Journal of Balkan Science and Technology
journal homepage: www.jbst.nku.edu.tr/

# Detection and Mitigation of Microplastics (MPs) in Environment and Applications on Legal Regulations–A Review

Gunay YILDIZ TORE[1*], Sirin ILHAN YILMAZ[2]

[1] *Tekirdağ Namık Kemal University, Faculty of Engineering, Department of Environmental Engineering, 59860 Corlu-Tekirdağ, Turkey*
[2] *TESKİ Department of Environmental Protection, 59030 Tekirdağ, Turkey*

**Review Article**

*Keywords:*
Microplastic (MP)
Emerging contaminant
Plastic footprint
Wastewater

Received: 06.04.2022
Accepted: 25.04.2022
Published:31.05.2022

**DOI:** 10.55848/jbst.2022

**ABSTRACT**

Plastics are one of the refractory pollutants produced in many and varied forms using chemistry and materials science. Microplastics (MPs), which are formed as a result of plastics breaking down into small pieces, are a new indicator that indicates that the plastic footprint of humans is growing today and this has become a risk for the general living health and sustainable environment. A wide range of products such as personal care products, shampoos, detergents, toothpastes, textiles, bags, shoes, car tires, and foods contain MPs. Depending on the point of use, they are either directly released to the air, water and soil or they break down into secondary MPs in the environment where they are discharged. Especially by means of domestic wastewater, plenty of MPs enter the sewage system on a daily basis; therefore, wastewater treatment plants (WWTPs) draw attention as an important source of MP pollution in coastal or surface waters such as sea, lake, river. There is still a limited number of studies on this subject in the literature and it has become the focus of many researchers around the world. So, the aim of this review paper is to evaluate the current scientific studies on MP pollution subject. On the scope of this aim, it includes discussions on the sources, most accurate detection and treatment perspectives of MPs. Thus, it takes attention to the subject that if awareness, encouragement, guidance, and legal restrictions, that will reduce our plastic footprint, are not put into effect rapidly, it will be inevitable to cause the new health problems, genetic diseases, increasing criminal cases, and environmental problems such as air, water and soil quality.

## 1. Introduction

Plastics are polymeric materials that we commonly use in our daily lives due to their light, flexible, easily processable, corrosion-resistant, good electrical and heat insulation, easy to use, and economical properties. Considering the consumption of plastic all over the world, it is estimated that the consumption, which was 7 million tons in the 1960s, is approximately 330 million tons today, and this consumption amount will reach 540 million tons after 2020 and increase by about 4-6.2% per year from now on [1].

Plastic wastes can be divided in two groups according to their sources; one of them called as manufacturing-based wastes such as scraps, pieces, spills, and faulty products; and the other is generated after use for domestic, industrial, transportation, and agricultural activities. Today, it is reported in the literature that only 10% of the estimated 330 million tons of plastic produced annually can be brought into the circular economy. Based on this situation, Andrew Russell initiated the "Plastic Disclosure Project". The main purpose of the project is decelerated that to reveal the knowledge of the industries about how much plastic they use, what they do for recycling, what measures they take to use less plastic, the disposal of waste and their tendency towards biodegradable materials. The concept of "plastic footprint" was introduced as a measure to bring a rational solution to the use of plastic and the damages it causes, to reduce excessive use and to create awareness in consumers, companies, factories, hospitals and universities with this project for the first time. Plastic footprint, with a definition similar to carbon footprint, means the pollution left by the plastics used per individual, company or organization to the environment [2].

On the other hand, when plastic wastes are left in natural environments, they break down into small plastic particles in the size ranging from 1 mm to 5 mm and are called microplastics (MPs). These are divided into two groups as primary and secondary MPs. While plastic production spills smaller than 5 mm and micro beads, used in cosmetics, are defined as primary MPs, synthetic textile fibers originating from textile products such as clothes and carpets, blankets, vehicle tire wastes, and other plastic wastes are defined as secondary MPs. In fact, secondary MPs can be defined as micro-nano pollutants which arise indirectly as a result of the comminution processes such as certain fragmentation and destruction.

The factors that break them apart can be anthropogenic or natural factors such as weather, wind, sun, UV rays, and water. MP particles are categorized according to their size in three main groups as nanoplastics (NPs) (those smaller than 1 µm), MPs (about <5 mm), and mesoplastics (about> 5 mm) [3]. A single plastic material can be broken down into millions of MP

* Corresponding author: *Department of Environmental Engineering, Faculty of Engineering, Tekirdağ Namık Kemal University, 59860, Çorlu-Tekirdağ, Turkey*
E-mail address: *gyildiztore@nku.edu.tr*

particles. MPs accumulate in city dust, places with heavy traffic, air, soil and water resources in industrial areas, pass through, are inhaled by animals, humans, and are swallowed by living creatures. Today, MPs are an important cause of pollution in all continents, land and water from the poles to the equator. They are contaminated with more material in densely populated areas. However, it is seen that such a great danger is not sufficiently recognized in the shadow of pollutants and poisoners like heavy metals. Most of these particles float on the water surface, but some can reach sediments in various ways. So, scientific studies in recent years [4] focus on pollution caused by MPs in both receiving waters and terrestrial environments. These can be sortable such as resulting in low biodegradability and high accumulation, large surface areas providing to sorb the emerging contaminants, and possibility to be ingested by aquatic macro creatures.

MPs can carry persistent organic pollutants such as DDT (Dikloro Difenil Trikloroetan), PBDE (Polybrominated diphenyl ether), PAH, PCB (polychlorinated biphenyls), and toxic pesticides on their surface by adsorbing. These micron-sized plastics cause the transport of organic pollutants which they adsorb through the food chain.

MPs cause organic compounds to enter the body of living creatures by blocking the digestive systems of aquatic organisms. In addition, toxic chemicals such as Bisphenol-A (BPA) prevent endocrine production by affecting the reproductive systems of fish, and MPs create a major environmental problem due to the potential of both physical and chemical damage to living creatures by preventing their reproduction. While previous studies in the literature [5-12] mostly indicate the presence of MPs in environments such as rivers, lakes, seas and sediments, recent studies [13; 14; 15; 16; 17] reveal that MPs can also be detected everywhere and the removal could not be carried out in Conventional Wastewater Treatment Plant (CWWTP) effluents and treatment sludge.

Furthermore, most of the studies, carried out in the literature, show that MPs are the presence in plankton samples [18], in sandy and muddy sediments and are absorbed by vertebrates and invertebrates, and interact with chemical pollutants. However, there are still limited studies to research the MPs in wastewaters (Municipal, industrial, urban etc.) and treatment plants.

So, the aim of this paper is to review of MPs as emerging pollutants and reveal their sources, fates, detection within the wastewaters and removal mechanisms in the treatment plants. Therefore, in this study, first of all, information about the current developments regarding the sources of MPs in water, wastewater and sediments is given. Then, the latest techniques for the characterization and detection of MPs are reviewed. After that, the effects of MPs on conventional wastewater treatment systems, the results of the studies about on the treatment and removal mechanisms of MPs held by sludge are discussed. Finally, the main issues that are needed to be addressed in terms of detection, removal and legal restrictions for MP pollution in the environment in the future are discussed. So, it is aimed that this contribution will eliminate the gaps on this subject in the literature.

## 2. General Characteristics of MPs

### 2.1. Form, Shape and Color Classification of MPs

MPs can be found in the form of plastic particles, pellets, yarn-fibers, plastic films, foamed plastics, granular plastics and styrofoam. Since MP particles are formed as a result of the degradation of macro-sized plastic particles, they do not have a specific shape and color. MPs can be found in the form of pellets and pieces mostly and in a wide variety of shapes, from amorphous to spherical or long thin fibers. However, it has been reported in the literature [19] that they generally have a spherical, film, oval, fiber and irregular structure. Pellet-shaped ones can be cylindrical, disc, flat, oval and spherical, while those in the form of pieces can be round, semi-round, angular, and semi-angular. Those in formless, long, fragmented, rough and broken-edged forms are called general forms.

Furthermore, while the parts of plastic-based synthetic fabrics can be in the form of fibers, MPs produced for personal care products are generally spherical. On the other hand, in the wastewater samples taken from 17 different wastewater treatment plants [20], the presence of MPs categorized in 5 classes as fiber, piece, film, foam and pellet was detected. Moreover, in the study conducted by Gies etal. [21] on MP pollution and morphology in 17 wastewater and 12 sludge samples, 6 different classes of MPs had been detected. It was observed that 65.6% was fiber, 28.1% was particle, 5.4% was pellet, and the remaining parts were in granule, layer and foam structure. Besides, studies on water samples taken from the sea and beaches revealed that 87% of MPs consist of irregular particles. In a study on the morphology of MPs in sand and water samples taken from the vicinity of Geoje Island [22], particles in the form of pieces, fibers, sheets, and expanded polystyrene had been detected. In another study [23; 24] it is reported that, most of MPs' fragments that had been found in tidal and estuary sediments are composed of fibers. This study showed that when MPs, in sediments taken from sewage discharges and sewage, had been examined, it had been observed that the proportions of polyester and acrylic fibers used in synthetic textile garments were similar. Furthermore, it had been understood that the shapes of MPs vary depending on the duration of their stay in the environment as well as the degradation processes they are exposed to. For example, sharp-edged MPs found in marinas may indicate that plastic fragments have just entered the sea, or that smooth fragments with rounded corners remain in the sediment for a long time and become smooth by being eroded by other substances in the sediment.

On the other hand, plastics create invisible pollution in water supplies since most plastic raw materials are colorless, transparent, or micro-fragmented. However, despite this, the existence of MPs in all colors can be mentioned in the literature. In a study conducted by Aliabad et al. [25] MPs were classified as white, blue, red, transparent, and in other colors. On the other hand, in a study carried out by Abayomi et al. [26], they reported that the dominant sample type consisted of blue fibers and the following colors were black, red, green, gray, and transparent in sea water, respectively. Moreover, Ceylan et al. [27] found that the dominant species in the samples, taken from the influent, aeration, sand trap and effluent of a domestic

WWTP, consists of dark blue, blue, and black fibers. In addition, in a study carried out by Blumenröder et al. [28], they conducted for the quantitative classification of MPs, and considering their morphology and colors, they found the color density of fiber-structured MPs as blue> black> purple> white> red> brownish> green, while they determined the classification of those in the particle structure as blue> red> yellow> red> black> orange> white> purple> brownish> silver. In addition, the amount of MPs in the form of fibers had been determined higher than the particle form.

## 2.2. Type Classification of MPs

In order to be able to categorize MPs, the sources and materials from which they are produced, their type, structure, shape, color, and wear status can be evaluated. MP particles are generally classified according to the raw material of the plastic waste from which they originate. So, the types, names, and usage areas of plastics & MPs that are widely used everywhere today are given in Table 1. Blumenröder et al. [28] found that 45% of MPs are polytetrafluorethylene (PET, PETE), 15% polyethylene (PE) or polyvinylidene (PV), 10% polyamide (PA), 8% polyester (PEST), 3% polyacrylonitrile (PAN) or polydimethylsiloxane (PDMS) based. Furthermore, Ziajahromi et al. [29] investigated wastewater-based MP pollution in primary, secondary, and tertiary WWTPs and identified mostly polyethylenetetraftalate fibers and irregularly shaped polyethylene particle-based MPs.

Wang et al. [105], mostly determined the presence of polyethylene and polypropylene-based MP types in Dongting Lake and Hong Lake. However, they reported that they also encountered polystyrene and polyvinylchloride-based MPs. According to the analysis results performed by Lares et al. [30] to determine the MP content of the samples, taken from a domestic WWTP and the discharge water of the facility, the presence of 79.1% polyester and polyethylene tetraftalate (PET), 11.4% polyethylene (PE), 3.7% polyamide (PA) and insignificant amounts of polypropylene (PP) were detected in the samples.

In the study conducted by Aliabad et al. [25] in Chabahar Bay, PE and PP had been reported to be the dominant MP species in Northern Italy. The amount of MPs reaching the receiving water environment from the large capacity WWTP, which serves a population of 1200000 people, has a wastewater flow of 400 000 m3/day and includes primary, secondary, and tertiary treatment stages and it has been reported that the dominant species are composed of PES and PA-based MPs. Furthermore, plastic-type classification made by Simon et al. [31] in raw wastewater and treated wastewaters; the dominant types are determined as acrylate, PES and PE-PP copolymer for raw wastewater and PE, PES and PE_PP copolymer for treated water, respectively. Moreover, a study by Hidalgo-Ruz et al. [32] divided MPs into two groups as positive swimmers and negative swimmers according to their being in different habitats and different flow paths (sandy beaches, tidal sediments, sea surface, water column, and ocean floor).

MPs' properties such as density, shape and size, as well as some external forces (seawater density, seabed topography and pressure, etc.) affect their spread. Studies on the transport and spreading of MPs in water [33] have indicated that the density of plastic particles is a very effective factor. The density of the plastics widely used today varies between 0.85-1.41 g / cm3. While the density of LDPE, HDPE and PP is less than 1 g/cm3, PS, nylon6, PVC, and PET are plastics with a density greater than 1 g/cm3. Accordingly, particle density is an important indicator for determining whether an MP particle covers a pelagic region in the benthic transport route, whether low-density plastics are present in the surface and neustonic environment, or high-density plastics in deep benthos.

## 2.3. Physicochemical Characteristic of MPs

MPs generally have hydrophobic surfaces; they swim; their ability to carry pollutants absorb POPs such as PCB and DDT; they have UV photo-oxidative degradation; they are thermo-oxidative; they have bio and/or thermal degradation; especially in biofilms, they have properties such as binding on biomass. MPs are effective absorbers for POPs and transport POPs from surface water sources to sediments. Therefore, this increases the exposure of benthic organisms to POPs.

Reported concentrations of POPs in plastic pellets found in seas around the world [34] range from 1 to10,000 ng/g plastic pellets. Polychlorinated biphenyl concentrations have been found worldwide in 4-980 ng/g plastic pellets and 169-324 ng/g in the northern sea. A positive correlation was found between macroplastic and PCB concentrations in birds as a result of seabird feeding and field investigation studies.

Some of the MPs and POPs are harmful man-made chemicals that persist in the environment because they are not biodegradable or degraded. For example, dioxins, PCBs, different types of organochlorine pesticides, DDTs and HCHs, polycyclic aromatic hydrocarbons (PAHs), hexachlorobenzene (HCBs), and brominated flame retardants are common POPs. Because they are essentially lipophilic (for example, they have a high affinity for oils and fats), POPs accumulate in the adipose tissues of marine organisms. This situation potentially causes many adverse effects (e.g. cancer, malformation, impairment of the immune system and reproductive ability) for wildlife and humans. Plastic pellets are also lipophilic and have an extremely high affinity for POPs. The concentration of POPs in plastic resin pellets is one million times higher than the surrounding sea water. This accumulation was observed for the first time in 1998 with on-site experiments. This is why resin pellet monitoring studies are important.

