Impact of micro- and nano-plastics on environment and food chain: A brief overview

Sathish Kumar Palaniappan[1], Manoj Kumar Singh[1], Sanjay Mavinkere Rangappa[1], Suchart Siengchin[1]

[1] Natural Composites Research Group Lab, Department of Materials and Production Engineering, The Sirindhorn International Thai-German School of Engineering (TGGS), King Mongkut's University of Technology North Bangkok (KMUTNB), Bangkok 10800, Thailand

The corresponding author: Sanjay Mavinkere Rangappa

Abstract

Micro- and nano-plastics (MPs coupled with NPs) are created from malfunctioning more oversized plastic products or with a straight launch. Their comprehensive circulation and determination have made them a considerable worldwide ecological concern. Plastic bits of smaller-sized dimensions determining from numerous µm to nm impact varied ecological communities of land, freshwater, and aquatic atmospheres. Their existence substantially impacts biodiversity, community equilibrium, and human health. This testimonial quickly looks at the paths and destiny coupled with the effects of MPs and NPs in the atmosphere and their unification into the food cycle. MPs and NPs are providers of toxic substances and viruses, increasing their prospective threats. The intake of these materials by different microorganisms consisting of plankton plus people leads to bioaccumulation and biomagnification, which boosts considerable concerns about food security and safety. The long-lasting impacts of MPs and NPs on the atmosphere and human health and wellness are not yet completely recognized, showing a requirement for additional examination. This testimonial summarizes the existing understanding and highlights the essential requirement for interdisciplinary research study coupled with the worldwide partnership to deal with the ecological and food cycle threats related to MPs coupled with NPs, thus advertising the lasting sustainability of eco-friendly systems associated with human health and wellness.

Keywords:

Microplastics; Nanoplastics; Food Chain; Environmental Concern; Plastic Waste; Degradation.

Highlights:

- Micro- and nano-plastics (MPs and NPs) are widespread environmental pollutants from larger plastic breakdowns.
- MPs and NPs threaten biodiversity and ecosystem health, impacting wildlife and human well-being.
- MPs and NPs carry harmful chemicals and pathogens, increasing their potential environmental and human health risks.
- MPs and NPs originate from multiple sources, complicating their detection and quantification.
- More research and global cooperation are essential to address the health and ecological risks of plastic pollution.

Submitted:

Accepted:

Published:

DOI:

1. Introduction

Plastics are flexible with versatile products that producers can conveniently use to make brand-new items and intermediates. Plastic is used in several sectors owing to its substantial flexibility in production or as a part of completion items. The forecasts for plastic manufacturing show that it may triple by 2050 from a projected 380 million tons in 2018 [1, 2]. Product packaging represented 40% of Europe's 51. 2 million metric tons of plastic usage in 2018 [3]. Drifting waste has built up dramatically in aquatic settings due to the boosted use of plastic and poor disposal techniques and facilities.

It has been revealed that 10% of the 8. 3 billion tons of plastic created worldwide by 2023 will result in plastic waste in freshwater and marine environments. This number highlights the enhancing issue of plastic air pollution. Researchers first concentrated on the result of plastics on the setting and the threat of biomagnification of connected plasticizers on human health and wellness in the early 1970s [4]. As it is understood, microplastics (MPs) together with nanoplastics (NPs) are the outcome of the sluggish failure of more significant plastic bits in both freshwater and aquatic settings [5, 6]. As it is recognized, the sea has long been approved as a global data for plastic waste.

Current research studies show dirt and other earthbound communities work as MP tanks [7, 8]. Individuals are susceptible to ecological plastics because they can breathe them in, ingest them via food, and obtain them via their skin. One more prospective path of indirect consumption of MPs and NPs is via individual treatment items consisting of lip balm and toothpaste coupled with cosmetics. MPs have entered the food web due to the bountiful plastics in the atmosphere, placing customers in danger. According to current research, MPs have been discovered in several products: water, fish and shellfish, sugar, honey, beer, and sea salt [9]. In several other ecological floor coverings, consisting of freshwater, aquatic debris, biota, dirt, and background air, MPs plus NPs, which are little pieces of artificial polymers (plastic), were discovered.

They are additionally located in food and water, which implies they are arising anthropogenic bit toxins [10-24]. The term MPs was first utilized in 2004 by Thompson et al. to define the little items of plastic discovered in marine atmospheres [25]. MPs need not be greater than 5 mm in dimension, according to Arthur et al. [26]. NPs are plastic bits with fibers smaller than 1 μm, whereas MPs are those between 1 μm and 1 mm in dimension [27-30]. MPs 1 to 5 mm in dimensions are considered huge [28 29]. Lightweight, functional, moldable, flame-resistant, and corrosion-resistant plastics have several usages and benefits. By promoting simplicity coupled with security in different applications, these attributes enhance the lives of countless individuals worldwide [31]. Nevertheless, plastic contamination in the atmosphere and food resources is an international trouble requiring instant interest.

