INTRODUCTION

Heavy use of plastic products inevitably ends up with small-sized plastic particles in the environment. Plastic particles less than 5 mm in size are called “microplastics” [1]. Recent studies revealed that microplastics are accumulating in the oceans [2-6] as well as in the terrestrial environments [7-12]. Because identified level of microplastics in the environment is much lower than estimated from mismanaged flows of plastic products [5,13,14], the actual level of microplastics including unidentified is suspected to be much higher than observed [4,13]. The increasing level of microplastics in the environment as well as biota has drawn great attention from researchers and general public with increasing evidences of adverse effects of microplastics [15-18].

The origins of microplastics are suspected to be engineered small plastic particles in products such as microbeads in cosmetics and other consumer products or breakage of bigger plastics into smaller particles via various weathering processes [19,20]. Due to long degradation half-life of plastics (often estimated over 100 years [21,22]), microplastics, once formed, may travel long distance and spread over the world like persistent organic pollutants [23-26]. Among many potential sources of microplastics to the environment, sewage treatment plants (STPs) are regarded as important point sources to the freshwater environments and released microplastics may ultimately reach to the oceans via river flows [19,20,27-41]. Thus, it is crucial to evaluate the contribution of STPs as sources of microplastics to the natural waterways.

In order to estimate the level of microplastics entering into and leaving from STPs, it is required to have reliable and reproducible experimental methods to count microplastic particles in sewage influent and effluent. Many researchers tried to isolate and quantify microplastics from wastewater influent and/or effluent [27,29,31-33,35-38,42-48]. In those studies, occurrence of microplastics is usually expressed in the units of number concentration of microplastics in STP influents was 15.1-640 L⁻¹, whereas those in the STP effluents were highly variable and ranged from not detectable to 65 L⁻¹. For most of cases, conventional STPs are removing microplastics very effectively. Fragments and fibers are dominant shapes of microplastics. Thermoplastics (polyethylene and polypropylene) and polyester are the predominant materials recovered. Although further research is needed, size distribution of microplastics in STPs is likely to follow a power law, implying that different studies using different size cutoffs may be compared after establishing a power law relationship.

Keywords: microplastic identification; sewage treatment plants (STPs); material type; shape; size distribution
**Table 1.** Summary of studies in which microplastics were identified in STP influents and effluents.

| Location   | Information of STP | Sampling method | Analytical Method | Number concentration<sup>a</sup> |
|------------|--------------------|-----------------|-------------------|-----------------------------------|
|            | Daily process capacity (× 10³ m³ d⁻¹) | Population Equivalent (× 1,000) | Sample volume (L) | Pretreatment | Analytical equipment | Size cut-off (mm) | Influent (MP L⁻¹) | Effluent (MP L⁻¹) | Ref. |
| Scotland   | 261                | 650             | Steel buckets (10 L) Steel sieve (65 μm) | filter (11 μm) | dissection microscope & FT-IR | 11              | 15.7 ± 5.23       | 0.25 ± 0.04       | [38] |
| Sweden     | 14                 |                 | Plankton net (mesh size; 300 μm) Suction pump |              | stereo microscope & FT-IR | 300             | 15.1 ± 1.54       | 0.0082 ± 0.0017   | [44] |
| USA        | 400-180, 45 μm     |                 | Steel sieve (400, 180, 45 μm) |              | microscope & FT-IR | 45              | 0                | 0                | [27] |
| Germany    | 0.52-35, 7-210     |                 | Mobile pumping device (10 μm stainless steel filter) | 390-1,000 | EM<sup>b</sup> WPO | 10              | 0.1 ± 0.05<sup>d</sup> | 0.01-9<sup>e</sup> | [43] |
| Netherlands| 2                   |                 | Glass jar | 2                  | light microscopy & FT-IR | 0.7  | 73 ± 13            | 65 ± 67           | [32] |
| USA        | 189                | 680             | Steel sieve (6, 1, 0.355, 0.125 mm) | filter (0.7 μm) | WPO dissection microscope & micro FT-IR | 125  | 0.21-1.5          | 640 ± 2.55        | [31] |
| Finland    | 310-800            |                 | Pump-filter device (200, 100, 20 μm) | 0.3              | stereo microscope | 20              | 610              | 13.5 ± 2.9        | [35] |
| Finland    | 270                | 800             | Pump-filter device (300, 100, 20 μm) | 0.1<sup>f</sup> 0.1<sup>g</sup> | 1,000<sup>f</sup> 10.5-13.5f | 20              | 568±165          | 640±255           | [37] |
| Australia  | 13-308             | 67-1,227        | Stainless steel sieve (500, 190, 100, 25 μm) | 3-200 | WPO dissection microscope & FT-IR | 25              | 0.21-1.5         | 0.6±0.2           | [31] |
| USA        | 2.3-382            | 3.5-56,000      | Tyler sieves (355, 125 μm) | 4,847            | WPO dissection microscope | 125  | 0.05 ± 0.024      |                 | [33] |
| USA        | 2.3-310            |                 | Stainless steel sieve (355, 125 μm) |                  | WPO dissection microscope | 125  | 0.022-0.13        |                 | [45] |
| Finland    | 10                 |                 | Stainless steel bucket sieve (0.25, 5 mm) | 4-30            | WPO optical microscope & FT-I R | 250  | 57.6 ± 32.8       | 1 ± 1.1           | [46] |
| France     | 240                |                 | Automatic sampler | filter (1.6 μm) | stereomicroscope | 100  | 293              | 35               | [47] |
| Finland    | 14-88              |                 | Pump-filter device (300, 100, 20 μm) |                  | stereomicroscope & FT-IR | 20              | 0.04-1.2         |                 | [36] |
| Canada     | 120                |                 | ISCO peristaltic pump (100 μm nylon mesh) | 100            | WPO stereomicroscope | 100  | 0.07             |                 | [48] |