Moreover, in addition to the absorption of POPs, marine plastics contain additives such as plasticizers, antioxidants, anti-static agents, and flame retardants. Some additives and additive-based chemicals (eg nonylphenol, bisphenol A) cause endocrine disruption in the body through hormones. These potential damages include impairment of brain development, learning and behavior, torso and limbs, normal These potential damages include impairment of brain development, learning and behavior, torso and limbs, normal sexual development (including males' feminization and feminization), and increased cancer events (e.g. breast and prostate cancers).

**Table 1.** Types, names and usage areas of plastics & MPs.

| Abbreviation/ Raw matter | Common Area of Use | Morphology | Density ($g.cm^{-3}$) | Reuse | Recycle |
|---|---|---|---|---|---|
| PET, PETE Polyethylene | Bottles of water, soft drinks and cooking oil | Crystalline Thermoplastic | 1,37 | No Single use | Very good |
| PE-HD, HDPE Polyethylene-high density | Cleaning agents, laundry detergent packaging, some bags, shampoo and milk bottles, pipes, tanks, barrels, | Crystalline Thermoplastic | 0,94 | Yes | Very good |
| PVC, VC Polyvinyl Chloride | Upholstery, home siding, pipes, stretch, food coating, bottles, glasses, artificial | Amorphous Thermoplastic | 1,38 | No | Very little convertible since the additives |
| PE-LD, LDPE Polyethylene-low | General purpose anywhere | Crystalline Thermoplastic | 0.91-0.93 | Yes | Usually it cannot be recycled |
| PP Polypropylene | Automobile sub-industry, garden furniture, food container, yoghurt and margarine containers, | Crystalline Thermoplastic (Translucent white) | 0.83-0.85 | Yes | Cannot be easily converted |
| PS Polystyrene | Food packaging, electronics and appliances, film, sheet, containers, lids, meat and | Amorphous Thermoplastic (Colorless, | 1.36-1.45 | No | Possible but not economical |
| Polycarbonate, Acrylic | Due to its high flame-retardant and self-extinguishing feature, | Numerous | | No | It is difficult because it contains mixed plastics |
| Polyester (PEST), 1.24-2.3 | Textile industry (Garment) Fiber production | Numerous | 1.24-2.3 | Yes | Very good |

While the additives used in pellets are harmful, more harmful additives are used in plastic parts making and plastic product finishing. One study [35] has shown that endocrine-disrupting nonylphenols are even present in water bottle lids.

## 2.4. Sources of MPs

Plastics that accumulate in nature as a result of industrial and domestic activities are broken down into smaller pieces as a result of various physical abrasions and form MPs. MPs are generally defined as plastic particles smaller than 5 mm and can be found in many different sizes in a wide variety of environments such as aquatic, terrestrial, and biota. Pollution caused by MPs chronically affects human health indirectly by mixing into the food chain through air, water, and soil.

Plastics that can crumble into very small particles in rivers can be transported by entering a cycle with anthropogenic effects as well as climate and nature movements such as wind and such serious levels of MPs are encountered in water sources such as seas, oceans, lakes, rivers and wastewater and even purified water. MPs can be commonly classified in two ways, according to the activity from which they originate: (1) Primary MPs, (2) Secondary MPs. The sizes and classification on the base of sources of MPs with high environmental damages are given in Table 2 and Table 3, respectively.

In a study conducted in Sweden [36] it is noted that the rate of MPs resulting from transportation can be serious. According to this study, approximately 13000 tons of MPs are formed from tires every year, and it is estimated that approximately 2300-3900 tons of MPs are mixed into rainwater per year; and in addition, every year 300 to 530 tons of them are lost in industrially produced plastic pellets.

**Table 2.** MP types and particle size ranges.

| PARTICLE TYPE | PARTICLE SIZE RANGE |
|---|---|
| NanoMPs | <000,1 mm (0,1 μm) |
| Small MPs | 0,0001 mm – 1 mm |
| Large MPs | 1 mm- 5 mm |
| Mesoplastics | 5 mm – 200 mm |
| Macroplastics | > 200 mm |

**Table 3.** MP sources based on activity.

| ACTVITY | MP SOURCES | MP CLASS |
|---|---|---|
| Consumer products | Microbeads in cosmetics, facial cleansing and peeling gels, shampoos and soaps, toothpaste, eyeliner, mascara, lip gloss, deodorant and sunscreens, etc. | Primary |
| Textile products | Polyester, polyamide (nylon) and polar textile materials used in clothing | Secondary |
| Industrial raw materials, residues and waste | They are MP materials arising from plastic production, processing and shaping processes. For example; pallets, plastic films, styrofoam, yarn-fibers, foamed plastics, etc. are the sources that pollute the environment. | Primary |
| Transportation | Vehicle tire debris | Secondary |
| Municipal and Industrial Wastewater Treatment | Domestic and industrial water usage. For example; laundry and dishwashing, take a bath and etc. | Secondary |
| Agriculture | Vehicle tire debris. For example; Plastics crumbled by the wear of the tires of vehicles used in agricultural activities pass into the soil, drip irrigation system material made of plastic polymer break up over time and pesticides stored in plastic containers and used by diluting, etc. | Secondary |

### 2.4.1. Wastewater Treatment Plants as a Main Sources of MPs

Since MPs can originate from all kinds of anthropogenic activities, especially domestic use, industrial production, agricultural activities and transportation equipment, influent-raw and effluent wastewaters of domestic, and industrial wastewater treatment plants are important MP sources (for both primary and secondary types) for the aquatic ecosystem. Research studies carried out on sewage samples of many different countries such as Russia, Sweden, France, Finland, USA, UK, Netherlands, Germany, Canada, Australia, Italy, Turkey, Denmark, Poland, China, and South Korea support this result. For example, Mintenig et al. [37] analyzed the amount and types of MPs in the samples taken from the discharge of 12 wastewater treatment plants in Germany. In the analyses performed using ATR FT-IR and Micro FT-IR, MP parts larger than 500 μm were found in all 10 plants except 2 plants with filtration units.

They found that mostly polyethylene MPs were released in all 12 plants. MPs smaller than 500 μm were detected in all 12 facilities and they determined that these MPs have 12 different polymer structures.

According to the results of the study conducted by Talvitie et al. [38] in Finland's largest wastewater treatment plant, it has been reported that $2x108 - 7.9x108$ micro garbage and $1.7-106 - 1.4108$ MPs are discharged daily from the treatment facility to the Baltic Sea. Gies et al. [39] had researched the amount of MPs in the effluents of pre-sedimentation and secondary settling tank, and in the sludges of a wastewater treatment plant in Canada. They found 14.9 MPs per gram of primary sludge, and 4.4 MPs per gram of secondary sludge. When they compared the amount of MPs in the effluent and sludge samples, they reported that 1.28 trillion and 0.15 trillion MPs are discharged annually from the pre-sedimentation sludge and effluent, respectively. On the other hand, they calculated that 0.36 trillion and 0.03 trillion MPs are discharged from the secondary settling sludge and effluent, respectively. Consequently, they found that the amount of MPs in the sludge samples was much higher than in the effluents and at the same time, secondary treatment has better removal efficiency (92%) than pre-sedimentation (88%). On the contrary, in the studies conducted on the characterization of MP pollution in the influent and effluent of wastewater treatment plants in recent years [40; 41; 42], it was stated that MP concentrations can vary from 103 to 108 MPs/m3 wastewater.

According to a study by Magnusson et al. [36], it is estimated and reported that every year 250-2000 tons of microbeads consisting of personal care products and plastic particles consisting of synthetic textile fibers with a particle size of more than 300 μm are discharged via domestic wastewaters into the Swedish sewage system. Most of them can be kept in the wastewater treatment plant, but about 4-30 tons of them were discharged into the receiving environment by the effluents of the wastewater treatment plant. In addition, according to the same study, it was calculated that 69 tons of MP particle size larger than 450 μm were discharged into the sewage system with liquid soaps in Sweden in 2012 and an average of 7 grams of household MP pollution per person was formed.

In another study carried out by Bilgin et al. [43] on MP pollution in different units of a secondary wastewater treatment plant in Turkey, removal efficiencies in these units were calculated by comparison. Composite samples were taken with

the filtration system prepared by using filters with different pore diameters. In the study conducted on wastewater and sewage sludge samples, firstly on samples for the extraction of MPs, washing, Fenton oxidation, centrifuge, and filtration processes were carried out. Subsequently, the samples were examined under an optical microscope and under the ATR-FT-IR microscope. As a result of detailed examinations, MPs were classified according to their shapes, sizes and types. As a result of the study, very high concentrations such as 5-10 MP/L and 570-1180 MP/L were measured in wastewater and sewage sludge, respectively. It has been calculated that the amount of MPs discharged daily is between 474 and822 million MP/day and the MP removal efficiency of the treatment plant is between 60-76%.

In a study conducted by Ceylan et al. in Turkey [27] on another urban wastewater treatment plant operating with an activated sludge system, the presence of MPs in the samples which are taken from untreated raw wastewater influent, sand trap, and treatment plant effluents, was detected and removal efficiency was evaluated. In order to separate the MPs in the samples taken, preparing a solution with increased density (weighted) with salt, flotation, centrifugation, filtration, washing, drying etc. processes have been applied. The MPs separated in this way were first classified and counted by type, color, and number with a light microscope; then, polymer types were determined with the ATR-FT-IR device with a microscope. As a result of the studies, it has been determined that the investigated urban wastewater treatment plant can retain 57.51% of the MPs in the wastewater and approximately 8415 million MPs are discharged into the receiving water every day.

In another study carried out by Basaran et al. in Turkey [44], on a synthetic textile industry wastewater treatment plant, it was reported that while fibers longer than 5 mm are remarkable, and fibers around 1.8 mm on average are found in untreated raw wastewater samples. Synthetic fibers around 2.2 mm were found in treatment plant effluents and it was determined that an average of 5 different MPs/L were discharged into the sewer. According to a study conducted by Bakkaloğlu et al. [45] in Turkey; samples taken at 4 different times at determined points (influent, sand trap and secondary settling effluents, and return sludge) in Bursa East Wastewater Treatment Plant had been analyzed. After the pretreatment stage, firstly shape, color, and size classification had been made and then the species had been determined by FTIR analysis. According to the results of the study, it has been reported that MPs determined investigated treatment plant can be categorized into 4 different classes, divided into 3 categories as piece + film, fiber, sphere in shape, although there are similar tones of 7 different color categories such as black-navy blue, blue, red-orange-pink, green, purple, brownish-cream, yellow, and white-gray can be determined and can be classified in 3 different categories (0.3 mm - 0.5 mm, 0.5 mm - 1 mm and 1 mm - 5 mm). In the species classification, 8 different types of MPs, namely PMMA, PE, PEVA, PES, PET, PA, PP, and PAA have been identified. In addition to these results, it was determined that the dominant MP shape in all samples was piece + film (50-60%), the dominant color was black-dark blue, and the dominant size range was between 0.3 mm-0.5 mm (>90%). The presence of the same structure has also been confirmed in the sludge samples. The MP removal efficiency of Bursa East Wastewater Treatment Plant had been calculated as approximately 93%.

### 2.4.2. Transportation of MPs in WWTPs

A CWWTP can be defined as a system in which organic, inorganic, and persistent pollutants are passed through primary (Physical), secondary (Chemical or Biological), and tertiary stages (advanced oxidation, filtration etc.). It has been reported in the literature [40] that many types of MPs that can be found in the structure of wastewater can be removed at a significant rate in the primary stage, and that the presence of MPs can be detected in secondary and tertiary treatment effluents and treatment sludge in a very small amount. A schematic representation explaining the removal efficiencies of MPs in CWWTP units is given in Fig. 1.

Apart from that, wastewater treatment plant configuration also has a significant impact on MP removal efficiency. For example, it has been reported in the literature by Li and Kim [47] that most of the MPs are removed in degreasing and screen units in a domestic wastewater treatment plant with an anaerobic-anoxic-aerobic configuration. In addition, this study revealed that the highest removal efficiency was observed in MPs with very small sizes in the range of 100-300 µ. It has been interpreted that this result may be due to the higher tendency of small-sized MPs to adhere on a surface compared to large sizes (>300µ).

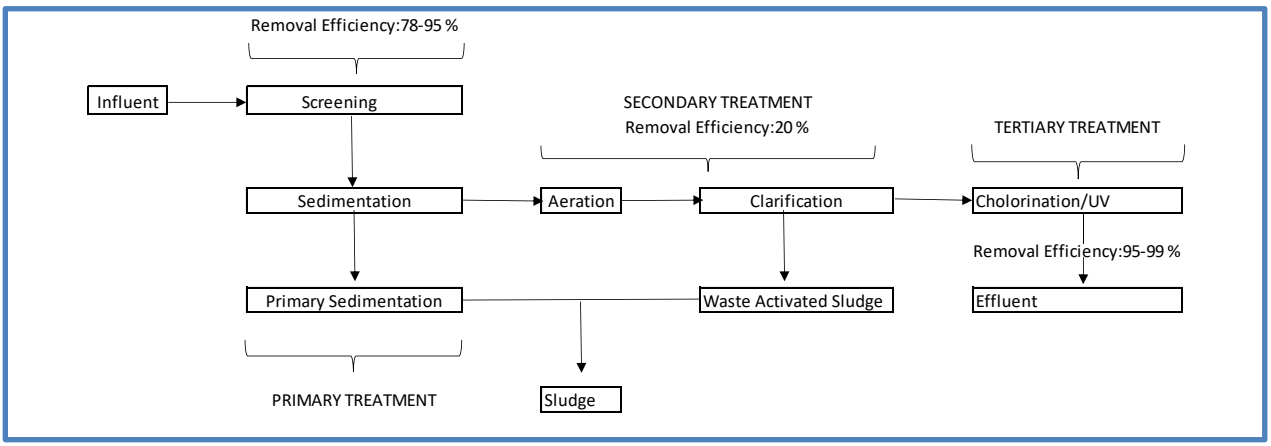


**Fig. 1.** A schematic removal efficiencies representation of MPs in CWWTP.

In another study [48], it was evaluated that MPs decreased significantly in the anaerobic digestion process and this situation can be accepted as an indicator of the presence of MPs in polymeric structure; therefore, it may be due to the degradation potential of microorganisms that have an important role in the anaerobic digestion process. However, it was stated that this interpretation should be supported by other studies. MP pollution removal efficiencies in samples taken from different points of wastewater treatment plants are summarized in Table 4.