The European Union's plastics manufacturing dropped slightly in 2018 and 2019 to 61.8 and 59. 7 Mt specifically. Nonetheless, plastic outcomes worldwide increased annually to 368 Mt in 2019 [31]. MPs contamination degrees are associated with the production phases of thermoplastics like polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), together with polyethylene terephthalate (ANIMAL). This reveals MPs' global visibility in alcohol consumption water and freshwater (PP & PS & PVC & ANIMAL) [32]. Polybutylene adipate-co-terephthalate (PBAT) and polylactide (PLA) are primarily used for farming and food product packaging applications. Tire wear fragments (TWP) are composed of 40-60% artificial polymers (such as styrene-butadiene rubber, SBR), and paint fragments or finishings additionally consist of MPs [27]. MPs generally have more than one element of fillers, pigments, binders, and ingredients. Table 1 provides the physical attributes of normal artificial polymers.

Scientists might apply numerous interdisciplinary research study techniques to comprehend better the long-lasting impacts of mini- and nano-plastics on human wellness. Longitudinal research is vital as it tracks health and wellness results in populations subjected to plastics over extensive durations, supplying understanding right into persistent direct exposure results. Toxicological analyses making use of in-vitro (lab-based) coupled with in vivo (pet) designs can assist in examining the organic influences of mini- and nano-plastics, concentrating on just how these bits are taken in by cells and their prospective dangerous impacts on numerous body organ systems. Furthermore, epidemiological research can examine existing wellness information to determine connections between direct exposure to mini- and nano-plastics and details health and wellness concerns, disclosing possible fads and threats connected with intake.

Involving professionals from numerous areas is essential for a detailed understanding of the influences of mini-coupled nano-plastics. Collaborations between toxicologists, ecologists, hygienics specialists, and product researchers can improve study results by incorporating various viewpoints and techniques. For example, toxicologists might provide an understanding of the activity of plastics within organic systems. At the same time, ecologists can research exactly how these products influence ecological wellness and biodiversity. This interdisciplinary technique improves the study and promotes cutting-edge options to reduce threats related to plastic contamination.

Effective plan adjustments are necessary for attending to the ecological influences of mini- and nano-plastics. More stringent laws on plastic manufacturing could be executed, consisting of caps on producing single-use plastics and rewards for businesses to create naturally degradable choices. This can dramatically minimize the quantity of plastic going into the atmosphere. In addition, boosting garbage disposal units is important. Purchasing facilities that advertise recycling plus waste-to-energy modern technologies can decrease the quantity of plastic waste in garbage dumps and seas, eventually reducing ecological contamination.

Public understanding projects are an additional important facet of efficient plan modifications. Informing customers regarding the effect of plastic contamination and motivating liable intake and disposal methods can bring about considerable behavior modifications. In addition, developing worldwide arrangements to restrict plastic manufacturing and advertising lasting techniques throughout countries is crucial. Such treaties can help with partnership in research study plus innovation sharing, producing a joined worldwide reaction to the obstacles positioned by mini- coupled with nano-plastics. A detailed technique incorporating research study, plan, and public involvement is vital for resolving this pressing ecological problem.

Table 1. Physical properties of typical polymers that undergo degradation into MPs and NPs [33, 34].

Chemical compound	**Mechanical properties**	**Common applications**	**Specific gravity ($g\ cm^{-3}$)**	**Common shape**
PS	Low heat conductivity, inert and long-lasting	Thermal insulation, food containers, building materials	0.96-1.1	Fragments, films, foams
Low-density polyethylene (LDPE)	-	Plastic bags, drinking straws, curtains	0.91-0.93	Fragments, films, foams
Polyethylene (PE)	High tensile strength	Shopping bags, bottles	0.91-0.96	-
High-density polyethylene (HDPE)	-	-	0.94	-
PP	High tensile strength, resistance to abrasion, and smooth texture	Textile fibers, packaging materials, straws	0.83-0.84	Fibers
PET	High tensile strength, resistance to abrasion, and smooth texture	Textile fibers and packaging materials	1.37	Fibers,fragments, films, foams
Polyamide/nylon (PA)	High durability and high tensile strength	Textiles, sportswear, carpets, fishing gear	1.0-1.2	Fibers
PVC	-	Piping	1.38	Fragments, films, foams
Polyacrylate/acrylic	Transparent, high resistance to breakage, elastic	Road markings	-	Fibers
Expanded Polystyrene (EPS)	-	Floats, cups, expanded packaging	<0.05	Fragments, films, foams
Acrylonitrile butadiene styrene (ABS)	-	3D printer, protective equipment	1.06-1.08	Pellets
PLA	-	3D printer	-	Pellets

2. Generation of MPs and NPs in the environment

Maritime communities comprise roughly 20% of MPs, whereas land resources comprise over 80%. Reduced thickness, strength, and buoyancy are 3 significant attributes of MPs that assist them in dispersing worldwide [35, 36]. Coastal tourism, angling, fish farming, and land-based resources are the key reasons for plastic contamination in aquatic communities [35, 37, 38]. Research studies discovered that more than 800 million statistics show that many plastics in the water body originate from land-based resources [39]. The tiny dimension of MPs and NPs makes it hard to filter throughout wastewater therapy.

