far more contaminated than waterbodies in other countries in Europe, North America, and Africa, implying that developing countries are dealing with a far more severe microplastic problem.

By keeping in mind, the importance of microplastics we conducted two experiments. In the first experiment we evaluated the efficacy of different filter media in retaining microplastics and in the second experiment we evaluated the quality of Danube River water in Budapest region in terms of the presence of MPs. It was concluded that in terms of the retention of MPs the size of the filter media along with the size of the MPs play a significant role. It was observed that smaller size filter media retained a significant proportion of MPs in the columns while a smaller portion of MPs was still passed through the columns and after visualization under microscope it was concluded that the passed MPs were of smaller size. From the second study concluded that the presence of microplastics in the water of the Danube in the Budapest area could not be found. Further investigations are needed.

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Last but most importantly, I am ineffably indebted to Allah for His sufficient grace that has sustained me to this end. *“....i**f anyone desires a reward in this life, We shall give it to him; and if anyone desires a reward in the Hereafter, We shall give it to him. And swiftly shall We reward those that (serve us with) gratitude” (3:145).***

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1. DECLARATION

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STUDENT DECLARATION

Signed below, Arslan Muhammad , student of the Szent István Campus of theHungarian University of Agriculture and Life Science, at the BSc Course of Environmental Engineering declare that the present Thesis is my own work and I have used the cited and quoted literature in accordance with the relevant legal and ethical rules. I understand that the one-page-summary of my thesis will be uploaded on the website of the Campus/Institute/Course and my Thesis will be available at the Host Department/Institute and in the repository of the University in accordance with the relevant legal and ethical rules.

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As primary supervisor of the author of this thesis, I hereby declare that review of the thesis was done thoroughly; student was informed and guided on the method of citing literature sources in the dissertation, attention was drawn on the importance of using literature data in accordance with the relevant legal and ethical rules.

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