<sup>a</sup>mean value ± standard deviation; <sup>b</sup>enzymatic maceration; <sup>c</sup>wet peroxide oxidation; <sup>d</sup>MP size > 500 mm; <sup>e</sup>MP size < 500 mm; <sup>f</sup>grab sampling; <sup>g</sup>24-h composite sampling.
ods for sampling, isolation and identification of plastic particles from wastewater samples were tried [27,31-33,35-38,42-48]. Thus, it is unclear that the differences in number concentration of microplastics in wastewater is due to the difference in the level of plastic contamination or due to the difference in sampling and analytical methods used.

In this mini-review, we summarize existing peer-reviewed articles on microplastics in STPs. Because a few reviews and reports have been published in a broader context [19-20,39-41], we narrowed the scope to microplastics in STP influents and effluents. The reported variations in the number concentrations, types, and size distribution of microplastics in STP influents and effluents are compared with experimental methods used for isolation and identification of microplastics. Percent removal of microplastics are also assessed based on reported data. Finally, we propose future research needs on the refined assessment of the microplastics in STPs.

**METHODS FOR ISOLATION AND IDENTIFICATION**

Table 1 summarizes recent peer-reviewed publications in which microplastics were identified in STP influents and/or effluents since mid-2010s [27,31-33,35-38,42-49]. As shown, researchers have used different methods of isolating, recovering, purifying, identifying, and counting methods.

Glass bottles or steel buckets were used for sampling STP influents that contain high concentration of microplastics and sampling volumes were from 0.1 to 30 L [32,35,37,38,44,46]. Larger volumes of STP effluents were required to isolate microplastics, ranging from 2 to 232,000 L [27,31-33,35,37,38,43,44,48]. Various sampling devices were used, including simple steel buckets [38,46], glass jars [32], commercial metal sieves [27,31,33,38,42,45], plankton nets [44], or custom-made pump-filter systems [35-37,43,44,47,48]. Pore size of filtering devices also highly varied. The smallest pore size was 0.7 μm [32] and the largest size cutoff was 300 μm [44]. Different size cutoffs inevitably lead to great variations in identified number concentration of microplastics.

In order to remove organic matters other than synthetic polymers, wet peroxide oxidation (WPO) method was predominantly used [31,33,42,43,45,46,48]. Reaction temperature and time varied depending on the concentration of organic matter. For some effluents, microplastics were isolated by simple filtration without any chemical treatment such as WPO [33,45,47,48]. Staining microplastics using fluorescent dyes such as Nile red are suggested for better detection of smaller microplastics [50-52].

Choosing an appropriate sampling volume is very crucial to obtain reliable number concentration of microplastics especially for analyzing influent samples in which concentration often exceeds 100 particles L⁻¹ since identifying plastic particles under infrared spectroscopy is time-consuming. Performing preliminary tests would be helpful to decide an appropriate sampling volume for a given size cutoff. WPO is frequently used for isolating plastic particles from organic-rich water samples. Although it was proven to be reliable [42], this also requires long digestion time and needs further refinement.