There are limited studies in the literature on the transport and removal of MPs in wastewater treatment units. Conley et al. [52] reported that there may be many reasons for the unretained MPs in wastewater treatment plants such as wastewater treatment capacity, site, area, seasonal changes in organic/inorganic loading on WWTP etc. For example, the presence of MPs in domestic wastewater in holiday areas may vary depending on the region and season, or since the wastewater treatment plant will be operated with an excessive load during summer periods, the efficiency of the wastewater treatment plant and therefore the MP removal efficiency will also decrease. For this reason, the efficiency of MP removal as well as the pollutant removal efficiency of the wastewater treatment plant within the annual period should be correctly characterized by considering these changes.2.4.3. Classification of MPs in the WWTPs effluent

In the literature, many studies about the presence of MPs in wastewater treatment plant effluents have been evaluated on the type, shape, size, chemical composition, and color of MPs. Recent studies of literature are given in Table 5.

According to Table 5, it has been reported in the literature that most fiber types of MPs, which are mostly detected in secondary stage output currents of WWTP, are in the range of 0.5-5 mm in size, their chemical composition is PEST, PEST + PA, or PEST + PE, and their color cannot be determined. But, there are still a limited number of studies of literature on the presence and disposal of MPs at different stages of sewage WWTPs. Comprehensive studies are still needed on the detection and fate of polyester and polyethylene-based MPs in WWTPs. In addition, there is a need for many studies that reveal how MP types, which are detected intensively in WWTPs, change in the treatment plant depending on the treatment processes and operating conditions, and how they affect the treatment efficiency. At the same time, issues such as removal efficiency and fate in new generation wetland, and low-cost treatment technologies are among the issues that need to be studied on a scientific scale.

**Table 4.** MP pollution removal efficiencies in WWTPs.

| Sampling Point | Location | Treatment System | MP Concentration | Removal Efficiencies | Reference |
|---|---|---|---|---|---|
| Effluent | Ljubljana, Slovenia | Secondary | - | 52% | [49] |
| Influent | United Kingdom | Secondary | 15,70 MPs*/L | 98,41% | [41] |
| Effluent | | Secondary | 0,25 MPs*/L | | |
| Effluent | | Primary (Grit and Grease Unit) | 8,7 MPs*/L | 44,59% | |
| Effluent | | Primary (Settling) | 3,4 MPs*/L | 33,75% | |
| Effluent | | Secondary | 0,25 MPs*/L | 20,07% | |
| Effluent | Finland | Tertiary (MBR) | - | 99,4% | [30] |
| Effluent | | Secondary | - | 98,3% | |
| Effluent | Finland | Primary | 6,9 MPs*/L | - | [38] |
| Effluent | | Tertiary (MBR) | 0,005 MPs*/L | 99,9% | |
| Secondary Effluent | | Tertiary (Rapid sand filter) | | 97% | |
| Effluent | | Tertiary (Dissolved air flotation) | | 95% | |
| Effluent | | Secondary | 0,5- 2,0 MPs*/L | 40% | |
| Effluent | | Tertiary (Disc filter) | 0,003–0,3 MPs*/L | 98,5% | |
| Influent | Turkey | Tertiary | 3,1 MPs*/L | 48% | [50] |
| Effluent | | | 1,6 (0,3–5.1) MPs*/L | | |
| Influent | | Secondary | 2,6 MPs*/L | 73% | |
| Effluent | | | 0,7 (0,2–1) MPs*/L | | |
| Influent | | Secondary | 1,5 MPs*/L | 60% | |
| Effluent | | | 0,6 (0,2–1,2) MPs*/L | | |
| Influent | Turkey | Secondary | 26,555 MPs*/$m^3$ | 73% | [51] |
| Effluent | | Secondary | 6999 MPs*/$m^3$ | | |
| Influent | | Secondary | 23,444 MPs*/$m^3$ | 79% | |
| Effluent | | Secondary | 4111 MPs*/$m^3$ | | |

Studies have shown that the WWTPs can remove some of the MPs. The MPs in WWTPs are mainly composed of polyester and polyethylene. The main morphology is granular and fibrous. The removal rate of granules in wastewater treatment processes is higher than that of fiber. Population density, economic level, urban greening areas, wastewater treatment process parameters, sludge dehydration, and treatment processes can affect the concentrations and behavior of MPs in various stages of WWTPs.

### 2.4.4. MPs in WWTP Sludge

MPs from both conventional and advanced wastewater treatment plants have revealed that approximately 99% can be removed by absorbing the sludge formed at various stages of treatment plant units. MPs in wastewater are mostly removed from the water along with primary, secondary, and tertiary treatment sludges in WWTPs. Most studies [39; 30; 54] have supported the richness of MPs in the WWTPs sludge. Therefore, although the treatment sludge with the potential to be applied agriculturally poses a significant threat to the environment, unfortunately a restriction on the reuse and storage criteria of the treatment sludge containing MP pollution is still not imposed at national/international level. Table 6 presents the recent literature about MP concentration in WWTPs' sludges.

When studies on the investigation of MP presence in treatment sludge in the literature are examined, it is seen that most of them focus on MPs characterization (chemical). composition, size, type, microbial community etc.) in different types of sewage sludge; and studies conducted in recent years are mostly on evaluating the effects of MPs on sludge treatment processes such as aerobic/anaerobic, thermal stabilization, lime stabilization, and also microbial community. So, especially since international legislation allows wastewater treatment plant sludge to be used in the field and it is possible for MP to pass to both receiving water and tertiary environments by means of treatment sludge, in the future, prevention of secondary MP contamination by pre-treatment before the sludge digestion process with emerging pyrolysis technologies (such as thermal pyrolysis, microwave-assisted pyrolysis and catalytic pyrolysis) should be investigated. In addition, MPs should be taken into account among water reuse criteria in water recovery applications to prevent MP pollution in the aquatic and terrestrial environment.

## 3. Environmental Impacts of MPs

MPs can turn into a "cocktail" of chemical pollutants for living creatures in aquatic environments. We can call it "plastic soup" [58] (Fig. 2). It is estimated that blue whales (Balaenoptera musculus), the largest animal on earth, feed on plankton, absorb, and retain MPs during their feeding [59; 60]. Albatross birds swallow excessive amounts of plastic-like food, along with mussels, fish, and squid while aquatic turtles feed on jellyfish and eat the MPs surrounding them, mistaking them for food. This is because plastics remain in easily removable particles and their surface is covered with a biofilm that is largely composed of organic materials.

**Table 5.** Recent literature about the classification of MPs in the WWTPs effluent.

| Sampling point | Classification of MPs (Type, Shape, Size, Chemical composition, Color) | Reference |
|---|---|---|
| Effluent-1 (Secondary) | **Type:** Fiber (60 %), films (20 %), fragments (20 %)<br>**Size:** 1–5 mm (40,5%)<br>**Chemical composition:** PEST (43,8 %) (Most common)<br>**Color:** N.D. | [51] |
| Effluent-2 (Secondary) | **Type:** Fiber (60%), films (20%), fragments (20%)<br>**Size:** 1–5 mm (34,9%)<br>**Chemical composition:** PEST (43,8%) (Most common)<br>**Color:** N.D. | |
| Effluent (Secondary) | **Type:** Lines (41%), films (38%), and fragments (21%)<br>**Size:** 0,1–0,5 mm (52%), 0,01–0,1 mm (27%), 1–5 mm (14%), and 0,5–1 mm, (7%)<br>**Chemical composition:** PEST and PA (Most common)<br>**Color:** N.D. | [53] |
| Effluent (Tertiary) | **Type:** Fibers (>50 %)<br>**Size:** 0,5-1 mm (> 50%)<br>**Chemical composition:** PEST and PE (Most common)<br>**Color:** N.D. | [38] |
| Effluent (Secondary) | **Type:** Fragments (>50 %)<br>**Size:** 20–100 μ (> 50%)<br>**Chemical composition:** PEST and PE (Most common)<br>**Color:** N.D. | [30] |
| Effluent (Secondary) | **Type:** Fibers (>50 %)<br>**Size:** > 500 μ (> 75 %)<br>**Chemical composition:** PE (Most common)<br>**Color:** Black, Blue, Transparent (53 %) | [50] |

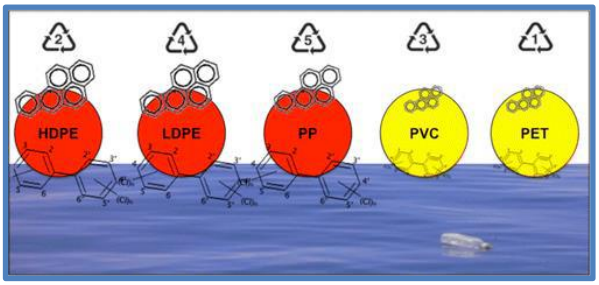


**Fig. 2** Cocktail of pollutants [57].

Recent experimental studies show that some invertebrates, fish, and zooplankton (for example, mussels (e.g. Mytilus edulis), [61] and bivalve mollusks such as oysters, echinoderms, crustaceans (e.g. water flea, copepod), lobster (Nephros norvegicus), sea cucumber) swallow MPs; and therefore, their organs and digestive systems are badly affected [62; 63]. Since creatures that feed by filtering water, such as mussels, can contain all kinds of substances in the water, especially in the receiving environments where wastewater is discharged, they metabolize MPs along with various nutrients in wastewater. Thus, it is inevitable for these pollutants to pass to humans through the food chain and cause various health problems.

MPs can cause toxic effects. Toxicity can be directly caused by polymer materials used in the production of plastic products; and additives that are added to plastic to improve the properties of plastics can also increase toxicity. Furthermore, the small size and sharp ends of MPs can cause inflammation in the living body [17]. A study on oysters showed that composition, size, type, microbial community etc.) in different types of sewage sludge; and studies conducted in recent years are mostly on evaluating the effects of MPs on sludge treatment processes such as aerobic/anaerobic, thermal stabilization, lime stabilization, and also microbial community. So, especially since international legislation allows wastewater treatment plant sludge to be used in the field and it is possible for MP to pass to both receiving water and tertiary environments by means of treatment sludge, in the future, prevention of secondary MP contamination by pre-treatment before the sludge digestion process with emerging pyrolysis technologies (such as thermal pyrolysis, microwave-assisted pyrolysis and catalytic pyrolysis) should be investigated. In addition, MPs should be taken into account among water reuse criteria in water recovery applications to prevent MP pollution in the aquatic and terrestrial environment.

**Table 6.** Recent literature about MP concentration in WWTPs sludges.

| Sampling point | Amount (MPs /Kg dried sludge) | Classification of MPs (Type, Shape, Size, Chemical composition, Color) | Reference |
|---|---|---|---|
| Sludge (28 WWTPs, 79 different sludge) | 22.7 x $10^{-3}$ | Type: Fiber (63%)<br>Size: 1–5 mm (40,5%)<br>Chemical composition: polyolefin (PO), acrylic fibers, PE, PA, alkyd resin, and PS<br>Color: White | [54] |
| Sludge (3 samples from Anaerobic Sludge and 2 samples from Primary Sludge occurred from Urban and industrial WWTP) | N.D. | Type: N.D.<br>Size: N.D.<br>Chemical composition: Ethyl acrylate (generally using for producing resins, | [55] |
| 7 WWTPs in Ireland which use anaerobic digestion (AD), thermal drying (TD), or lime stabilization (LS) treatment | 4196–15385 | Type: Fibers (>75,8 %), Fragment (18,4%) films (1,9%), spheres (0,3%), and other (0,9%)<br>Size: Smaller size in LS<br>Chemical composition: HDPE, PE, and PA<br>Color: N.D. | [48] |
| Municipal WWTP (Kenk€averonniemiWWTP) sludge in Finland | 23x$10^3$ (±4,2) (Activated Sludge)<br>171 x $10^3$ (±28,7) (Digested Sludge) | Type: Fibers (>50 %)<br>Size: > 500 µm and < 500 µm<br>Chemical composition: PEST (79.1%), E (11,4%) and PA (3,7%)<br>Color: N.D. | [30] |
| 6 WWTPs' sludges in Germany | 1x $10^3$ – 2,4 x $10^4$ | Type: Fibers (>50 %)<br>Size: > 500 µ (> 75%)<br>Chemical composition: PE, PP, PA and PS<br>Color: N.D. | [37] |
| Raw WAS in China | 2,1 x $10^3$ | Type: N.D.<br>Size:< 5 mm<br>Chemical composition: PET<br>Color: N.D. | [56] |
| Raw WAS in China | 200 x $10^3$ | Type: N.D.<br>Size: 40 ± 2 µm<br>Chemical composition: PE (87-96 %)<br>Color: N.D. | [57] |
| Raw WAS in China | 2,1 ± 1,1 x $10^3$ | Type: N.D.<br>Size: 1 mm<br>Chemical composition: PET<br>Color: N.D. | [56] |

## 3. Environmental Impacts of MPs

MPs can turn into a "cocktail" of chemical pollutants for living creatures in aquatic environments. We can call it "plastic soup" [58] (Fig. 2). It is estimated that blue whales (Balaenoptera musculus), the largest animal on earth, feed on plankton, absorb, and retain MPs during their feeding [59; 60]. Albatross birds swallow excessive amounts of plastic-like food, along with mussels, fish, and squid while aquatic turtles feed on jellyfish and eat the MPs surrounding them, mistaking them for food. This is because plastics remain in easily removable particles and their surface is covered with a biofilm that is largely composed of organic materials.

Recent experimental studies show that some invertebrates, fish, and zooplankton (for example, mussels (e.g. Mytilus edulis), [61] and bivalve mollusks such as oysters, echinoderms, crustaceans (e.g. water flea, copepod), lobster (Nephros norvegicus), sea cucumber) swallow MPs; and therefore, their organs and digestive systems are badly affected [62; 63]. Since creatures that feed by filtering water, such as mussels, can contain all kinds of substances in the water, especially in the receiving environments where wastewater is discharged, they metabolize MPs along with various nutrients in wastewater. Thus, it is inevitable for these pollutants to pass to humans through the food chain and cause various health problems.

MPs can cause toxic effects. Toxicity can be directly caused by polymer materials used in the production of plastic products; and additives that are added to plastic to improve the properties of plastics can also increase toxicity. Furthermore, the small size and sharp ends of MPs can cause inflammation in the living body [17]. A study on oysters showed that polyester-based MPs have negative effects on reproductive disorders and juvenile oysters [64]. It is known that MPs have an effective role in the transport of toxic pollutants along the food chain. Unfortunately, MPs, which we almost cannot escape in our daily life, are known to be present in foods and beverages such as salt, seafood, sugar, honey and even soda, and indoor and outdoor air. This suggests that all living creatures are exposed to MPs through nutrition and inhalation, but this leads to new health and environmental problems and its effects are not yet known, results sometimes irreversible. Studies on the negative effects of MPs in terms of physiology and homeostasis highlight their chemical and microbial hazards. Inhaled and swallowed MPs may accumulate in tissues and impair homeostasis locally or in general, either suppressing the immune system or making it hypersensitive. Monomers, additives in plastics, are adsorbed and chemical toxicity may occur as a result of contaminants leaking into tissues. Generally, seeing the effects related to chronic exposure makes the process more dangerous and studies in this area are still insufficient. For instance, MPs with sizes in the range of 1-5 mm can cause blockages in the primary treatment stage.