Subsequently, these plastic pieces will likely wind up in the drinkable supply system, rivers, and seas [40]. MPs, as well as NPs, can be discovered in waterways like rivers along with seas as a result of all-natural disintegration procedures that take place in dirt [41]. Number 1 reveals that main plus additional resources produce MPs and NPs [42]. Key resources define fabricated MPs and NPs with numerous customer and commercial uses, such as exfoliants in cosmetics and cleansers, substance shipment bits in medications, and commercial air-blowing treatments [36].

The second resource of MPs and NPs in terrestrial and water atmospheres is MP items that break down into smaller bits than microns [36]. Different procedures like biodegradation can wear down plastics into smaller bits called MPs and NPs (Figure 1). Hydrolysis, thermal-oxidative deterioration, physical deterioration, photodegradation, and thermal deterioration are instances of non-biodegradation devices [43-46].

Thermal deterioration, an additionally called warm decline, is a non-natural industrial procedure. On the other hand, weathering is a physical weardown that damages larger polymers into small plastics. All-natural chain reactions, called photodegradation plus hydrolysis, use water particles plus ultraviolet light to weaken polymers right into their part monomers. Plastics that do not mineralize undergo architectural disintegration, which changes their mechanical attributes and raises their area. This change boosts the physical-chemical responses and communications with microbes [47].

Biodegradation of plastics is feasible with the assistance of all-natural microorganisms [49]. These microorganisms create extracellular enzymes that damage the chemical bonds in plastics [50]. This strategy creates polymers with transformed molecular frameworks called nano-sized plastics, which are small plastic bits. A solitary gram of MPs generates billions of NPs with a more significant surface area. The day-to-day circulation of plastic right into the seas shows that NPs generously exist in the aquatic community. Additionally, plastic waste deteriorates quicker in seaside locations than in sea atmospheres.

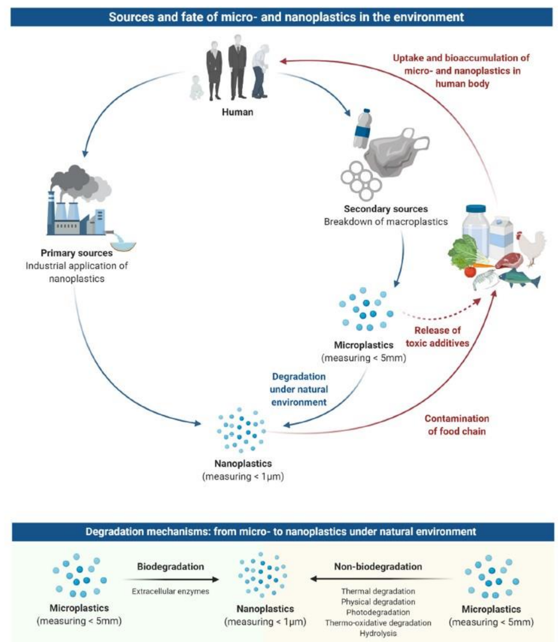

Figure 1. Primary and secondary sources of MPs and NPs [48].

Plastics primarily disintegrate by oxidation, which is started by direct solar UV exposure [51]. Furthermore, salt makes plastic break down quickly in seaside locations [52]. Plastic breaks down much faster in aquatic environments than in the world because of usually existing germs and enhanced salt focus [41].

3. MPs and NPs in the food chain

MPs and NPs located in food systems will majorly influence human wellness [42 53 54]. Probably several foods consist of MPs and NPs because of their high bioavailability and substantial frequency in marine and terrestrial communities. Pet usage [55], contamination throughout food prep work [56], and/or leaching from food as well as beverage product packaging [57] are several ways of how MPs plus NPs become part of human diet regimens, according to a study. Some foods with MPs coupled with NP fragments are honey, beer, a glass of wine, salt, sugar, fish, hen, prawns, earthbound snails, and water [58-63]. Research studies have shown that honeybees can accumulate MPs from the air and their communications with plants, dirt, and water (Figure 2) [64]. FTIR evaluation disclosed the visibility of MPs in water examples accumulated from different resources, consisting of faucets, mineral water together, and mineral water. The water examples accumulated from 159 places worldwide have MP bits smaller than 5 mm (practically 81%) [65]. The search revealed that 93% of the examples (259 containers from 11 brand names and 27 private sets) had MP bits [57]. The compliance with normal quantities of MP contamination in food has been located statistically: fish and shellfish - 1. 48 particles/g, sugar - 0. 44 particles/g, honey - 0. 10 particles/g, salt - 0. 11 particles/g, alcohol - 32. 27 particles/l, mineral water—94. 37 particles/l, faucet water—4. 23 particles/l, and air—9. 80 particles/centimeters ^{2}, specifically [66, 67]. The approximate quantity of MP fragments that people ingest annually varies from 39,000 to 52,000 and differs according to sex and age.