**OCCURRENCE OF MICROPLASTICS IN STP INFLUENTS AND EFFLUENTS**

As summarized in Table 1, occurrence of microplastics in STP influents and effluents was expressed on the basis of the number concentration. Further details such as treatment...

![Figure 1](http://e-eht.org/)
methods of the investigated STPs, year of sampling campaign, sources of the influent are in the web-only Supplementary data file. Although it is difficult to directly compare literature values due to different size cutoffs, the reported number concentrations were not much different among STP influents [32,35,37,38,44,46], ranging between 15.1 and 640 L⁻¹. It is not surprising that the greatest value was obtained when the influent was filtered through a 20 μm filter [37]. Unlike relative invariance among different STP influents, the reported number concentration in STP effluents varied from not detectable to 65 L⁻¹. There is a general trend that the reported median number concentration increases with decreasing size cutoff (Figure 1).

The removal efficiency of STPs could be estimated when the number concentrations in both the influent and the effluent were reported although they are not based on the conservation of mass. It is not surprising that conventional STPs are very efficient for removing microplastics. The calculated removal efficiency was 98.3-99.9% [35,37,38,44,46] except for one study in the Netherlands [32], supporting that microplastics are easily removed during the conventional sewage treatment. Because microplastics are thought to be removed by settling to sewage sludge, recovering microplastics from STP sludge would be important to complete the mass balances of microplastics in STPs. This will help us understand the fate of microplastics entering STPs.

MATERIAL TYPES AND SHAPES OF MICROPLASTICS

The term “plastics” in the polymer industry often refers one of five forms of synthetic polymers, namely fibers, elastomers, plastics, adhesives, and coatings [53]. Plastics are further divided into thermoplastics and thermosets depending on the ease of reprocessing after molten plastics solidify into a shape [54]. However, the term “microplastics” is often used to include all types of anthropogenic polymers [1,55].

Figure 2 describes the relative abundance in percent of material-types of microplastics in STP influents and effluents. Representative thermoplastics (polyethylene (PE), polypropylene (PP), and polystyrene (PS)) and polyester are major materials. The relative abundance agrees with the reported production volumes [56]. PE is the most largely produced plastic material in the world and it has density lower than water [56]. The higher abundance of polyester is characteristic in STPs and is different from the material types of microplastics identified in the oceans and beaches, mainly PE, PP, and PS [55]. Because polyester is used as synthetic fibers in garments, sewage water may contain large amount of micro-sized polyester fibers from laundry effluents [28,57-59]. For example, more than 6 million microfibers may be released from a typical 5 kg polyester fabrics during domestic washing conditions [59].

Figure 3 describes morphology of microplastics in STPs. Fibers forms, mainly from synthetic fibers for fabrics, are the most dominant followed by flakes/fragments. This suggests that microplastics entering STPs are mainly those used as synthetic fibers and fragmented secondary microplastics. Less than 10% are films, pellets, and foams. Because STPs in the United States, Europe, and Australia were studied, further investigation in other regions would provide different abundance patterns owing to different culture and life-styles.
STP AS SOURCES OF MICROPLASTICS TO FRESHWATER SYSTEMS

As summarized in Table 1, majority of studies on the occurrence of microplastics was from the United States, Europe and Australia. Because plastics are also massively used in the other geographic regions, it is expected that microplastics are widespread in other nations as well. If the volumetric flow rate and the population size are counted, it is possible to estimate the microplastics load per capita to the freshwater systems [27,33,37,38]. Murphy et al. estimated daily discharge of \(6.5 \times 10^7\) microplastic particles per day from a secondary STP treating \(2.6 \times 10^5\) m\(^3\) d\(^{-1}\) and the population equivalent to 650,000 [38]. Large amount of microplastics daily discharge from STPs in spite of high removal efficiency, which denotes the requirement of further investigation on the contribution of STPs as point sources of microplastics.

Although no peer-reviewed publications were found yet for Asian countries, a few technical reports were accessible. In Korea, 0-2.2 particles m\(^{-3}\) were detected in river water [60], which were similar to the level in the United Kingdom and Austria [61]. In one Korean STP, the number concentrations in the influent and the effluent were 1.3-4.6 \( \times 10^3\) L\(^{-1}\) and 0.007-0.022 L\(^{-1}\), respectively, indicating more than 99.99% removal [60]. In Japan, microplastic fibers were detected in STP influent and primary sludge by a research group in National Institute of Environmental Studies [62]. However, no number concentration was reported in this study [62].