### 3.1. Effect of MPs on Pollutant Removal and WWTPs' Process Efficiency

Treatment processes commonly used in wastewater treatment are divided into 3 groups: primary (physicochemical), secondary (biological), and tertiary (advanced). While the solid and suspended organic and inorganic substances in the wastewater, which can be removed by the effect of relative gravity, are removed physicochemically, most of the dissolved organics can be removed by the secondary treatment stage. While biological treatment processes, which are widely preferred in wastewater treatment, are designed to remove conventional parameters such as COD, nitrogen, and phosphorus, recent studies have revealed that a significant portion of MPs are attached to treatment sludge. If a chemical coagulant is used at this stage, the high surface area and hydrophobic nature of MPs will result in a decrease in the removal efficiency at this stage, so a high amount of chemical use is required during this removal, and too small amount of MPs are discharged to aquatic environments with effluents. Because of these properties, they can adversely affect removal efficiency as they can adsorb toxic substances. On the other hand, MPs in raw wastewater negatively affect biological treatment. Especially NPs cause the most impact on the microbial community in nitrogen removal processes. It has been reported in the literature [65] that it reduces the oxidation of NH4-N to NO3 during the nitrification process. In other studies [66; 67], it is suggested that it causes inhibition of denitrified bacteria by causing ammonia accumulation during the denitrification process. On the other hand, it has a lower negative effect on phosphorus removal than nitrogen removal. It has been suggested that this can be explained by the fact that organisms that play a role in nitrogen removal are more sensitive than those in the phosphorus process [68]. Thus, although it depends on the size and chemical composition of the MP, it generally creates more significant negative effects on the nitrogen removal process than on phosphorus.

When the literature studies on the effects of MPs on wastewater treatment system efficiency [49; 69; 57] are examined, it has been reported that they do not have any significant effects on Sequencing Batch Reactor (SBR) systems; and although they provide a suitable surface area for microbial adhesion and proliferation in Biological Active Filter (BAF) systems, the head load loss in the filter increases and requires more frequent cleaning. Also due to its' spherical form, it easily binds to suspended solids in wastewater and reduces the amount of volatile suspended solids in the effluent. Furthermore, studies in the literature [70; 71; 72] have proven by respirometric measurements that polyethylene-based positively charged nanomicroplastics (NMPs) have a high tendency to attach onto activated sludge culture (Fig. 3), which is considered to have a negative charge, and cause acute inhibition at high MPs concentrations [73]. A representation of NMPs with different charges that can interact with the cell wall of microorganisms is presented in Fig. 4. In addition, it has been stated that NMPs cause changes in the protein structure of extracellular polymeric substances (EPS) released from activated sludge culture during the biochemical oxidation processes in ASS.

In addition, in studies conducted on the presence and removal of MPs in sewage sludge [57] it has been demonstrated that in cases where MPs are continuously entering wastewater treatment plants, MPs result in an increase in the amount of sludge by approximately 9.1%; and since MPs are generally removed from wastewater with sewage sludge, parallel to this, an increase in sludge removal and disposal costs is observed.

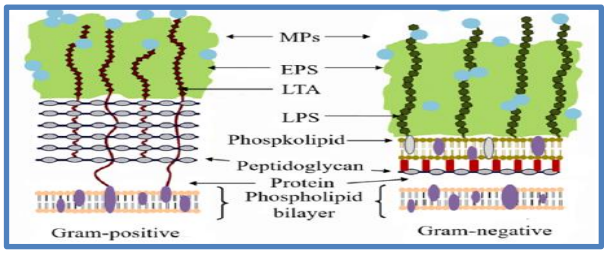


**Fig. 3** Schematic representation of MP attaching mechanism to on microbial community [72].

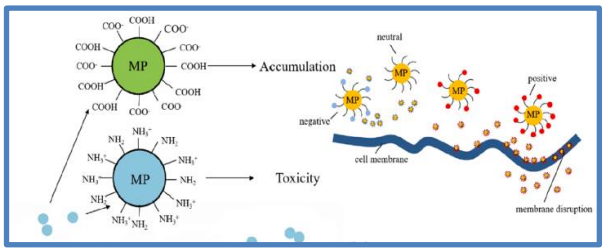


**Fig. 4** NMPs with different charges that can interact with the cell wall of microorganisms [72].

So, it has been reported in the literature [41, 74-75] that WWTP operating conditions (F/M ratio, hydraulic holding time, sludge age, volumetric loading rate, etc.) may cause an increase in MP amounts (mostly in the form of fiber and white color) in the effluent or sludge (primary, secondary, or tertiary).

On the other hand, in tertiary treatment processes (chemical settlement, disinfection) by using chemicals such as aluminum or iron salts, chloride, ozone, it has been reported [75; 76] that the need for chemicals increases due to MPs with negative surface charges, hinders chlorine effect, and can be oxidized easily by oxidants which cause an increase in tertiary treatment costs. Similarly, in flotation applications, due to MPs, which have a high tendency to bind the suspended substances, the amount of air as a basis in system design is not sufficient to carry these materials to the surface; and thus, it results in an increase in air demand and increased treatment costs. In addition, due to the potential of MPs to cause irreversible clogging on polymer membrane surfaces, it has been demonstrated in the literature that the membrane process efficiency decreases and energy consumption increases [77; 78; 79; 80].

Furthermore, MPs also have effects on sludge dewatering, aerobic, and anaerobic sludge digestion processes, which are widely used in wastewater treatment plants. Since the main mechanism in anaerobic sludge digestion processes, which have been used widely in recent years, is based on the conversion of particulate organic materials into dissolved organics under anaerobic conditions, the presence of MPs in the sludge can directly affect this transformation. For example, when the studies on this subject are examined [81], it is observed that where the PVC form of MPs is the dominant type in the wasted sludge, the amount of dissolved COD increases as the amount of MPs increases, while PE-based ones do not cause any effect on this transformation. In addition, it has been observed that there are studies [57; 82; 56] showing that MPs cause negative effects on the hydrolysis of polysaccharides and proteins in the sludge and the degradation of intermediate products such as butyrate in the anaerobic phase. Besides, it has been determined that the anaerobic digestion process of MPs with nanoparticular structure also has effects on methane production efficiency. Wei et al. [57] reported that the presence of PE-based NMPs in wastewater treatment plant sludges in high concentrations caused a decrease in the hydrolysis rate during anaerobic digestion and thus a decrease in methane production efficiency.

## 4. Recent Developments on MPs Detection in Wastewater and WWTPs

When the studies in the literature on the detection of different types of MPs in both raw wastewater and WWTP effluent and sludge are examined, it is understood that different approaches and standards can be applied. But generally, it is observed that 4 stages are very important to identify accurately and precisely of the characterization of MPs found in different size, shapes, and chemical compositions in the environment. These stages can be summarized as Sampling Approach and Extraction Method, Pre-Treatment Application (Digestion) and Separation Techniques, Qualitative and Quantitative Analytic Techniques, and Quality Control for Measurement Accuracy.

MPs of different sizes, shapes and compositions are difficult to characterize in wastewater and sludge. Therefore, depending on the wastewater/sewage sludge source we will examine, it is necessary to examine the studies in the literature before deciding which approach to adopt for these 4 stages.

### 4.1. Sampling Approach and Extraction Method

Two different approaches such as grab and continuous can be used during sampling for MP characterization. Both approaches have advantages and disadvantages relative to each other. However, while grab sampling can cause unavoidably high errors in detecting micro-and nano-sized MPs, the continuous sampling approach [38; 83] can determine the day and night fluctuations of MPs in wastewater and reveal their random (e.g. in the measuring range set in hours or minutes for 24 hours) distribution, giving more realistic results. Therefore, it would be more accurate to adopt a continuous sampling approach during the sampling phase. On the other hand, sampling from sludge samples is slightly different. In sludge sampling, the use of van Veen trap samplers is generally preferred. However, the most important point to note here is that the samples must be washed with deionized water and filtered through a series of mesh sieves before analysis. [84]. Also, the chemical treatment of sludge can create significant changes in the concentration and morphology of MPs in the sludge [48; 85]. In this case, it is absolutely necessary to take a sample before the sludge treatment process.

Furthermore; MPs in wastewater can be collected in different ways, mainly including container collection, autosampler collection, separate pumping, filtration, and surface filtration [86; 41; 87]. In general, the sample volume of raw wastewater is preferred to be small. Raw wastewater is dense in terms of organic matter, and large volumes of samples cause clogging of filters and sieves [88]. To minimize sampling errors and maximize data quality, an MP sampling guide should be developed, which aims to provide an effective and informed

choice of appropriate sampling mode and frequency for each case. Therefore, in the literature, it is recommended to reduce the sampling uncertainty of MPs in the wastewater system by adjusting the sampling mode and sampling frequency according to the purpose of the study and flow characteristics [89; 90].

However, other aspects such as particle dynamics related to the density and geometry of MPs should also be considered when deciding on the sampling approach. Collected wastewater samples are usually filtered to concentrate MPs. Thus, the pore sizes of the sieves and filters will have a great influence on the amount of MPs collected [86]. However, studies so far show that a very wide sieve range between 38-4750 µm can be used [91]. The MPs kept on the sieves are pre-treated after they are washed with distilled water and dried.

On the other hand, the sample volume that will be needed for the characterization of MPs is different for raw and treated wastewater. Especially in the structure of raw wastewater, sampling in large volumes is not appropriate due to the presence of high amounts of organic pollutants that can quickly clog the filters and sieves to be used during sampling. However, in wastewater treatment plant effluent with low organic content, high volumes of wastewater samples are needed to accurately and precisely determine the amount of MPs. Especially if it is aimed to identify large MP particles (>300 µ), working on high volume samples, such as approximately 10.5–13.5 L, contributing 5% of the total amount of particles, will always give more accurate results [95]. However, if the detection of small-sized MPs (20 µm -100 µm MPs contributing 70% of the total amount of particles,) is targeted, then only 2 L will be sufficient [38]. However, in the literature, it is recommended to determine the entire MP presence between 1 µm and 5000 µm in order to make a comprehensive characterization [88; 92].

Moreover; sampling for MP characterization in sludge samples is slightly different. For MPs in sewage sludge, separation by direct filtration has rarely been applied (applies only to spectroscopic measurement) as the sludge contains a much higher percentage of solids and organic matter than wastewater [86; 41]. It is sufficient to collect the sludge sample (~5-20g) in a glass container and cool it in the dark (~4 °C) before transporting it to the laboratory for MP extraction.

The most commonly used method for a sample collection from WWTPs is the filtration collection technique. In this application, wastewater is collected from the treatment processes either through surface filtration or pump/steel bucket/autosampler which is then filtered with a sieve or a set of sieves such as stainless-steel filter, Trawl, Tyler sieve, Ruttner sampler, steel sieve or glass fiber filter. The retained MPs are washed and filtered at the point where they are sampled in a clean container using ultrapure water, and sent to the laboratory after being stored in the sampler for further laboratory processing. It is stated that various metallic mesh or sieves are used for filtration, usually combined with mechanical sieving [84]. While these mesh/sieve sizes vary up to the size of the MPs collected, the use of different sieve series is noted to provide a more precise characterization of the MPs by size [93].

### 4.2. Pre-treatment Application (Digestion) and Separation Techniques

After the sampling stage, depending on the content of the sample (wastewater or sludge) to be examined, either the removal of the contaminants outside the MPs in the sample and then the separation process, or the direct further analysis of the sample after some advanced separation techniques (Electrostatic separation, Pressurized fluid extraction, Ultrasonic dispersion, Fluidization-flotation, Density fractionation, Oil extraction, Heating, Elutriation, Magnetic extraction) without removing these contaminants can be performed. In some studies carried out in the literature, it has been reported that MPs are collected from the surface by filtration and are characterized by direct further analysis of the MPs in the sample without removing other contaminants. The studies conducted by Tagg et al. in 2017 [94] reported that the samples, containing high organic matter content which is likely to be found in higher amounts compared to the presence of MPs, collected from both receiving environments and wastewater treatment plants may interfere with advanced analysis techniques such as FTIR and Raman Spectroscopy which are used in the chemical characterization of MPs. In the literature, mainly, it has been reported that either oxidative enzymatic degradation through the use of enzymes such as protease, lipase and cellulose, or the conventional oxidative purification can be used for this purpose. Conventional oxidative treatment is reported to be more appropriate, since enzymatic degradation takes place over a very long time, such as 13 days [37].

Among conventional oxidative methods, chemical pretreatment is the preferred method to separate organic particles from MPs. For this purpose, as pre-treatment steps in both sludge and wastewater samples, different options can be used, mainly acidic treatment, alkali treatment, NaClO, Fenton reactants, H2O2, Alcohol, HCl, nitric acid, and KOH [75; 95; 96]. Studies have shown that nitric acid and KOH can damage biopolymers and cellulose, respectively; while among all these studies, H2O2 has the best potential to degrade organic matter in samples without damaging MPs [87]. In addition, some studies in the literature have shown that the use of 30% H2O2 is quite successful in removing organic matter and bound biogenic materials, especially before the identification of MPs in the samples by FTIR and Raman spectroscopy [97; 98] . On the other hand, in a study conducted by Munno et al. in 2018 [99], they concluded that a short heating period of 30 minutes helps speed up the reaction process and provides better and easier filtering of the samples. However, the most important point to be considered here is that it would not be appropriate to reach higher temperatures considering the possibility that the temperature to be applied may melt some MPs that may be present in the sample [99]. Although there are many primary treatment methods in the literature for the separation of MP residues from other pollutants in the wastewater sample, the catalytic Wet Peroxide Oxidation (WPO) method which is declared by NOAA Marine debris program, is both effective and fast: oxidation time (reaction time) can be reduced to hours or minutes compared to days in other methods.

The Catalytic Wet Peroxide Oxidation (WPO) method is a commonly preferred method for the extraction of MPs. In this method, hydroxyl radicals formed during the decomposition of hydrogen peroxide can be used successfully in the extraction of MPs from wastewater, since they do not decompose MPs while oxidizing most natural organic substances to carboxylic acids, aldehydes, CO2, and H2O. Also in this method, the presence of catalysts (FeSO4) allows rapid degradation of organic materials under mild conditions. The specific way of application is to add FeSO4 and H2O2 to the sample and then heat at 70 °C and mix for 30 minutes or until the reaction is complete. Residual organic matter can be oxidized with the addition of 30% hydrogen peroxide, known as Fenton reactants, and Fe (II) catalyst (20 mmol/L) [20]. The dosage of Fenton reactants ranges from 5 mL to 20 mL depending on the solid mass of the samples. After 3 hours of reaction, the samples are dried at 60 °C until the remaining H2O2 has completely evaporated [100].