The results of plastic bits enhance the yearly overall worth by 74,000 to 121,000 bits. Nonetheless, compared to individuals who consume alcohol solely, mineral water faucet water users are most likely to take in just around 4,000 additional bits daily [67]. According to the research study, their food cycle substantially impacts the human consumption of MP.

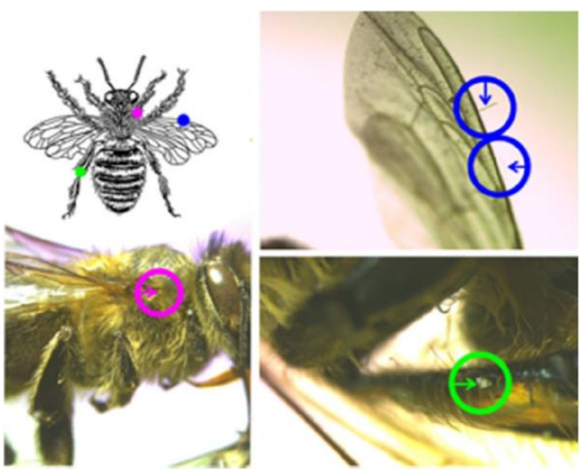

Figure 2. MPs from the active samples of honeybees [64].

Evidence for the presence of NPs in food is lacking due to the scarcity of readily available testing procedures [66, 68]. The breakdown of MP waste shows the presence of NPs in food chains, as shown by several studies [45, 68]. Research on polystyrene beverage cup lids found that NPs were released during the degradation of material over time [49]. Marine ecosystems experience microbial degradation due to the presence of microbes that decompose hydrocarbons. A "plastisphere" ecology has been developed due to the presence of these microorganisms in plastic waste [46]. Many plastic wastes in aquatic environments explain that MPs may survive degradation processes and result in additional NPs [69]. Many products employ NPs for commercial purposes; eventually, these NPs available in rivers and landfills will find their way to enter human food chains [66, 68].

4. Challenges and outlook

Identifying the polymer type or the interactions between MPs and living organisms with existing risk and exposure assessments of MPs is insufficient. Another difficulty arises because natural particles cannot be adequately isolated from MPs throughout the sampling, analysis, and characterization operations. Figure 3 summarizes the primary characterizations of plastic waste as reported in the literature, along with the methodologies employed for their identification and analysis.

Furthermore, there currently needs to be a way to get the exact information needed to calculate the MP concentrations and degradation times, including details on sources, dispersion methods, standardized measures, parameters, and timescales. However, it is still a big problem for scientists to determine whether micrometer-sized natural particles, such as cellulose, clay, or chitin, are poisonous. The ongoing contamination of the atmosphere with MPs and the high rates of plastic waste generation every year has led environmental protection organizations to impose landfill limitations in regions like the European Union. Incineration, gasification, and pyrolysis are some waste-to-energy processes that have been forced into use. Incineration is the most common, releasing heavy metals, halogens, and persistent organic pollutants. Many things that affect emissions include the incinerator's design, operational parameters, the burned materials, and the technology used to control air pollution [70]. A more practical strategy is implementing a circular economic approach that maximizes the recycling of polymers for extended usage. This will reduce plastic waste and decrease the generation of MPs and NPs. Furthermore, it is anticipated that the increasing utilization of biodegradable polymers will decrease the time of mesoplastics' environmental retention time and MPs' emissions.