STPs are regarded as one of the most important sources of microplastics in public waterways and a few studies quantitatively estimated the microplastic load via STPs [27,35,38]. However, it is still not clear whether STPs contribute predominantly compared to other routes of entrance (e.g., direct input to rivers and lakes, stormwater runoff, dry and wet deposition from air, etc.). Contributions by different routes of entrance warrant further investigations. In addition, published results about microplastics in STPs are mainly from developed countries where most of sewer is treated though STPs. However, percentage of sewage treatment is much lower in developing countries [63]. Thus, microplastic input to freshwater systems might be greater in developing countries because STPs are found to be able to remove microplastics very efficiently [35,37,38,44,46,60]. Another aspect to be considered is that the annual plastic consumption in developing countries is lower than developed countries. Further studies on the occurrence of microplastics in various geographic regions, especially in developing nations, would provide better estimates of global microplastic load to freshwater environment.
SIZE DISTRIBUTION OF MICROPLASTICS

As shown in Table 1, researchers have used different size cutoffs for isolation of microplastic particles. Except for primary microplastics that are engineered to small sizes, microplastics are thought to be formed via various weathering processes from bigger plastic products. Although our understanding of these fragmentation processes is very limited, it may be assumed that the fragmentation of plastic particles to smaller ones is a scale-independent process within the size range of microplastics predominantly found (20 \(\mu m - 5 mm\)). Thus, the size distribution of microplastics should follow the power law [64]. Laboratory fragmentation study by Song et al. [65] provides a good support for this hypothesis. However, the size distribution of microplastics isolated from environmental samples did not always satisfy the power law relationship [4,45,66,67]. In a recent study using a novel Nile red staining method, more small-sized microplastics were found and the size distribution followed the power law [52].

Only a few studies reported size distribution of microplastics in STPs using size fractionation [31,37]. Figure 4 describes particle size distribution, \(log(\Delta N/\Delta dp)\) versus dp, where \(N\) denotes number concentration (particles L\(^{-1}\)) and \(dp\) is the median size in \(\mu m\) for the number concentration of microplastics reported by Ziajahromi et al. [31] (A) and Talvitie et al. [37] (B). The median values of reported \(dp\) were used to draw the size distribution. As shown, the particle size distribution in general follows the power law although the slopes were obtained from only 3 points. Interestingly, the slopes in Figure 4 did not vary much (-2.68 ~ -1.92 in Ziajahromi et al. [31] and -2.39 ~ -1.08 in Talvitie et al. [37]) among different STPs in two studies. It is also noteworthy that the slopes of the size distribution curve are smaller than those obtained in batch tests by Song et al. (-4.57 ~ -2.74) [65]. This might be because of the enhanced aggregation and removal of smaller plastic particles in the real environment that do not occur in a batch test.

The slope in the size-distribution of microplastics is important for the practical purpose of comparing experimental data using different size cutoffs. It is allowed to compare reported concentration data with different size cutoffs, if the size-distribution of microplastics in STPs or in other environmental media follows the power law with a specific exponent. It is also important to know how the shape distribution over which the power law is applicable. Studies on the size distribution of microplastics in environmental media warrants further investigation to estimate the current number and mass of microplastics in the environment.

CONCLUDING REMARKS AND FUTURE RESEARCH NEEDS

Recent investigations on microplastics in STPs show that microplastics are ubiquitously found all over the world. Although the occurrence of microplastics was investigated only in limited regions, secondary microplastics and synthetic fibers originated from garments are major source of microplastics in STPs [28,46,49]. Conventional STPs under typical operation conditions are found to be removing microplastics from their influents. However, the occurrence of microplastics in STPs in other geographic regions are needed to study for a better global estimation of microplastics load to freshwater systems. Further studies on the size distribution of microplastics in STPs are also needed to understand the fate of microplastics in STPs and to compare results from different studies using different size cutoffs.

CONFLICT OF INTEREST

The authors have no conflicts of interest associated with the material presented in this paper.