Alternative methods for removing organic matter in wastewater and sludge samples include alkaline treatment and acid treatment [29]. However, there is concern about the application of these methods. Coles et al. (2014) found that this (10M NaOH at 60°C) would damage MPs. Also, strong oxidizing acids such as sulfuric acid and nitric acid destroy or damage low pH intolerant polymers (e.g. polyamide, polystyrene) [85; 101]. Acid purification is usually carried out with a heating block or microwave digestion at 110-120 °C, while some MPs have even been observed to melt at 90 °C [40]. While only one study used isopropyl alcohol to remove organic matter impregnated into MPs, its removal efficiency was not tested [55].

Other approaches, such as ultrasonication combined with deionized water or SDS (sodium dodecyl sulfate) solution, have also been applied to treat seawater samples in the past, but not for wastewater samples, possibly due to the formation of MPs smaller than brittle plastic samples by applying these methods [102; 103]

Moreover, after removing the impurities other than MPs in the sample, the most commonly preferred separation step is based on density difference. This method is based on the density difference between the polymers and the sample medium. Each polymer in the wastewater structure has a characteristic density ranging from 0.90 to 1.6 g/cm3. Therefore, MPs flotation is accomplished using a solution with a higher density than polymers such as sodium iodide (NaI), sodium chloride (NaCl), sodium polytungstate (SPT), and zinc chloride (ZnCl2). NaCl (1.2 g/cm3) is an inexpensive and environmentally friendly salt used for the extraction of low-density polymers. The choice of this saturated solution depends on the density of the polymer to be extracted, such as PE (0.91– 0.92 g/cm3), PS (1.04–1.1 g/cm3), and PP (0.9–0.91 g/cm3) have densities. On the other hand, NaI (1.8 g/cm3), SPT (1.4 g/cm3) or ZnCl2 (1.5-1.7 g/cm3) mainly PET (1.37– 1.45 g/cm3), and PVC (It has been reported in the literature to be used for the extraction of high-density MPs such as 1.6-1.58 g/cm3) [32;104;105].

Sewage sludge is a more challenging sample than sediment, as most of the organic matter, microorganisms, and inorganic particles in sewage sludge are bound together by biopolymers and consist of a viscous matrix with high affinity for polymer surfaces. Currently, methods of extracting MPs from sludge are time consuming and require expensive density separation reagents and large numbers of oxidants for organic matter removal. Hurley et al. has also confirmed the applicability of Fenton's reagent along with density separation in the extraction of MPs from solid substrates (sludge, soil, etc.). For this purpose, an ice bath will be used to reduce the decomposition of hydrogen peroxide and regulate the reaction temperature and keep the temperature below 40 °C, thus providing a great protection for MPs [106]. On the other hand, similar to wastewater, saturated solutions such as ZnCl2, NaI, and CaCl2 can be used for density-based extraction of MPs from sludge. When sludge samples are placed in a high-density salt solution, the plastic particles float on the surface of the solution while the denser sludge materials remain below the solution. The use of high-density salts such as ZnCl2 and NaI is preferred to improve MPs recovery. In summary, these processes include adding the extractant to the sample, static precipitation, and then filtration through a polycarbonate membrane filter. These steps are repeated several times to extract MP from the sludge samples. It is also very important to consider the economic principle when choosing extraction methods.

### 4.3. Qualitative and Quantitative Analysis Techniques

In general, the analysis of MPs can be classified into physical characterization and chemical characterization. Physical characterization mainly refers to characterizing the size distribution of MPs as well as evaluating other physical parameters such as shape and color. On the other hand, chemical characterization has mainly been applied to explore the composition of MPs.

Microscopy is the most widely used technique for physical characterization. It can be used directly to measure the size and characterize morphology. However, MPs that are too small in size in the microscopic analysis are more likely to be missed or incorrectly counted. For example, it is sometimes difficult to distinguish between synthetic and natural fibers such as textile fibers made from cotton [86]. Therefore, different measures have been taken to avoid possible errors. Grid petri dishes with sequentially numbered grids were used to facilitate particle counting [40]. A number of criteria have been applied to distinguish synthetic fibers from biological ones. These criteria [107; 32]:

- Synthetic fibers must be of equal thickness over their entire length
- Synthetic fibers must not be completely straight, indicating a biological origin
- No cellular or organic structures should appear that would qualify a fiber as MP

Also, a staining method was used to minimize the prediction of suspicious MPs [29]. By applying the Rose-Bengal solution, natural microparticles such as natural fibers should be dyed pink, which provides visual separation of non-plastic particles and pink [108]. It has been demonstrated that the accuracy of MP characterization by microscopy can be

increased with the above-mentioned measures. However, the method has been reported as time consuming due to the inability to distinguish polymer types and the lack of automation. It is difficult to precisely identify each specific type of plastic in the samples due to its unique physical and chemical structure. Conventional methods used to identify MPs include visual identification, advanced analytical techniques such as FTIR (Fourier transform infrared) and Raman. It is difficult to precisely identify each specific type of plastic in the samples due to its unique physical and chemical structure. Chemical characterization of MPs can increase the accuracy of MP identification and their composition can be determined more accurately. FTIR is the most frequently reported method for the analysis of MPs obtained from AATs. With this technique, the MP particle is exposed to infrared radiation and a spectrum is obtained in which characteristic peaks correspond to specific chemical bonds between atoms. The resulting spectrum can be used to identify sample composition by comparison with the reference spectrum library.

However, these reference spectra always represent ideal samples not typically found in the environment [41]. Therefore, it is necessary to establish a library of atypical reference plastics from various sources, including wastewater treatment plants, which allows the comparison of many more environmental samples. In addition, conventional FTIR analysis is laborious because MPs must first be selected under the light microscope and then analyzed for the spectra of each particle individually [109].

Due to the high cost of these conventional advanced analytical techniques in recent years; qualitative methods such as TED-GC–MS (Thermal extraction desorption-gas chromatography-mass spectrometry, Stereomicroscope, AFM-IR (Atomic Force Microscopy) and quantitative methods such as NR-FTIR (Nile Red- FTIR ), Micro-Raman, FPA-FTIR (Focal Plane Array-FTIR), ATR-FTIR (Attenuated Total Reflection-FTIR), DH (Digital Holography), TGA-DSC (Thermogravimetric Analyzer-Differential Scanning Calorimetry), Vis-NIR (Visible Near Infrared) Spectrum, Pyr-GC-MS (Pyrolysis-Gas Chromatography-Mass Spectrometry), SEM-EDS (Scanning Electron Microscope-Energy Dispersive Spectrometer) , Reflection Microscope, NMR (Nuclear Magnetic Resonance), and GPC (Gel Permeation Chromatography).

FTIR combined with FPA (Focal Plane Array) detector, NR staining, TGA-DSC etc. are new methods and have been developed that are more economical and capable of identifying with higher precision. The discovery of new analytical instruments and their inter-pairing or combining existing conventional instruments can overcome recent challenges in the identification of MPs. The recent development of focal plane array (FPA)-based micro-FTIR imaging may be more effective for evaluating the spectra of individual particles in a sample, resulting in high-throughput analysis of the total MPs in a sample [110]. Mintenig et al. [37] used FPA-based transmission micro-FTIR to identify MPs in both wastewater and sludge samples, as they thought that IR transmission showed better images than IR reflectance. However, the FPA-micro-FTIR technique is still limited [37]. In addition, since the lateral resolution of micro-FTIR spectroscopy is always limited to certain diffraction ranges (for example, 10 μm at 1000 cm-1), samples up to 10 mm-20 mm can hardly be analyzed [103].

Raman spectroscopy is another frequently used spectroscopic method to identify MPs. This is a vibrational spectroscopy technique based on the inelastic scattering of light. It provides information about the molecular vibrations of a system in the form of a vibration spectrum and enables the identification of the components present in the sample [111]. Compared to FTIR, Raman techniques show better spatial resolution (up to 1 mm) [112]. It also has higher sensitivity to non-polar functional groups. However, Raman spectroscopy is prone to light interference from microbiological, organic, or inorganic substances in samples. Therefore, purification of samples should be done carefully to avoid unwanted sample modification before Raman analysis [113].

MPs can also be analyzed by scanning electron microscopy (SEM) based techniques. Conventional SEM produces images of MPs by scanning the surface with a focused electron beam, which is used to characterize the surface morphology of MPs in sewage sludge [48]. In addition, SEM-energy dispersive X-ray spectroscopy (SEM-EDS) and scanning electron microscopy-EDS (ESEM EDS) can be used both to characterize the surface morphology of MPs and to determine the elemental composition of polymers based on diffraction and reflection [114;115;116].

On the other hand, GC-MS-based techniques and LC-based techniques can be used for the rapid identification of plastic in the sample. GC-MS methods are generally applied with thermo-analytical techniques that identify MPs by analyzing mass spectrometry of thermal degradation products [117; 118]. A capillary column (Agilent Technologies, Santa Clara, USA) with 250 μm ID and 0.25 μm film thickness is used for chromatographic separation. LC-based techniques can be performed in the form of size chromatography, which separates dissolved analytes from their hydrodynamic volume as a function of the effective size of the molecules [113]. Both methods can analyze polymer types and obtain quantitative results with appropriate calibration, which facilitates the assessment of contamination of the ecosystem under consideration with plastic particles. Unlike spectroscopic techniques, these methods do not have any requirements for MP size at the time of measurement because they do not provide direct information about the size and number of particles. It is still debated how to link the two dimensions of the analysis output (i.e. mass and number) to gain a holistic view of MP concentrations. Moreover, these methods are still under development for environmental sample analysis and have not yet been applied for the analysis of MPs from WWTPs.

While nano-sized MPs can be successfully detected using AFM technology combined with IR or Raman spectroscopy, polystyrene-based MPs can be detected sensitively with AFM-IR hybrid technology. Biosensor technology, which uses the relationship between the proteins on the surface of nanoplastics and the stress response genes of specific substance-sensitive microorganisms, has also been reported in the literature as a candidate method for the detection of nanoplastics [119]. Conventional techniques used during preprocessing, which is the most important step of MPs identification stages, are time-

consuming and have a high probability of obtaining erroneous results. For this reason, it has been demonstrated in recent years that MPs in water can be detected quickly without applying pre-processing steps in a portable Raman micro spectrometer operating on the basis of continuous spectral analysis of flowing water as a reliable and easy method that can be used in real environmental samples. Şim et al. reported that a 5 mg/L NR (fluorescent staining) solution can effectively stain MPs and can be easily detected by green fluorescence. It has also been reported that, in addition to PVC, PA and PES, PE, PP, PS, PC, PU, and poly (ethylene-vinyl acetate) based MPs can be successfully detected with the NP staining technique [120]. This method has been found to be quite successful in terms of identifying MP samples in the laboratory and quantitatively detecting them directly and quickly. In addition, the rose-red staining technique, which makes it easier to detect plastic-based materials without any toxic effects, has also been studied for the detection of MPs [121].

### 4.4. Quality Control for Measurement Accuracy

Contaminations during sample collection and pretreatment [17] can result from the equipment and devices used, and even from workers' clothing [10; 37; 38]. Therefore, different precautions must be taken to avoid potential bias from these contaminations. For example, all equipment should be thoroughly rinsed before use, and the use of plastic materials should be avoided as much as possible. It is recommended to wear laboratory clothing made of natural fabric during all laboratory procedures. Samples should usually be sealed in petri dishes or covered with aluminum foil to minimize airborne plastic contamination. It has also been suggested to set up a control sample, which is processed in parallel with the test samples, along with all stages of sample processing, to identify any possible plastic contamination from the laboratory [29].

Another issue with MP detection is potential sample loss during sample extraction [122; 123; 94]. It is therefore recommended to test the recovery of MPs after the extraction processes. A certain amount of MPs of a certain size and color can be added to the water and subjected to the same pretreatment and extraction processes such as wastewater or sludge samples to determine the recovery rate. The number of specific MPs added is then counted and the recovery rate can be calculated. It has been reported that a high recovery rate of $84.5 \pm 3.3\%$ was achieved after enzymatic purification using polyethylene (PE) as the model polymer [123].

## 5. MPs Policies/Applications in The World and Turkey

Since plastic pollution is a global environmental problem, preventions taken against plastic pollution require countries to work in cooperation and coordination in policy making and taking precautions. Although policies to prevent MPs are becoming widespread, most countries aim to expand the scope of these policies. For example, the placing of products used for rinsing, peeling, or cleaning containing solid plastic particles on the market is prohibited from January 1, 2018 onwards in France. The use of plastic bags in supermarkets has been banned and it is aimed to introduce a ban for plastic cotton buds as of January 1, 2020. The German Federal Environment Agency (UBA) published a report on MPs in 2015 and stated that microbeads used in cosmetics and personal care products do not have an effective role in MP pollution. They also pointed out that it would be more effective to reduce plastic waste at the national and global level. In addition, Italy has announced that it will ban non-biodegradable plastic cotton buds from January 1, 2019 onwards, while microbeads used in cosmetics would also be banned in 2020. In March 2017, the Environment Directorate of the Norwegian Ministry of Climate and Environment prepared a report on reducing marine litter and MPs, and declared that it aimed to reduce the amount of MPs increasing in the ocean. Norway focused on secondary MPs such as automobile tires, artificial turf, paint, and abrasion of textiles, and stated that equipment used in the fishing and aquaculture sectors, which are among the most common activities in the country, are among the important sources of MP pollution. For this reason, it has brought the obligation to prepare expanded manufacturer responsibility plans for this equipment regionally in Norway. Belgian industry has expressed its full support for a voluntary agreement to phase out MPs in all rinses and cosmetics and toothpastes. Although the discussions about which product should be used as a substitute for the use of microbeads continue, it has announced that it aims to ban all plastic particles (microbeads) by 2020. They ban on the use of rinsing products and cosmetic products containing microbeads in Switzerland which entered into force at the beginning of 2018, and as of January 2019, it is aimed to ban all products that cause MP to be released. However, in this regulation, products containing "natural polymers, long molecules that are not synthesized and chemically modified" are excluded from the scope of the ban. Moreover, the government stated that the implementation of these policies and prohibitions at the EU level, not at the national level, would yield more effective results [124]. While the manufacture of microbeads used in rinses and cosmetics was banned by the British Government in January 2018, rinsing and cosmetic products containing microbeads were banned from June onwards. However, it is aimed to ban not only microbeads, but also disposable plastics, plastic sticks, and cotton bud sticks.