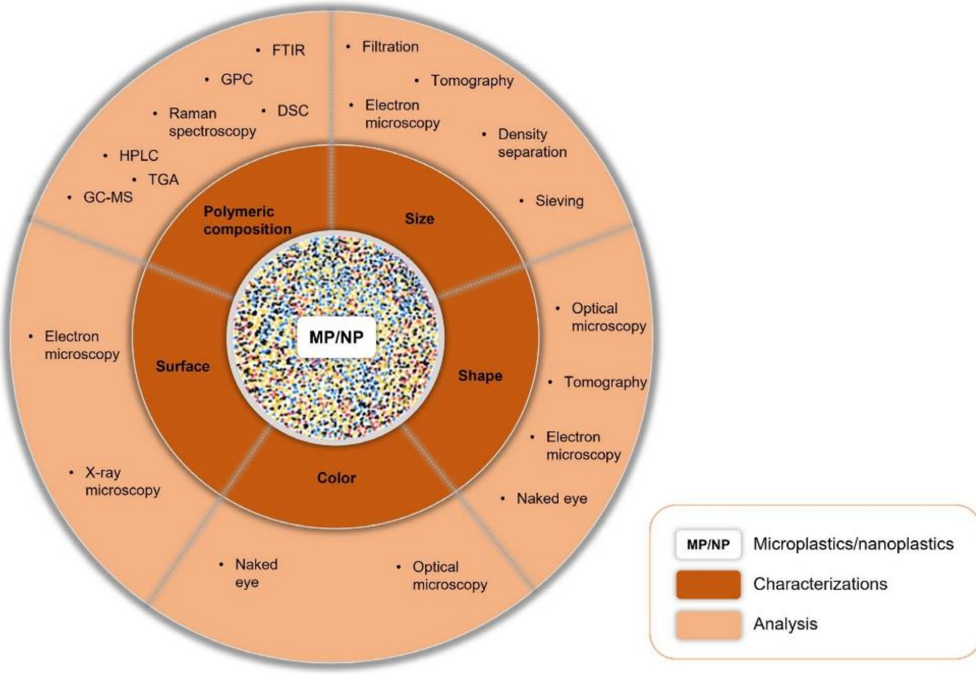

Figure 3. Overview of common plastic waste characterization techniques and analytical methods [33].

5. Summary and conclusions

The continual fragmentation of polymeric products or their calculated manufacturing within commercial procedures are significant resources for MPs and NPs. The nonexistence of specified procedures for tasting, examining, and quantifying plastic waste appears in the readily available literary works and positions trouble. Establishing trusted requirements for identifying MPs and NPs' past easy dimension summary is the topic of extreme study. In interior ambient air problems, one of the most typical morphologies of MPs consists of flakes, portions, movies, polyester, polyamide, and polyacrylate-based fibers. Contrasted to even more typical cleansing techniques such as sweeping vacuuming, it is better at minimizing the resuspension of MPs and NPs. Rugs, furnishings treatments, and drapes made from artificial fibers must be utilized carefully. In addition, interior MPs must be adequately caught by keeping air purification plus conditioning devices. Aspects were fundamental and extrinsic to the polymer, present ecological scenarios, and the activities of naturally degradable microorganisms will certainly function in establishing the disintegration price. Routine cleansing procedures of water bodies influenced by plastic waste regulation, including the polluter pays concept and business social duties, are necessary for alleviating MPs and NP contamination. These activities intend to decrease the manufacturing of MPs/NPs coupled with their capacity to go across ecological floor coverings.

Ecological defense companies are required to restrict the quantities of MPs and NPs in the atmosphere and food webs in both all-natural and synthetic problems. Consequently, numerous study initiatives around MPs and NPs are driven by the unexpected trouble of plastic contamination, which is an outcome of the exceptional renovations in modern technology, medication, and way of living that might be connected to the growth of adaptable polymer products. The new information is likely to help decrease the adverse effects of new products in the future.

Conflict of Interest

The authors claim no conflict of interest exists in the review research works.

References

[1]. Geyer, R., Jambeck, J.R. and Law, K.L., 2017. Production, use, and fate of all plastics ever made. Science advances, 3(7), p.e1700782.

[2]. Rubio, L., Marcos, R. and Hernández, A., 2020. Potential adverse health effects of ingested micro-and nanoplastics on humans. Lessons learned from in vivo and in vitro mammalian models. Journal of Toxicology and Environmental Health, Part B, 23(2), pp.51-68.

[3]. Europe, P., 2015. An analysis of European plastics production, demand and waste data. Plastics–the facts, 147.

[4]. Carpenter, E.J. and Smith Jr, K.L., 1972. Plastics on the Sargasso Sea surface. Science, 175(4027), pp.1240-1241.

[5]. Gillibert, R., Balakrishnan, G., Deshoules, Q., Tardivel, M., Magazzù, A., Donato, M.G., Maragò, O.M., Lamy de La Chapelle, M., Colas, F., Lagarde, F. and Gucciardi, P.G., 2019. Raman tweezers for small microplastics and nanoplastics identification in seawater. Environmental science & technology, 53(15), pp.9003-9013.

[6]. González-Pleiter, M., Tamayo-Belda, M., Pulido-Reyes, G., Amariei, G., Leganés, F., Rosal, R. and Fernández-Piñas, F., 2019. Secondary nanoplastics released from a biodegradable microplastic severely impact freshwater environments. Environmental Science: Nano, 6(5), pp.1382-1392.

[7]. Piehl, S., Leibner, A., Löder, M.G., Dris, R., Bogner, C. and Laforsch, C., 2018. Identification and quantification of macro- and microplastics on an agricultural farmland. Scientific reports, 8(1), p.17950.