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REFERENCES

1. GESAMP. Sources, fate and effects of microplastics in the marine environment: A global assessment. Kershaw PJ, Eds. IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, Rep. Stud. 2015; GESAMP No. 90, 96p.
2. Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AWG, et al. Lost at sea: where is all the plastic? Science 2004;304(5672):838.
3. Barnes DKA, Galgani F, Thompson RC, Barlaz M. Accumulation and fragmentation of plastic debris in global environments. Phil Trans R Soc B 2009;364:1985-1998.
4. Cózar A, Echevarría F, González-Gordillo JJ, Irigoien X, Úbeda B, Hernández-León S, et al. Plastic debris in the open ocean. Proc Natl Acad Sci 2014;111(8):10239-10244.
5. Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, et al. Plastic waste inputs from land into the ocean. Science 2015;347(6223):768-771.
6. Moore CJ. Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environ Res 2008;108(2):131-139.
7. Blair RM, Waldron S, Phoenix V, Gauchotte-Lindsay C. Micro- and nanoplastic pollution of freshwater and wastewater treatment systems. Springer Sci Review 2017;5(1-2):19-30.

8. Ng E-L, Lwanga EH, Eldridge SM, Johnston P, Hu H-W, Geissen V, et al. An overview of microplastic and nanopollution in agroecosystems. Sci Total Environ 2018;627(10):1378-1388.

9. de Souza Machado AA, Kloas W, Zarfl C, Hempel S, Rillig MC. Microplastics as an emerging threat to terrestrial ecosystems. Global Change Biol 2018;24(4):1405-1416.

10. Eriksen M, Mason S, Wilson S, Box C, Zellers A, Edwards W, et al. Microplastic pollution in the surface waters of the Laurentian Great Lakes. Mar Pollut Bull 2013;71(1-2):177-182.

11. Klein S, Worch E, Knepper TP. Occurrence and spatial distribution of microplastics in river shore sediments of the Rhine-Main area in Germany. Environ Sci Technol 2015;49(10):6070-6076.

12. Wang W, Ndungu AW, Li Z, Wang J. Microplastics pollution in inland freshwaters of China: A case study in urban surface waters of Wuhan, China. Sci Total Environ 2017;575:1369-1374.

13. Jang YC, Lee J, Hong S, Mok JI, Kim KS, Lee YJ, et al. Estimation of annual flow and stock of marine debris in South Korea for management purposes. Mar Pollut Bull 2014;86(1-2):505-511.

14. Kim M, Hyun S, Kwon J-H. Estimation of the environmental load of high- and low-density polyethylene from South Korea using a mass balance approach. Arch Environ Contam Toxicol 2015;69(3):367-373.

15. de Sá LC, Luís LG, Guilhermino L. Effects of microplastics on juveniles of the common goby (Pomatoschistus microps): Confusion with prey, reduction of the predatory performance and efficiency, and possible influence of developmental conditions. Environ Pollut 2015;196:359-362.

16. Lee K-W, Shim WJ, Kwon OY, Kang J-H. Size-dependent effects of micro polystyrene particles in the marine copepod Tigriopus japonicus. Environ Sci Technol 2013;47(19):11278-11283.

17. Lönstedt OM, Eklöv P. Environmentally relevant concentrations of microplastic particles influence larval fish ecology. Science 2016;352(6290):1213-1216.

18. Jeong C-B, Won E-J, Kang H-M, Lee M-C, Hwang D-S, Hwang U-K, et al. Microplastic size-dependent toxicity, oxidative stress induction, and p-JNK and p-p38 activation in the monogonont rotifer (Brachionus koreanus). Environ Sci Technol 2016;50(16):8849-8857.

19. Auta HS, Emenike CU, Fauziah SH. Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions. Environ Int 2017;102:165-176.

20. Rezania S, Park J, Din MF, Taib SM, Talakhozani A, Yadav KK, et al. Microplastics pollution in different aquatic environments and biota: A review of recent studies. Marine Pollut Bull 2018;133:191-208.

21. Artham T, Sudhakar M, Venkatesan R, Madhavan Nair C, Murty K, Doble M. Biofouling and stability of synthetic polymers in sea water. Int Biodeterior Biodegrad 2009;63(7):884-890.

22. Restrepo-Flórez J-M, Bassi A, Thompson MR. Microbial degradation and deterioration of polyethylene-A review. Int Biodet Biodegr 2014;88:83-90.