Besides, Canada is one of the countries that should have a high responsibility for plastic pollution because it has long coastlines and continues its activities in the oceans. In November 2018, the Ministry of Environment set up a science agenda in Canada and hosted science workshops covering the development of Canadian science on plastics. Regulatory precautions such as prohibitions, fees, producer responsibility programs, and garbage regulations covering plastic products and other wastes have been taken into consideration in public, regional, and municipal administrations. In addition, they took part in non-regulatory practices such as education campaigns, recycling, and deposit programs on this subject. The recycling system for beverage containers is well established across the country, with Canadian companies taking action to reduce plastic waste and marine litter. As a national policy, Canada started to charge consumers 5 cents for all shopping bags in February 2016 . On the Island of Montreal, a tax was introduced in 2018 for plastic bags larger than 50 m. New federal wastewater regulations came into force in 2012. The scope of this regulation includes mandatory minimum standards for secondary wastewater treatment. These standards aim to no longer discharge untreated wastewater into Canada's freshwater

and marine environment after this regulation [125]. While bans on primary MPs in Canada are a step toward mitigating pollution, the presence of secondary MPs still causes decomposition of plastics and accumulation in marine environments [5]. Microbeads, one of the types of MPs, were defined as toxic substances under the Canadian Environmental Protection Coverage Act (CEPA) on August 1, 2015. The steps to ban the import, production, and sale of cosmetics and personal care products using microbeads accompanied this law. In these studies, the limitations of cleaning products, printer toners, and abrasive substances, which are among the products that use microbeads, were left in the background, especially focusing on cleaning and cosmetic products [126]. Import and production of personal care products and toiletries containing microbeads started to be banned on July 1, 2018 and these bans were completed in 2019. The Fisheries, Oceans and Canadian Coast Guard identified MPs as a research priority from 2017 to 2020 [138] and funded different projects to better understand the effects of MPs on aquatic life. Although there are studies to ban MP sources in Canada, the bans are not comprehensive. The most important reason for this is that there is no substitute product to be used instead of MP sources used in medical products. However, even if the MPs in the oceans are mitigated, the plastic particles formed as a result of the breakdown of macroplastics continue to pollute the oceans.

Due to national/international concern in Turkey, importance was given to the integrated and regular conduct of coastal and marine monitoring studies, and an ecosystem-based and holistic monitoring approach was introduced with the EU Marine Strategy Framework Directive (DSFD) and EU Water Framework Directive (WFD) strategies in the 2000s. MPs have been monitored in the DSFD and since there is no international certainty about sampling and analysis of MP monitoring, qualified researches have been carried out at only 9 points in Turkey since 2013 [127]. As an example of the monitoring studies carried out with the support of the Ministry of Environment and Urbanization, the monitoring programs covering the years 2014-2016 by TÜBİTAK Marmara Research Center can be shown. These programs were made for all seas, and presented to the public as "Integrated Marine Pollution Monitoring Work 2014-2016 Summary Reports" aiming to guide the policies to be followed. In addition, an agreement has been made in cooperation with TÜBİTAK-MAM to establish a monitoring program for the 2017-2019 periods at the Ministry of Environment, Urbanization and Climate Change. It was decided to carry out a three-year monitoring in Marmara and two-year monitoring on the other coasts, and pilot studies were carried out on MPs between 2014 and2016 [128]. Within the scope of the project, workshops were held in the Marmara region in 2017, the Black Sea region in 2018, and the Mediterranean and Aegean region in 2019, and the reports obtained as a result of monitoring at these workshops were shared with NGOs (National Govermental Organisations), universities, municipalities, public institutions, and other relevant stakeholders. In addition, projects such as marine waste/MP researches and "I Know My Sea, I Protect My Sea Education" for primary education are carried out at METU-Marine Sciences Institute. While the National Monitoring project was supported by the Ministry of Environment, Urbanization and Climate Change; MP 1 and MP 2 project was supported by TÜBİTAK [129].

With the regulation in the Law on the Amendment of the Environmental Law and Some Laws, as of January 1, 2019, the pricing of plastic shopping bags has been regulated. According to this regulation, the agreed fee must be collected by the point of sale upon the consumer's request for plastic bags. When we look at the regulation on plastic bags, this taxation does not cover all bags. Bags with a thickness of more than 15 microns are charged a fee, and bags used for cosmetics, food, and nuts are not included in the scope of taxation. In addition, in the thin bags where the food is placed for hygiene requirements in the markets; and plastic bags used for foods such as bread and vegetables are not given to the consumer free of charge. Although there are no direct policies for MPs in Turkey, there are practices to solve this problem. Integrated monitoring studies are carried out with the support of the Ministry of Environment, Urbanization and Climate Change. It is aimed to increase these monitoring programs, which are carried out as a pilot application, over time. The National Zero Waste Program and the pricing of plastic bags, which have been implemented since January 1, 2019, are among the policies for the plastics created. It is aimed to expand this practice across the country in 2023. The Zero Waste National Program and the pricing of plastic bags are important practices created within this framework in Turkey. Furthermore, efforts to ensure easy separation of recyclable wastes are carried out at the level of pilot applications, and it is aimed to expand it all over the country as a national program in 2023. The destruction of plastics in nature, their continuous release to the environment, and the absence of restrictions on their production, cause the need for broader policies to prevent this problem. Another policy is to charge plastic bags. This policy creates dissatisfaction in many ways and is not seen as a solution. While evaluating the effectiveness of the wage policy applied to plastic bags, the decrease in the use of only taxed bags constitutes an obstacle for reaching the reduction statistics for plastic bags in general. The fact that people do not prefer to use plastic bags after charging does not indicate that the use of plastic bags has decreased. However, they do not have enough information about the harms of plastics and their impact on nature may have negative effects on the internalization of this practice, which is for punishment. At the same time, the continuation of the use of thin plastic bags shows that there is a low level of reduction in release to the nature, since these plastic bags decompose more easily in nature. The plastic garbage import, which Turkey has already increased, is also one of the situations that pose a great danger since the disposal facilities are not running with 100% capacity [124].

When we look at the environmental policies and practices related to MPs, it is understood that there is no direct policy towards this in Turkey, but studies are carried out on the problem. These studies are carried out with the support of the Ministry of Environment, Urbanization and Climate Change. Considering the policies created at the global level, Turkey needs to take new steps in policymakers to prevent MP pollution. For this, the dangers posed by these micro-level plastic particles should be noticed urgently in Turkey, and the awareness of both the public and policy makers on this issue

should be increased. Turkey's practices within the scope of environmental policies need to be expanded. It is important to support research on the presence of MPs in habitats, examining their sources and evaluating their effects. In addition, In addition, microbeads added to cosmetics and personal care products, plastic parts produced especially for industrial and domestic activities, tiny fibers broken off from synthetic fabrics are released into nature. Legislation is needed to prevent emissions. Regulations brought to the plastics industry to reduce macro plastic waste, as well as banning single-use plastics for plastic consumption and promoting substitute products; banning the use of plastic bags completely or developing a deposit system; taxing not only plastic bags but also other plastic wastes will be important steps to be taken towards this problem. Furthermore, priority should be given to R&D studies in order to adequately filter the wastewater released into nature from sewers, sinks, and washing machines. Inadequate filtration of these channels causes MPs in peeling, rinsing products, and personal care products to mix with nature, and also causes small particles such as microfibers and fibers to mix with the water flowing from washing machines. To address this problem, treatment systems need to be developed and monitored. There are many ways that plastic waste enters the environment. In addition to the capacities of recycling and disposal facilities, it is also important how much the secondary waters discharged into nature are treated in wastewater discharges and the level of filtering techniques of these systems [124].

## 6. Conclusion

Studies show that the most important source of MPs is wastewater treatment plants and that they can be detected in different parts of the world through these facilities, revealing that they seriously threaten the aquatic ecosystem in the world. While studies have been done and continue to show how much damage MPs are to the marine ecosystem, it becomes more important to reduce the use of MPs based on the principle of reducing the pollutant at its source, and preventing its meeting with nature by working on its removal in treatment plants. Like all other pollutants, the most effective way to reduce MP pollution is to reduce the use of plastics at the source. For this, it is necessary to avoid the use and consumption of all kinds of materials, such as personal care products made of plastic and its derivatives or containing plastic, and to reduce waste generation. Since the methods applied for sampling and detection of MPs in wastewater treatment plants vary widely, it is not possible to compare the results between studies, which creates significant difficulties in revealing the extent of MP pollution in the world.

The most common MP-based polymers detected in WWTPs are polyester, polyethylene, polyethylene terephthalate, and polyamide, with fiber type MPs making up the largest portion. Despite the relatively low concentrations of MPs found in the effluent of WWTPs, the total discharge load is still calculated as the average of 2 x 106 particles/day for an annual wastewater flow rate of 5 x 107 m3/year.

Although MPs are effectively removed from WWTPs, Membrane filtration technology has been identified as the most effective method for reducing MPs in final wastewater. A significant part of the MP removal from WWTP takes place via sewage sludge. Therefore, sludge incineration has been reported as an effective way to completely prevent MPs from entering the environment from wastewater. Current studies on MPs in WWTPs have mainly investigated MPs greater than 20 µm. However, reports indicate that smaller MPs have a high abundance in the aquatic environment and may have more severe biotoxicity than aquatic species can enter the circulatory system. Therefore, it would be beneficial to include small MPs (less than 20 µm) in future studies. For this purpose, it has been stated that Raman spectroscopy and thermoanalytical techniques can be preferred as a successful option for the analysis of small-sized MPs.

Since many types of MPs are removed by sewage sludge in conventional WWTP, it is important that future studies can focus on investigating the potential environmental impact of land application of sewage sludge and prevent the release of MPs into the environment. So, in order to reduce the amount of MPs' discharged from WWTPs and released from sewage sludge, the development of MPs targeted treatment processes is another important issue that needs to be studied. Furthermore, future efforts could be directed at improving plastic regulations as well as separating MPs from wastewater at household scales.

## Declaration

**Author Contribution:** Conceive-G.Y.T.; Design- G.Y.T.; Supervision-G.Y.T.; Literature Review- G.Y.T., S.I.Y; Writer-G.Y.T., S.I.Y; Critical Reviews -G.Y.T.

**Acknowledgements:** This review paper was organized from the project entitled ''Evaluation of The Removal of Microplastic Pollution from Domestic Wastewater with Eco-Friendly New Generation Nanocomposites'' which is supported by the grants from the Research Fund of the Tekirdag Namık Kemal University, project numbers NKUBAP.06.YL.21.327.

**Conflict of interests:** The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## Orcid ID

Günay Yıldız Töre https://orcid.org/0000-0002-7899-3917
İlhan Şirin https://orcid.org/0000-0001-6176-4790

## References

[1] [http://www.basf.com/group/corporate/en_GB/function/conversions:/publish/content/investorelations/newspublications/presentations/2007/download/070625_BASF_IR Day_Feldmann_Plastics.pdf], The date of acces: 17.09.2014.]

[2] [http://www.plasticdisclosure.org/], The date of access: 20.06.2014]

[3] A. Isobe, K. Kubo, Y. Tamura, S. Kako, E. Nakashima, N. Fujii, "Selective Transport of MPs and Mesoplastics by Drifting in Coastal Waters'', Marine Pollution Bulletin, vol.89, pp.324-330, 2014.

[4] M.A. Browne , P. Crump , S.J. Niven, E. Teuten, A. Tonkin, T. Galloway, R. Thompson ""Accumulation of MP on Shorelines Worldwide: Sources and Sinks".

Environ. Sci. Technol., vol. 45, no.21, pp. 9175-9179, 2011.

[5] M. Cole, P. Lindeque, C. Halsband, T. S. Galloway "Microplastics as contaminants in the marine environment: a review'', Marine pollution bulletin, vol.62, no.12, pp.2588-2597, 2011. https://www.sciencedirect.com/science/article/pii/S0025326X11005133.

[6] SL. Wright, RC. Thompson, TS. Galloway "The physical impacts of microplastics on marine organisms: a review'', Environ. Pollut., vol.178, pp.483–492, 2013. https://doi.org/10.1016/j.envpol.2013.02.031.

[7] JAI. Do Sul, MF. Costa "The present and future of microplastic pollution in the marine environment'', Environ. Pollut., vol.185, pp.352–364, 2014. https://doi.org/10.1016/j.envpol.2013.10.036.

[8] L.G.A. Barboza, B.C.G. Gimenez "Microplastics in the marine environment: current trends and future perspectives'', Marine Pollution Bulletin, vol.97, pp.5–12, 2015. https://doi.org/10.1016/j.marpolbul.2015.06.008.

[9] J.C. Anderson, BJ. Park, VP. Palace "Microplastics in aquatic environments: implications for Canadian ecosystems'', Environ. Pollut., vol.218, pp. 269–280, 2016. https://doi.org/10.1016/j.envpol.2016.06.074.

K. Duis, A. Coors "Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects '', Environ. Sci. Eur., vol.28, pp.1–25, 2016. https://doi.org/10.1186/s12302-015-0069-y

[10] H.S. Auta, C.U. Emenike, S.H. Fauziah "Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects and potential solutions'', Environ. Int., vol. 102, pp.165–176, 2017.

[11] OS. Alimi, J.F. Budarz, L.M. Hernandez, N. Tufenkji "Microplastics and nanoplastics in aquatic environments: aggregation, deposition, and enhanced contaminant transport'', Environ. Sci. Technol., vol.52, pp.1704–1724, 2018. https://doi.org/10.1021/acs.est.7b05559

[12] S. Estahbanati, N.L. Fahrenfeld "Influence of wastewater in surface water'', Chemosphere, vol.162, pp.277–284, 2016. https://doi.org/10.1016/j.chemosphere.2016.07.083.

[13] L. Morris, V. Colombo, K. Hassell et al. "Municipal wastewater effluent licensing: a global perspective and recommendations for best practice'', Sci. Total Environ., vol.580, pp.1327–1339, 2017. https://doi.org/10.1016/j.scitotenv.2016.12.096.

[14] E.E. Burns, A.B.A. Boxall "Microplastics in the aquatic environment: evidence for or against adverse impacts and major knowledge gaps'', Environ. Toxicol. Chem., vol. 37, pp.2776–2796, 2018. https://doi.org/10.1002/etc.4268.

[15] H. Kang, H. Park, O. Kwon et al. "Occurrence of microplastics in municipal sewage treatment plants: a review'', Environ. Health Toxicol., vol.33, pp.43–48, 2018.

[16] J. Sun, X. Dai, Q. Wang et al. "Microplastics in wastewater treatment plants: detection, occurrence and removal'', Water Res., vol.152, pp.21–37, 2019. https://doi.org/10.1016/j.watres.2018.12.050.

[17] J.A. Ivar do Sul, M.F.Costa "The Present and Future of Microplastic Pollution in the Marine Environment'', Environmental Pollution, vol.185, pp.352-364, 2014.

[18] A.H. Abu-Hilal, T.H. Al-Najjar "Plastic pellets on the beaches of the northern Gulf of Aqaba, Red Sea'', Aquatic Ecosystem Health and Management, vol.12, no.4, pp. 461–470, 2009. https://doi.org/10.1080/14634980903361200.

[19] SA. Mason, D. Garneau, R. Sutton et al. "Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent'', Environ. Pollut., vol.218, pp.1045–1054, 2016. https://doi.org/10.1016/j.envpol.2016.08.056.

[20] E.A. Gies, J.L. LeNoble, M. Noe¨l et al. "Retention of microplastics in a major secondary wastewater treatment plant in Vancouver, Canada'', Mar. Pollut. Bull., vol. 133, pp. 553–561, 2018. https://doi.org/10.1016/j.marpolbul.2018.06.006.