[8]. Corradini, F., Meza, P., Eguiluz, R., Casado, F., Huerta-Lwanga, E. and Geissen, V., 2019. Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal. Science of the total environment, 671, pp.411-420.

[9]. Karbalaei, S., Hanachi, P., Walker, T.R. and Cole, M., 2018. Occurrence, sources, human health impacts and mitigation of microplastic pollution. Environmental science and pollution research, 25, pp.36046-36063.

[10]. Koelmans, B., Pahl, S., Backhaus, T., Bessa, F., van Calster, G., Contzen, N., Cronin, R., Galloway, T., Hart, A., Henderson, L. and Kalcikova, G., 2019. A scientific perspective on microplastics in nature and society. SAPEA.

[11]. Kershaw, P.J., Turra, A. and Galgani, F., 2019. Guidelines for the monitoring and assessment of plastic litter and microplastics in the ocean.

[12]. Ocean Protection Council: Statewide Microplastics Strategy; Senate Bill No. 1263; State of California, 2018; https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1263.

[13]. California Safe Drinking Water Act: Microplastics; Senate Bill No.1422; State of California, 2018; https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1422.

[14]. Pico, Y., Alfarhan, A. and Barcelo, D., 2019. Nano-and microplastic analysis: Focus on their occurrence in freshwater ecosystems and remediation technologies. TrAC Trends in Analytical Chemistry, 113, pp.409-425.

[15]. Wagner, M., Scherer, C., Alvarez-Muñoz, D., Brennholt, N., Bourrain, X., Buchinger, S., Fries, E., Grosbois, C., Klasmeier, J., Marti, T. and Rodriguez-Mozaz, S., 2014. Microplastics in freshwater ecosystems: what we know and what we need to know. Environmental Sciences Europe, 26, pp.1-9.

[16]. Nguyen, B., Claveau-Mallet, D., Hernandez, L.M., Xu, E.G., Farner, J.M. and Tufenkji, N., 2019. Separation and analysis of microplastics and nanoplastics in complex environmental samples. Accounts of chemical research, 52(4), pp.858-866.

[17]. Prata, J.C., Da Costa, J.P., Duarte, A.C. and Rocha-Santos, T., 2019. Methods for sampling and detection of microplastics in water and sediment: A critical review. TrAC Trends in Analytical Chemistry, 110, pp.150-159.

[18]. Hale, R.C., 2017. Analytical challenges associated with the determination of microplastics in the environment. Analytical Methods, 9(9), pp.1326-1327.

[19]. Hale, R.C., Seeley, M.E., La Guardia, M.J., Mai, L. and Zeng, E.Y., 2020. A global perspective on microplastics. Journal of Geophysical Research: Oceans, 125(1), p.e2018JC014719.

[20]. Dehaut, A., Hermabessiere, L. and Duflos, G., 2019. Current frontiers and recommendations for the study of microplastics in seafood. TrAC Trends in Analytical Chemistry, 116, pp.346-359.

[21]. Li, J., Liu, H. and Chen, J.P., 2018. Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. Water research, 137, pp.362-374.

[22]. Silva, A.B., Bastos, A.S., Justino, C.I., da Costa, J.P., Duarte, A.C. and Rocha-Santos, T.A., 2018. Microplastics in the environment: Challenges in analytical chemistry-A review. Analytica chimica acta, 1017, pp.1-19.

[23]. Delgado-Gallardo, J., Sullivan, G.L., Esteban, P., Wang, Z., Arar, O., Li, Z., Watson, T.M. and Sarp, S., 2021. From sampling to analysis: A critical review of techniques used in the detection of micro-and nanoplastics in aquatic environments. ACS ES&T Water, 1(4), pp.748-764.

[24]. Ivleva, N.P., Wiesheu, A.C. and Niessner, R., 2017. Microplastic in aquatic ecosystems. Angewandte Chemie International Edition, 56(7), pp.1720-1739.

[25]. Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W., McGonigle, D. and Russell, A.E., 2004. Lost at sea: where is all the plastic?. Science, 304(5672), pp.838-838.

[26]. Arthur, C.; Baker, J.; Bamford, H. Proceedings of the Second Research Workshop on Microplastic Debris, November 5−6, 2010; NOAA Technical Memorandum NOS-OR&R-39; Marine Debris Division, Office of Response and Restoration, Ocean Service, NOAA, 2011; https://marinedebris.noaa.gov/proceedings-second-researchworkshop-microplastic-marine-debris.

[27]. Hartmann, N.B., Huffer, T., Thompson, R.C., Hassellov, M., Verschoor, A., Daugaard, A.E., Rist, S., Karlsson, T., Brennholt, N., Cole, M. and Herrling, M.P., 2019. Are we speaking the same language? Recommendations for a definition and categorization framework for plastic debris.