23. Barnes DKA, Walters A, Gonçalves L. Macroplastics at sea around Antarctica. Mar Environ Res 2010;70(2):250-252.

24. Ivar do Sul JA, Spengler A, Costa MF. Here, there and everywhere. Small plastic fragments and pellets on beaches of Fernando de Noronha (Equatorial Western Atlantic). Mar Pollut Bull 2009;58(8):1229-1244.

25. Thompson RC, Swan SH, Moore CJ, vom Saal FS. Out plastic age. Phil Trans R Soc B 2009;364:1973-1976.

26. Rohmann R. Microplastics are not important for the cycling and bioaccumulation of organic pollutants in the oceans—but should microplastics be considered POPs themselves? Integ Env Assess Manag 2017;13(3):460-465.

27. Carr SA, Liu J, Tesoro AG. Transport and fate of microplastic particles in wastewater treatment plants. Water Res 2016;91:174-182.

28. Cesa FS, Turra A, Baruque-Ramos J. Synthetic fibers as microplastics in the marine environment: A review from textile perspective with a focus on domestic washings. Sci Total Environ 2017;598:1116-1129.

29. Kalkicová G, Alíč B, Skalár T, Bündschuh M, Gotvajn AŽ. Wastewater treatment plant effluents as sources of cosmetic polyethylene microbeads to freshwater. Chemosphere 2017;188:25-31.

30. Lasee S, Mauricio J, Thompson WA, Karnjanapiboonwong A, Kasumba J, Subbiah S, et al. Microplastics in a freshwater environment receiving treated wastewater effluent. Int Environ Assess Manag 2017;13(3):528-532.

31. Ziazjahromi S, Neale PA, Rintoul L, Leusch FDL. Wastewater treatment plants as a pathway for microplastics: Development of a new approach to sample wastewater-based microplastics. Water Res 2017;112:93-99.

32. Leslie HA, Brandsma SH, van Velzen MJM, Vethaak AD. Microplastics en route: Field measurements in the Dutch river delta and Amsterdam canals, wastewater treatment plants, North Sea sediments and biota. Int Environ Int 2017;101:133-142.

33. Mason SA, Garneau D, Sutton R, Chu Y, Ehmann K, Barnes J, et al. Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent. Environ Pollut 2016;218:1045-1054.

34. Prata JC. Microplastics in wastewater: State of the knowledge on sources, fate and solutions. Mar Pollut Bull 2018;129(1):262-265.

35. Talvitie J, Heinonen M, Pälkkönen J-P, Vahtera E, Mikola A, Setälä O, Vahala R. Do wastewater treatment plants act as a potential point source of microplastics? Preliminary study in the coastal Gulf of Finland, Baltic Sea. Water Sci Technol 2015;72(9):1495-1504.

36. Talvitie J, Mikola A, Koistinen A, Setälä O. Solutions to microplastic pollution - Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. Water Res 2017;123:401-407.

37. Talvitie J, Mikola A, Setälä O, Heinonen M, Koistinen A. How well is microlitter purified from wastewater? - A detailed study on the stepwise removal of microlitter in a tertiary level wastewater treatment plant. Water Res 2017;109:164-172.

38. Murphy F, Ewins C, Carbonnier F, Quinn B. Wastewater treatment works (WWTW) as a source of microplastics in the aquatic environment. Environ Sci Technol 2016;50(11):5800-5808.

39. Eerkes-Medrano D, Thompson RC, Aldridge DC. Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritization of research needs. Water Res 2015;75:63-82.

40. Dрис R, Imhof H, Sanchez W, Gasperi I, Galgani F, Tassin B, et al. Beyond the ocean: Contamination of freshwater ecosystems with (micro-) plastic particles. Environmental Chemistry, CSIRO Publishing.
41. Lassen C., Hansen SF, Magnusson K, Hartmann NB, Rehne Jensen P, Nielsen TG, et al. Microplastics: Occurrence, effects and sources of releases to the environment in Denmark. Copenhagen K: Danish Environmental Protection Agency. 2015. pp. 206.

42. Dyachenko A, Mitchell J, Arsem N. Extraction and identification of microplastic particles from secondary wastewater treatment plant (WWTP) effluent. Anal Methods 2017;9:1412-1418.

43. Mintenig SM, Int-Veen I, Löder MGI, Primpke S, Gerds G. Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-Fourier-transform infrared imaging. Water Res 2017;108:365-372.