[21] S.Y. Kyoung, S.H. Hong, M. Jang, G.M. Han, W.J. Shim "Occurrence and Distribution of Microplastics in the Sea Surface Microlayer in Jinhae Bay, South Korea'', Arch. Environ. Contam. Toxicol., vol.69, pp.279-287, 2015, https://doi.org/10.1007/s00244-015-0209-9.

[22] MA. Browne, P. Crump, S.J. Niven, E.L. Teuten, A. Tonkin, T. Galloway, RC. Thompson "Accumulations of Microplastic on Shorelines Worldwide: Sources and Sinks'', Environ. Sci.Technol., vol.45, pp.9175−9179, 2011.

[23] RC. Thompson, Y. Olsen, RP. Mitchell, A. Davis, S.J. Rowland, A.W.G. John, D. McGonigle, A.E. Russell "Lost at Sea: Where is all the Plastic?'', Science, vol. 304, pp.838. 2004.

[24] M.K. Aliabad, M. Nassiri, K. Kor "Microplastics in the surface seawaters of Chabahar Bay, Gulf of Oman (Makran Coasts)'', Mar. Pollut. Bull., vol. 143,pp p.125-133, 2019.

[25] O.A. Abayomi, P. Range, M.A. Al-Ghouti, J.P. Obbard, S.H. Almeer, R. BenHamadou "Microplastics in coastal environments of the Arabian Gulf.'', Mar. Pollut. Bull., vol.124, pp.181–188, 2017. https://doi.org/10.1016/j.marpolbul.2017.07.011.

[26] B. Ceylan "Investigation of Microplastic Pollution in Wastewater'', M.Sci. Thesis, Sakarya University Institute of Science and Technology, Sakarya/Turkey, 2017.

[27] J. Blumenröder, P. Sechet, J.E.Kakkonen, M.G.J. Hartle "Microplastic contamination of intertidal sediments of Scapa Flow, Orkney: A first assessment'', Marine Pollution Bulletin, vol.124, pp. 112–120, 2017.

[28] S. Ziajahromi, PA. Neale, L. Rintoul, F.D.L. Leusch "Wastewater treatment plants as a pathway for microplastics: development of a new approach to sample wastewater based microplastics'' Water Res., vol.112, pp.93–99, 2017, https://doi.org/10.1016/j.watres.2017.01.042.

[29] M. Lares, M.C. Ncibi, M. Sillanpa¨a¨, M. Sillanpa¨a¨ "Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology'', Water Res., vol.133, pp.236–246, 2018. https://doi.org/10.1016/j.watres.2018.01.049.

[30] M. Simon, N. Van Alst, J. Vollertsen "Quantification of microplastic mass and removal rates at wastewater treatment plants applying focal plane array (FPA)-based fourier transform infrared (FT-IR) imaging'', Water Res., vol.142, pp.1–9, 2018. https://doi.org/10.1016/j.watres.2018.05.019.

[31] V. Hidalgo-Ruz, L. Gutow, R.C. Thompson, M. Thiel "Microplastics in the Marine Environment: A Review of the Methods used for Identification and Quantification'', Environ. Sci. Technol., vol.46, pp.3060–3075, 2012.

[32] S. Morét-Ferguson, K.L. Law, G. Proskurowski, E.K. Murphy, E.E. Peacock, C.M. Reddy "The Size, Mass, and Composition of Plastic Debris in the Western North Atlantic Ocean'', Marine Pollution Bulletin, vol.60, no.10, pp.1873-1878, 2010.

[33] E. Besseling, A. Wegner, EM. Foekema, MJ. Van den Heuvel-Greve, A.A.Koelmans "Effects of Microplastic on Fitness and PCB Bioaccumulation by the Lugworm Arenicola marina (L.)'', Environ Sci. Technol., vol.47, no.1, pp.593-600, 2012.

[34] H. Takada "Microplastics and the Threat to Our Seafood", Ocean Health Index, Environmental Organic Geochemist, Tokyo University of Agriculture and Technology and Founder of International Pellet Watch, 2013, Available from: http://www. oceanhealthindex.org/News/Microplastics.

[35] K. Magnuson, K. Eliason, A. Frane, K. Haikonen, J. Hulten, M. Olshammar, J. Stadmark, A.Voisin "Swedish sources and pathways for microplastics to the marine environment'', © IVL Swedish Environmental Research Institute, Report No.C183, 2016, https://www.diva-portal.org/smash/get/diva2:1549783/FULLTEXT01.pdf.

[36] SM. Mintenig, I. Int-Veen, M.G.J. Lo¨der et al. "Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-Fourier-transform infrared imaging'', Water Res., vol.108, pp. 365–372, 2017. https://doi.org/10.1016/j.watres.2016.11.015.

[37] J. Talvitie, A. Mikola, A. Koistinen, O. Seta¨la¨ "Solutions to microplastic pollution—removal of microplastics from wastewater effluent with advanced wastewater treatment technologies'', Water Res., vol.123, pp. 401–407, 2017a. https://doi.org/10.1016/j.watres.2017.07.005.

[38] E.A. Gies, J.L. LeNoble, M. Noe¨l et al. "Retention of microplastics in a major secondary wastewater treatment plant in Vancouver, Canada'', Mar. Pollut. Bull., vol.133, pp.553–561, 2018. https://doi.org/10.1016/j.marpolbul.2018.06.006.

[39] S.A. Carr, J. Liu, A.G. Tesoro "Transport and fate of microplastic particles in wastewater treatment plants'', Water Res., vol.91, pp.174–182, 2016. https://doi.org/10.1016/j.watres.2016.01.002.

[40] F. Murphy, C. Ewins, F. Carbonnier, B. Quinn "Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment ", Environ. Sci. Technol., vol.50, pp.5800–5808, 2016. https://doi.org/10.1021/acs.est.5b05416.

[41] H. Hidayaturrahman, T. Lee "A study on characteristics of microplastic in wastewater of South Korea: identification, quantification, and fate of microplastics during treatment process'', Mar. Pollut. Bull., vol.146, pp.696–702, 2019.

[42] M. Bilgin "Development of Microplastic Investigation Techniques in Different Types of Wastewater and Sewage Sludge'', M.Sci. Thesis, Sakarya University Institute of Science and Technology, Sakarya/Turkey, 2019.

[43] T. Başaran "Investigation of microplastics in textile industry wastewater and indoor air'', M.Sci. Thesis, Sakarya University Institute of Science and Technology, Sakarya/Turkey, 2019.

[44] E. Bakkaloğlu "Fate and Transport of Microplastics in Wastewater Treatment Plants'', M.Sci. Thesis, Bursa Technical University, Institute of Science and Technology, Bursa/Turkey, 2019.

[45] S. Raju, M. Carbery, A. Kuttykattil et al. "Transport and fate of microplastics in wastewater treatment plants: implications to environmental health'', Rev. Environ. Sci. Biotechnol., vol.17, pp.637–653, 2018. https://doi.org/10.1007/s11157-018-9480-3.

[46] H. Lee, Y. Kim "Treatment characteristics of microplastics at biological sewage treatment facilities in Korea'', Mar. Pollut. Bull., vol.137, pp.1–8, 2018. https://doi.org/10.1016/j.marpolbul.2018.09.050.

[47] A.M. Mahon, B.O. Connell, M.G. Healy et al. "Microplastics in sewage sludge: effects of treatment'', Environ. Sci. Technol., vol.51, pp.810–818, 2017. https://doi.org/10.1021/acs.est.6b04048.

[48] G. Kalcˇı´kova´, B. Alicˇ, T. Skalar et al. "Wastewater treatment plant effluents as source of cosmetic polyethylene microbeads to freshwater'', Chemosphere, vol.188, pp.25–31, 2017. https://doi.org/10.1016/j.chemosphere.2017.08.131.

[49] C. Akarsu, A. E. Kıdeyş, H. Kumbur "Microplastic threat to aquatic ecosystems of the municipal wastewater treatment plant'', Turkish Journal of Hygiene and Experimental Biology, vol.74 (Supp: Water Congress), pp.73-78, 2017. https://doi.org/10.5505/TurkHijyen.2017.36845.

[50] S. Gündoğdu, C. Cevik, E. Güzel, S. Kilercioğlu "Microplastics in municipal wastewater treatment plants in Turkey: a comparison of the influent and secondary effluent concentrations'', Environ Monit Assess., vol.190, no.626, pp.1-10, 2018. https://doi.org/10.1007/s10661-018-7010-y.

[51] K. Conley, A. Clum, J. Deepe, H. Lane, B. Beckingham "Wastewater treatment plants as a source of microplastics to an urban estuary: removal efficiencies and loading per capita over one year'' Water Res., vol.3, no.100030, pp.1–9, 2019. https://doi.org/10.1016/j.wroa.2019.100030.

[52] S. Magni, A. Binelli, L. Pittura et al. "The fate of microplastics in an Italian wastewater treatment plant'', Sci. Total Environ., vol.652, pp.602–610, 2019. https://doi.org/10.1016/j.scitotenv.2018.10.269.

[53] X. Li, L. Chen, Q. Mei et al. "Microplastics in sewage sludge from the wastewater treatment plants in China'', Water Res., vol.142, pp.75–85, 2018b. https://doi.org/10.1016/j.watres.2018.05.034.

[54] J. Bayo, S. Olmos, J. Lo´pez-Castellanos, A. Alcolea "Microplastics and microfibers in the sludge of a municipal wastewater treatment plant'', Int. J. Sustain. Dev. Plan., vol.11, pp.812–821, 2016. https://doi.org/10.2495/SDP-V11-N5-812-821.

[55] W. Wei, Y. T. Zhang, Q.S. Huang, B.J. Ni "Polyethylene terephthalate microplastics affect hydrogen production from alkaline anaerobic fermentation of waste activated sludge through altering viability and activity of anaerobic microorganisms'', Water Research, vol.163, pp.114881, 2019a. https://doi.org/10.1016/j.watres.2019.114881.

[56] Wei W., QS. Huang, J. Sun, X. Dai, B.J. Ni "Revealing the Mechanisms of Polyethylene Microplastics Affecting Anaerobic Digestion of Waste Activated Sludge'', Environ. Sci. Technol., vol.53, no.16, pp.9604–9613, 2019b. https://doi.org/10.1021/acs.est.9b02971.

[57] C.M. Rochman, E. Hoh, B.T. Hentschel, S. Kaye "Long-Term Field Measurement of Sorption of Organic Contaminants to Five Types of Plastic Pellets: Implications for Plastic Marine Debris'', Environ. Sci. Technol., vol.47, no.3, pp.1646-1654, 2013.

[58] http://www.chelsearochman.com/Research.html], Date of access: 10.11.2014.

[59] http://plasticsoupnews.blogspot.com.tr/2013/07/stephanie-carrow-in-waters-of-trash.html], Date of access: 20.05.2014.

[60] P. Farrel, K. Nelson "Trophic Level Transfer of Microplastic: Mytilus edulis (L.) to Carcinus maenas (L.)'', Environ. Pollut., vol.177, pp.1-3, 2013.

[61] M.A..Browne, A. Dissanayake, T.S. Galloway, D.M. Lowe, R.C. Thompson "Ingested Microscopic Plastic Translocates to the Circulatory System of the Mussel, Mytilus edulis (L.)'', Environ. Sci. Technol., vol.42, pp.5026-5031, 2008.

[62] M. Cole, P. Lindeque, E. Fileman, C. Halsband, R. Goodhead, J. Moger, T.S. Galloway "Microplastic Ingestion by Zooplankton'', Environ. Sci.Technol., vol. 47, no.12, pp.6646-6655, 2013.

[63] R. Sussarellu et al. "Oyster reproduction is affected by exposure to polystyrene microplastics'', PNAS, vol.113, no.9, pp.2430–2435, 2016. https://www.pnas.org/doi/pdf/10.1073/pnas.1519019113

[64] Q. Sun, S.-Y. Ren, H.-G. Ni. "Incidence of microplastics in personal care products: An appreciable part of plastic pollution", Sci. Total Environ., vol.742 (Nov), no..140218, pp.1-10, 2020, https://doi.org/10.1016/j.scitotenv.2020.140218.

[65] L.I. Bendell, K. Chan, S. Crevecoeur, C. Prigent "Changes in ammonium and pH within intertidal sediments in relation to temperature and the occurrence of nonindigenous bivalves'', Open J. Mar. Sci., vol.4, no.3, pp.151-162, 2014. https://doi.org/10.4236/ojms.2014.43015.

[66] M. Cluzard, T.N. Kazmiruk, V.D. Kazmiruk, L.I. Bendell "Intertidal concentrations of microplastics and their influence on ammonium cycling as related to the shellfish industry'', Arch. Environ. Con. Tox., vol.69, pp.310–319, 2015.

[67] S.D. Ling, M. Sinclair, C.J. Levi, S.E. Reeves, G.J. Edgar"'Ubiquity of microplastics in coastal seafloor sediments'', Mar. Pollut. Bull., vol.121, pp.104–110, 2017.

[68] J. Talvitie, A. Mikola, O. Setälä, M. Heinonen, A. Koistinen "How well is microliter purified from wastewater? – a detailed study on the stepwise removal of microliter in a tertiary level wastewater treatment plant'', Water Res., vol.109, pp.164–172, 2017.

[69] L. Feng, J. Wang, S. Liu, X. Sun, X. Yuan, S. Wang "Role of extracellular polymeric substances in the acute inhibition of activated sludge by polystyrene nanoparticles'', Environ. Pollut., vol.238, pp.859–865, 2018.

[70] A.R. Badireddy, S. Chellam, P.L. Gassman, M.H. Engelhard, A.S. Lea, K.M. Rosso "Role of extracellular polymeric substances in bioflocculation of activated sludge microorganisms under glucose-controlled conditions'', Water Res., vol.44, pp.4505–4516, 2010.

[71] P. Bhattacharya, S. Lin, J.P. Turner, P.C. Ke "Physical adsorption of charged plastic nanoparticles affects algal photosynthesis'', J. Phys. Chem. C., vol.114, pp.16556–1656, 2010.

[72] C. Della Torre, E. Bergami, A. Salvati, C. Faleri, P. Cirino, K.A. Dawson, I. Corsi "Accumulation and embryotoxicity of polystyrene nanoparticles at early stage of development of sea urchin embryos Paracentrotus lividus'', Environ. Sci. Technol., vol.48, pp.12302–12311, 2014.

[73] Z. Long, Z. Pan, W. Wang, J. Ren, X. Yu, L. Lin, H. Lin, H. Chen, X. Jin "Microplastic abundance, characteristics, and removal in wastewater treatment plants in a coastal city of China'', Water Res., vol.155, pp.255–265, 2019.

[74] Z. Zhang, Y. Chena "Effects of microplastics on wastewater and sewage sludge treatment and their removal: A review'', Chemical Engineering Journal, vol.382, pp.122955, 2020.