[28]. ISO, U., 2020. TR 21960: 2020; Plastics-Environmental Aspects-State of Knowledge and Methodologies. International Organization for Standardization: Geneva, Switzerland.

[29]. Braun, U., Altmann, K., Bannick, C.G., Becker, R., Bitter, H., Bochow, M., Dierkes, G., Enders, K., Eslahian, K.A. and Fischer, D., 2020. Status report: Analysis of microplastics sampling. preparation and detection methods within the scope of the Bmbf research focus plastics in the environment: Sources, sinks, solutions.

[30]. Gigault, J., Ter Halle, A., Baudrimont, M., Pascal, P.Y., Gauffre, F., Phi, T.L., El Hadri, H., Grassl, B. and Reynaud, S., 2018. Current opinion: what is a nanoplastic?. Environmental pollution, 235, pp.1030-1034.

[31]. Europe, P., 2020. Plastics–the facts 2020. PlasticEurope, 1, pp.1-64.

[32]. Koelmans, A.A., Nor, N.H.M., Hermsen, E., Kooi, M., Mintenig, S.M. and De France, J., 2019. Microplastics in freshwaters and drinking water: Critical review and assessment of data quality. Water research, 155, pp.410-422.

[33]. Kung, H.C., Wu, C.H., Cheruiyot, N.K., Mutuku, J.K., Huang, B.W. and Chang-Chien, G.P., 2023. The current status of atmospheric micro/nanoplastics research: characterization, analytical methods, fate, and human health risk. Aerosol and Air Quality Research, 23(1), pp.220362.

[34]. Geyer, R., Jambeck, J.R. and Law, K.L., 2017. Production, use, and fate of all plastics ever made. Science advances, 3(7), p.e1700782.

[35]. Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T. and Thompson, R., 2011. Accumulation of microplastic on shorelines woldwide: sources and sinks. Environmental science & technology, 45(21), pp.9175-9179.

[36]. Karbalaei, S., Hanachi, P., Walker, T.R. and Cole, M., 2018. Occurrence, sources, human health impacts and mitigation of microplastic pollution. Environmental science and pollution research, 25, pp.36046-36063.

[37]. Browne, M.A., Underwood, A.J., Chapman, M.G., Williams, R., Thompson, R.C. and van Franeker, J.A., 2015. Linking effects of anthropogenic debris to ecological impacts. Proceedings of the Royal Society B: Biological Sciences, 282(1807), p.20142929.

[38]. Thushari, G.G.N. and Senevirathna, J.D.M., 2020. Plastic pollution in the marine environment. Heliyon, 6(8).

[39]. Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R. and Law, K.L., 2015. Plastic waste inputs from land into the ocean. science, 347(6223), pp.768-771.

[40]. Vance, M.E., Kuiken, T., Vejerano, E.P., McGinnis, S.P., Hochella Jr, M.F., Rejeski, D. and Hull, M.S., 2015. Nanotechnology in the real world: Redeveloping the nanomaterial consumer products inventory. Beilstein journal of nanotechnology, 6(1), pp.1769-1780.

[41]. Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E. and Svendsen, C., 2017. Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Science of the total environment, 586, pp.127-141.

[42]. Cole, M., Lindeque, P., Halsband, C. and Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: a review. Marine pollution bulletin, 62(12), pp.2588-2597.

[43]. Turner, A., Holmes, L., Thompson, R.C. and Fisher, A.S., 2020. Metals and marine microplastics: Adsorption from the environment versus addition during manufacture, exemplified with lead. Water research, 173, p.115577.

[44]. Kazour, M., Terki, S., Rabhi, K., Jemaa, S., Khalaf, G. and Amara, R., 2019. Sources of microplastics pollution in the marine environment: Importance of wastewater treatment plant and coastal landfill. Marine Pollution Bulletin, 146, pp.608-618.

[45]. Andrady, A.L., 2011. Microplastics in the marine environment. Marine pollution bulletin, 62(8), pp.1596-1605.

[46]. Zettler, E.R., Mincer, T.J. and Amaral-Zettler, L.A., 2013. Life in the "plastisphere": microbial communities on plastic marine debris. Environmental science & technology, 47(13), pp.7137-7146.

[47]. Lucas, N., Bienaime, C., Belloy, C., Queneudec, M., Silvestre, F. and Nava-Saucedo, J.E., 2008. Polymer biodegradation: Mechanisms and estimation techniques–A review. Chemosphere, 73(4), pp.429-442.

[48]. Yee, M.S.L., Hii, L.W., Looi, C.K., Lim, W.M., Wong, S.F., Kok, Y.Y., Tan, B.K., Wong, C.Y. and Leong, C.O., 2021. Impact of microplastics and nanoplastics on human health. Nanomaterials, 11(2), pp.496.

[49]. Lambert, S. and Wagner, M., 2016. Characterisation of nanoplastics during the degradation of polystyrene. Chemosphere, 145, pp.265-268.