44. Magnusson K, Norén F. Screening of microplastic particles in and down-stream a wastewater treatment plant. 2014. Swedish Environmental Research Institute. p19.

45. Sutton R, Mason SA, Stanek SK, Willis-Norton E, Wren IF, Box C. Microplastic contamination in the San Francisco Bay, California, USA. 2016;109:230-235.

46. Lares M, Ncibi MC, Sillanpää M. Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology. Water Res 2018;133:236-246.

47. Dris R, Gasperi I, Rocher V, Saad M, Renault N, Tassin B. Microplastic contamination in an urban area: a case study in Greater Paris. Environ Chem 2015;12(5):592-599.

48. Vermaire JC, Pomeroy C, Herczegh SM, Haggart O, Murphy M. Microplastic abundance and distribution in the open water and sediment of the Ottawa River, Canada, and its tributaries. FACETS 2017;2:301-314.

49. Bayo J, Olmos S, López-Castellanos J, Alcolea A. Microplastics and microfibers in the sludge of a municipal wastewater treatment plant. Int J Sus Dev Plann 2016;11(5):812-821.

50. Shim WJ, Song YK, Hong SH, Jang M. Identification and quantification of microplastics using Nile Red staining. Mar Pollut Bull 2016;113(1-2):469-476.

51. Cole M. A novel method for preparing microplastic fibers. Sci Rep 2016;6:34519.

52. Erni-Cassola G, Gibson MI, Thompson RC, Christie-Oleza JA. Lost, but found with Nile Red: A novel method for detecting and quantifying small microplastics (1 mm to 20 μm) in environmental samples. Environ Sci Technol 2017;51(23):13641-13648.

53. Carragher Jr. CE. Introduction to Polymer Chemistry, 2nd ed., CRC Press, Boca Raton, FL. 2010.

54. Baker AMM, Mead J. Thermoplastics. In Harper CA eds. Modern Plastics Handbook, McGraw-Hill, New York, NY, 2000.

55. Shim WJ, Hong SH, Eo S. Marine microplastics: abundance, distribution, and composition, In Microplastic Contamination in Aquatic Environments, Zeng EY eds. 2018, Elsevier Inc.

56. Plastic Europe. Plastics – the Facts 2017: An analysis of European plastics production, demand and waste data.

57. Hernandez E, Nowack B, Mitran D. Polyester textiles as a source of microplastics from households: A mechanistic study to understand microfiber release during washing. Environ Sci Technol 2017;51(12):7036-7046.

58. Napper IE, Thompson RC. Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. Mar Pollut Bull 2016;112(1-2):39-45.

59. De Falco E, Gullo MP, Gentile G, Di Pace E, Cocca M, Gelabert L, et al. Evaluation of microplastic release caused by textile washing processes of synthetic fabrics. Environ Pollut 2018;238:916-925.

60. Lee JH, Park CH, Huh IA, Lee SH, Lee YS, Lee SK and Lee SH. Studies on the investigation method of microplastic in the freshwater. NIER 2016;RP2016-282

61. Sadri SS and Thompson RC. On the quantity and composition of floating plastic debris entering and leaving the Tamar Estuary, South-west England. Mar Pollut Bull 2014; 81(1):55-60.

62. http://www.nies.go.jp/risk_health/chemsympo/2017/h29_youshi/sympo20180216-006-ogawa_fumiaki.pdf (In Japanese) (Accessed on July 20, 2018).

63. European Union, Eurostat – Water statistics. url: http://ec.europa.eu/eurostat/statistics-explained/index.php/Water_statistics (Accessed on July 11, 2018)

64. Newman MEJ. Power laws, Pareto distributions and Zipf’s law. Comtemp Phys 2005;46:323-351.

65. Song YK, Hong SH, Jang M, Han GM, Jung SW, Shim WJ. Combined effects of UV exposure duration and mechanical abrasion on microplastic fragmentation by polymer type. Environ Sci Technol 2017;51(8):4368-4376.

66. Chae D-H, Kim I-S, Kim S-K, Song YK, Shim WJ. Abundance and distribution characteristics of microplastics in surface seawaters of the Incheon/Kyeonggi coastal region. Arch Environ Contam Toxicol 2015; 69(3):269-278.

67. Peng G, Zhu B, Yang D, Su L, Shi H, Li D. Microplastics in sediments of the Changjiang estuary, China. Environ Pollut 2017;225:283-290.