[75] W. Perren, A. Wojtasik, Q. Cai "Removal of microbeads from wastewater using electrocoagulation'', ACS Omegai , vol.3, pp.3357–3364, 2018.

[76] C.Y.A. Lai, A. Groth, S. Gray, M. Duke "Enhanced abrasion resistant PVDF/nanoclay hollow fibre composite membranes for water treatment'', J. Membr. Sci., vol. 449, pp.146–157, 2014, https://doi.org/10.1016/j.memsci.2013.07.062.

[77] G.M. Geise, H. Lee, D.J. Miller, B.D. Freeman, J.E. McGrath, D.R. Paul "Water purification by membranes: the role of polymer science'', J. Polym. Sci. Part B: Polym. Phys., vol.48, pp.1685–1718, 2010.

[78] B. Ma, W. Xue, C. Hu, H. Liu, J. Qu, L. Li "Characteristics of microplastic removal via coagulation and ultrafiltration during drinking water treatment'', Chem. Eng. J., vol.359, pp.159–167, 2019.

[79] A. Abdelrasoul, H. Doan, A. Lohi "A mechanistic model for ultrafiltration membrane fouling by latex'', J. Membr. Sci., vol.433, pp.88–99, 2013.

[80] D.K. Tripathi, S. Shweta Singh, S. Singh, R. Pandey, V.P. Singh, NC. Sharma, S.M. Prasad, N.K. Dubey, D.K. Chauhan "An overview on manufactured nanoparticles in plants: uptake, translocation, accumulation and phytotoxicity'', Plant Physiol. Biochem., vol.110, pp.2–12, 2017. https://doi.org/10.1016/j.plaphy.2016.07.030.

[81] M.S. Ak, M. Muz, O.T. Komesli, C.F. Gökçay "Enhancement of bio-gas production and xenobiotics degradation during anaerobic sludge digestion by ozone treated feed sludge'', Chem. Eng. J., vol.230, pp.499–505, 2013.

[82] A. Dyachenko, J. Mitchell, N. Arsem "Extraction and identification of microplastic particles from secondary wastewater treatment plant (WWTP) effluent'', J.Anal.

Methods, vol.9, pp.1412–1418, 2017. https://doi.org/10.1039/C6AY02397E.

[83] H. Ou, E.Y. Zeng "Occurrence and fate of microplastics in wastewater treatment plants. In: Microplastic Contamination in Aquatic Environments'' Chapter 10, ISBN 9780128137475, Editor(s): Eddy Y. Zeng, pp. 317-338, 2018. https://doi.org/10.1016/B978-0-12-813747-5.00010-2.

[84] M. Cole, H. Webb, P.K. Lindeque, E.S. Fileman, C. Halsband, T.S. Galloway "Isolation of microplastics in biota-rich seawater samples and marine organisms'', Sci. Rep., vol.4, pp.4528, 2014. https://doi.org/10.1038/srep04528.

[85] K. Magnusson, F. Nore´n, IVL. Swedish, "Screening of microplastic particles in and down-stream a wastewater treatment plant". IVL Swedish Environ. Res. Inst.Rep., C55, NV-05269-13, pp.1-22, 2014, https://www.diva-portal.org/smash/get/diva2:773505/FULLTEXT01.pdf, date of acces:19.04.2022.

[86] A.S. Tagg, M. Sapp, J.P. Harrison, J.J. Ojeda "Identification and quantification of microplastics in wastewater using focal plane array-based reflectance micro-FT-IR imaging'', Anal. Chem., vol.87, pp.6032–6040, 2015. https://doi.org/10.1021/acs.analchem.5b00495.

[87] G. Gatidou, O.S. Arvaniti, A.S. Stasinakis "Review on the occurrence and fateof microplastics in Sewage Treatment Plants'', J. Hazard. Mater., vol.367, pp.504–512, 2019.

[88] C. Ort, M.G. Lawrence, J.R. Rieckermann, A. Joss "Sampling for pharmaceuticals and personal care products (PPCPs) and illicit drugs in wastewater systems: are your conclusions Valid? A critical review'', Environ. Sci. Technol., vol.44, no.16, pp.6024-6035, 2010a.

[89] C. Ort, M.G. Lawrence, J. Reungoat, J.F. Mueller "Sampling for PPCPs in wastewater systems: comparison of different sampling modes and optimization strategies'', Environ. Sci. Technol., vol.44, no.16, pp.6289-6296, 2010b.

[90] N. Bakaraki Turan, H.Sari Erkan, G. Engin Önkal, "Microplastics in wastewater treatment plants: Occurrence, fate and identification", Process Safety and Environmental Protection, vol.146, pp.77–84, 2021.

[91] J. Vollertsen, A.A.Hansen "Microplastic in Danish Wastewater: Sources,Occurrences and Fate'', The Danish Environmental Protection Agency, Environmental Project No:1906, ISBN:978-87-93529-44-1, 2017.

[92] C.B. Alvim, J. Mendoza-Roca, A. Bes-Piá "Wastewater treatment plant asmicroplastics release source–quantification and identification techniques'', J.Environ. Manage., vol.255, pp.109739, 2020.

[93] A.S. Tagg, J.P. Harrison, Y. Ju-nam et al. '"Fenton's reagent for the rapid and efficient isolation of microplastics from wastewater'', Chem Commun., vol.53, pp.372–375, 2017, https://doi.org/ 10.1039/c6cc08798a.

[94] S. Kühn, B. Van Werven, A. Van Oyen, A. Meijboom, E.L.B. Rebolledo, J.A. Van Franeker "The use of potassium hydroxide (KOH) solution as a suitable approachto isolate plastics ingested by marine organisms'', Mar. Pollut. Bull., vol.115, no.1–2, pp.86–90, 2017.

[95] C.G. Avio, S. Gorbi, F. Regoli "Experimental development of a new protocol forextraction and characterization of microplastics in fish tissues: first observationsin commercial species from Adriatic Sea'', Mar. Environ. Res., vol.111, pp.18–26, 2015.

[96] H. Leslie, S. Brandsma, M. Van Velzen, A. Vethaak "Microplastics enroute: field measurements in the Dutch river delta and Amsterdam canals,wastewater treatment plants, North Sea sediments and biota'', Environ. Int., vol.101, pp.133–142, 2017.

[97] M. Majewsky, H. Bitter, E. Eiche, H. Horn "Determination of microplasticpolyethylene (PE) and polypropylene (PP) in environmental samples using ther-mal analysis (TGA-DSC)'', Sci. Total Environ., vol.568, pp.507–511, 2016.

[98] K. Munno, P.A. Helm, D.A. Jackson, C. Rochman, A. Sims "Impacts of tempera-ture and Selected chemical digestion methods on microplastic particles'', Environ.Toxicol. Chem. , vol.37, no.1, pp.91–98, 2018, https://doi.org/10.1002/etc.3935.

[99] NOAA Marine debris program, https://marinedebris.noaa.gov/what-marine-debris/plastic, Date of access: 16.03.2022.

[100] M. Claessens, L. Van Cauwenberghe, M.B. Vandegehuchte, C.R. Janssen "New techniques for the detection of microplastics in sediments and field collected organisms'', Mar. Pollut. Bull., vol.70, pp.227–233, 2013, https://doi.org/10.1016/j.marpolbul.2013.03.009.

[101] D.A. Cooper, P.L. Corcoran "Effects of mechanical and chemical processes on the degradation of plastic beach debris on the island of Kauai, Hawaii'', Mar. Pollut. Bull., vol.60, pp.650–654, 2010, https://doi.org/10.1016/j.marpolbul.2009.12.026.

[102] J. Li, H. Liu, J.P. Chen "Microplastics in freshwater systems: a review on occurrence, environmental effects, and methods for microplastics detection'', Water Res., vol.137, pp.362–374, 2018a, https://doi.org/10.1016/j.watres.2017.12.056.

[103] T. Rocha-Santos, A.C. Duarte "A critical overview of the analytical approaches to the occurrence, the fate and the behavior of microplastics in the environment'', TrAC Trends Anal. Chem., vol.65, pp.47–53, 2015, https://doi.org/10.1016/j.trac.2014.10.011.

[104] W. Wang, J. Wang "Investigation of microplastics in aquatic environments: an overview of the methods used, from field sampling to laboratory analysis'', Trends Anal. Chem., vol.108, pp.195–202, 2018, https://doi.org/10.1016/j.trac.2018.08.026.

[105] R.R. Hurley, A.L. Lusher, M. Olsen, L. Nizzetto "Validation of a method forextracting microplastics from complex, organic-rich, environmental matrices'', Environ. Sci. Technol., vol.52, no.13, pp.7409–7417, 2018.

[106] R. Dris, J. Gasperi, V. Rocher, M. Saad, N. Renault, B. Tassin "Microplasticcontamination in an urban area: a case study in Greater Paris '', Environ. Chem., vol.12, no.5, pp.592–599, 2015.

[107] G. Liebezeit, E. "Liebezeit, Synthetic particles as contaminants in German beers''. Food Additives &

Contaminants: Part A, no.31, pp. 1574–1578, 2014, https://doi.org/10.1080/19440049.2014.945099.

[108] J. P. Harrison, J.J. Ojeda, M.E. Romero-Gonzalez "The applicability of reflectancemicro-Fourier-transform infrared spectroscopy for the detection of synthetic microplastics in marine sediments'', Science of the Total Environment, vol.416, pp.455–463, 2012.

[109] M.G.J. Löder, M. Kuczera, S. Mintenig et al. "Focal Plane Array Detector-Based Micro-Fourier-Transform Infrared Imaging for the Analysis of Microplastics in Environmental Samples'', Environ. Chem., vol.12, no.5, pp.563–581, 2015.

[110] D. Schymanski, C. Goldbeck, H. U. Humpf, P. Fürst "Analysis of microplastics by micro-Raman spectroscopy: release of plastic particles from different packaging into mineral water'', Water Res., vol.129, pp.154–162, 2018, doi: 10.1016/j.watres.2017.11.011.

[111] P. Ribeiro-Claro, M. Nolasco, C. Arau´jo "Characterization of Microplastics by Raman Spectroscopy'', In: T.A.P., Editors Rocha-Santos, A.C. Duarte, Comprehensive Analytical Chemistry. Amsterdam: Elsevier, Chap. 5, pp. 119–151, 2016.

[112] A.M. Elert, R. Becker, E. Duemichen, P. Eisentraut, J. Falkenhagen, H. Sturm, U. Braun "Comparison of different methods for MP detection: what can we learn from them, and why asking the right question before measurements matters?'', Environ. Pollut., vol.231, no.2, pp.1256–1264, 2017. https://doi.org/10.1016/j.envpol.2017.08.074.

[113] F. Dubaish, G. Liebezeit "Suspended microplastics and black carbon particles in the Jade system, souther North Sea'', Water, Air, & Soil Pollution, vol.224, no.2, pp.1-8, . 2013. https://doi.org/10.1007/s11270-012-1352-9.

[114] M. Eriksen, S. Mason, S. Wilson, C. Box, A. Zellers et al. "Microplastic pollution in the surface waters of the Laurentian Great Lakes'', Mar. Pollut. Bull., vol.77, pp.177–182, 2013.

[115] A. Vianello, A. Boldrin, P. Guerriero et al. "Microplastic particles in sediments of Lagoon of Venice, Italy: first observations on occurrence, spatial patterns and identification'', Estuar Coast Shelf Sci., vol.130, pp.54–61, 2013. https://doi.org/10.1016/j.ecss.2013.03.022.

[116] E. Dümichen, A.-K. Barthel, U. Braun, C.G. Bannick, K. Brand, M. Jekel, R. Senz "Analysis of polyethylene microplastics in environmental samples, using a thermal decomposition method'', Water Res., vol.85, pp.451–457, 2015.

[117] E. Fries, J.H. Dekiff, J. Willmeyer, M.-T. Nuelle, M. Ebert, D. Remy "Identification of polymer types and additives in marine microplastic particles using pyrolysis-GC/MS and scanning electron microscopy'', Environ. Sci. Proc. Improv., vol.15, pp.1949–1956, 2013. doi: 10.1039/c3em00214d.

[118] F. Von der Kammer, P.L. Ferguson, P.A. Holden, A. Masion, K.R. Rogers, S.J. Klaine, A.A. Koelmans, N. Horne, J.M. Unrine "Analysis of engineered nanomaterials in complex matrices (environment and biota): general considerations and conceptual case studies'', Environ Toxicol Chem., vol.31, no.1, pp.32-49, 2012. doi: 10.1002/etc.723.

[119] W.J. Shim, Y.K. Song, S.H. Hong, M. Jang "Identification and quantification of microplastics using Nile Red staining'', Mar. Pollut. Bull., vol.113, pp.469–476, 2016.

[120] M. Lares, M.C. Ncibi, M. Sillanpää, M. Sillanpää "Intercomparison study on commonly used methods to determine microplastics in wastewater and sludge samples'', Environ. Sci. Pollut. R., vol.26, pp.12109–12122, 2019.

[121] S. Bagchia, S. Probasco, B. MardanDoost, B.S. Sturma "Fate of microplastics in water resource recovery facilities (WRRFs) and national environmental loading estimates'', Proceedings of the Water Environment Federation, vol.7, pp.353-361, 2016.

[122] M.G.J. Löder, H.K. Imhof, M. Ladehoff et al. "Enzymatic purification of microplastics in environmental samples'', Environ. Sci. Technol., vol.24, pp.14283–14292, 2017. https://doi.org/10.1021/acs.est.7b03055.

[123] İ.B. Kanlı, Y. Kurt "An Evaluation of Microplastic Pollution Within The Scope Of Environmental Policies Of Turkey '', 22nd International Congress On New Horizons In Education And Social Sciences (ICES - 2019) Proceedings, June 18-19, 2019, Istanbul-TURKEY. 0.21733/ibad.585043.

[124] D. Xanthos, T. R. Walker "International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): A review'', Marine Pollution Bulletin, vol.118, no.1-2, pp.17-26, 2017. doi:10.1016/j.marpolbul.2017.02.048

[125] S. Pettipas, M. Bernier, T. R. Walker "A Canadian policy framework to mitigate plastic marine pollution'', Marine Policy, vol.68, pp.117-122, 2016. https://www.sciencedirect.com/science/article/pii/S0308597X16300665.

[126] Environment and urban ministry, Integrated Marine Pollution Monitoring https://lab.csb.gov.tr/denizdeki-butunlesik-kirlilik-izleme-i-5886, Accessed on 12/06/2019.

[127] TUBITAK Marmara Research Center, http://mam.tubitak.gov.tr/tr/haber/2017-2019-donemi-denizdeki-butunlesik-kirlilik-izleme-projesi. 13/06/2019.

[128] M.E.T.U. 2017 "I Know My Sea, I Protect My Sea Training for primary education and marine waste/microplastic research at METU - Marine Sciences Institute'', Accessed on 15/06/2019.