[50]. Yuan, J., Ma, J., Sun, Y., Zhou, T., Zhao, Y. and Yu, F., 2020. Microbial degradation and other environmental aspects of microplastics/plastics. Science of the Total Environment, 715, p.136968.

[51]. Andrady, A.L., 2015. Persistence of plastic litter in the oceans. Marine anthropogenic litter, pp.57-72.

[52]. Corcoran, P.L., Biesinger, M.C. and Grifi, M., 2009. Plastics and beaches: a degrading relationship. Marine pollution bulletin, 58(1), pp.80-84.

[53]. Kolandhasamy, P., Su, L., Li, J., Qu, X., Jabeen, K. and Shi, H., 2018. Adherence of microplastics to soft tissue of mussels: a novel way to uptake microplastics beyond ingestion. Science of the total environment, 610, pp.635-640.

[54]. Wang, Y.L., Lee, Y.H., Chiu, I.J., Lin, Y.F. and Chiu, H.W., 2020. Potent impact of plastic nanomaterials and micromaterials on the food chain and human health. International journal of molecular sciences, 21(5), p.1727.

[55]. Santillo, D., Miller, K. and Johnston, P., 2017. Microplastics as contaminants in commercially important seafood species. Integrated environmental assessment and management, 13(3), pp.516-521.

[56]. Karami, A., Golieskardi, A., Keong Choo, C., Larat, V., Galloway, T.S. and Salamatinia, B., 2017. The presence of microplastics in commercial salts from different countries. Scientific reports, 7(1), p.46173.

[57]. Mason, S.A., Welch, V.G. and Neratko, J., 2018. Synthetic polymer contamination in bottled water. Frontiers in chemistry, 6, p.389699.

[58]. Li, J., Yang, D., Li, L., Jabeen, K. and Shi, H., 2015. Microplastics in commercial bivalves from China. Environmental pollution, 207, pp.190-195.

[59]. Neves, D., Sobral, P., Ferreira, J.L. and Pereira, T., 2015. Ingestion of microplastics by commercial fish off the Portuguese coast. Marine pollution bulletin, 101(1), pp.119-126.

[60]. Devriese, L.I., Van der Meulen, M.D., Maes, T., Bekaert, K., Paul-Pont, I., Frère, L., Robbens, J. and Vethaak, A.D., 2015. Microplastic contamination in brown shrimp (Crangon crangon, Linnaeus 1758) from coastal waters of the Southern North Sea and Channel area. Marine pollution bulletin, 98(1-2), pp.179-187.

[61]. Yang, D., Shi, H., Li, L., Li, J., Jabeen, K. and Kolandhasamy, P., 2015. Microplastic pollution in table salts from China. Environmental science & technology, 49(22), pp.13622-13627.

[62]. Liebezeit, G. and Liebezeit, E., 2013. Non-pollen particulates in honey and sugar. Food Additives & Contaminants: Part A, 30(12), pp.2136-2140.

[63]. Liebezeit, G. and Liebezeit, E., 2014. Synthetic particles as contaminants in German beers. Food Additives & Contaminants: Part A, 31(9), pp.1574-1578.

[64]. Kosuth, M., Mason, S.A. and Wattenberg, E.V., 2018. Anthropogenic contamination of tap water, beer, and sea salt. PloS one, 13(4), p.e0194970.

[65]. Vitali, C., Peters, R.J., Janssen, H.G. and Nielen, M.W., 2023. Microplastics and nanoplastics in food, water, and beverages; part I. Occurrence. TrAC Trends in Analytical Chemistry, 159, pp.116670.

[66]. EFSA Panel on Contaminants in the Food Chain (CONTAM), 2016. Presence of microplastics and nanoplastics in food, with particular focus on seafood. Efsa Journal, 14(6), p.e04501.

[67]. Cox, K.D., Covernton, G.A., Davies, H.L., Dower, J.F., Juanes, F. and Dudas, S.E., 2019. Human consumption of microplastics. Environmental science & technology, 53(12), pp.7068-7074.

[68]. Bergmann, M., Gutow, L. and Klages, M., 2015. Marine anthropogenic litter (p. 447). Springer Nature.

[69]. Cózar, A., Echevarría, F., González-Gordillo, J.I., Irigoien, X., Úbeda, B., Hernández-León, S., Palma, Á.T., Navarro, S., García-de-Lomas, J., Ruiz, A. and Fernández-de-Puelles, M.L., 2014. Plastic debris in the open ocean. Proceedings of the National Academy of Sciences, 111(28), pp.10239-10244.

[70]. Verma, R., Vinoda, K.S., Papireddy, M. and Gowda, A.N.S., 2016. Toxic pollutants from plastic waste-a review. Procedia Environmental Sciences, 35, pp.701-708.