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A REVIEW ON MICROPLASTIC IN THE SOILS AND THEIR IMPACT ON SOIL MICROBES, CROPS AND HUMANS

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ABSTRACT

For modern human life, since the beginning of the 21st century, plastic become indispensable. The golden period for the plastic industry was the second half of the 20th century when plastic-based products bucket to the car were manufactured. Due to mismanagement, and indiscriminate use microplastics are emerging as persistent terrestrial pollutants. In the last decade, environmental scientists and other stakeholders have paid serious attention to soil pollution by microplastics. In soils, the microplastic particles act as a vector for the toxic persistent organic pollutants and potentially toxic metals which are easily sorbed by plants and enter the food chain.

Microplastic pollutants not only influence the soil's physicochemical properties but also impact the feeding habits of soil biota. Microplastic in soils is due to sewage sludge, bio waste compost amendments, plastic mulching, wastewater irrigation, leachate from landfills and atmospheric deposition. The quantity of microplastic particles in the soils varied from nil to13000 items per kg of soil. The quantity of microplastic in the soil is 5-23 times that in the ocean. The microplastic in soil retards seed germination and plant growth. Enzymatic activities of the soil are also influenced by microplastic. Plastic Pellets, Personal Care Products and Cosmetics, Synthetic Textiles, the Abrasion of Tyres, City Dust, and the Abrasion of Road Markings etc. are the environmental sources of microplastic. Intake by humans via food causes respiratory toxicity, cytotoxicity, immunotoxicity and reproductive toxicity among other effects. The present work reports the sources and distribution of microplastic in the soil environment and their impact on soil biota, plants, and human health.

Keywords: Microplastic, Soil, Sewage Sludge, Bio-Compost, Soil Biota, Plants, Human Health

1. INTRODUCTION

Plastic long-chain synthetic polymers are versatile materials and are composed of Carbon, hydrogen, oxygen, and chlorine. Due to their high durability, lightweight, cost-efficient, convenience, hygiene, and ease of processing after the Second World War (the1950s) the demand and production of plastic are continuously increasing and the limited natural products such as ivory, wood, stone, tusk, horn, bone etc have been replaced by these polymers. In modern times it is not possible for a person living on earth to avoid plastic as it not only fulfils basic needs such as clothes, cosmetics, shampoos and toys, these compounds have wide applications in the medical field, in rockets and aircraft, electronics. Plastics are also used in grocery bags, forks to wrappers of candy. Since 2020 due to Covid-19 disease the use of plastic in personal protective equipment (PPE kits, gloves, and masks) has increased vastly. In the year 2021golbally, approximately 416 metric tonnes of plastic and more than 100 million metric tons of textile fibres were produced, out of 100 million metric tons of textile fibres, 60% were plastic fibres, 27% natural fibres and 6% cellulose fibres and is expected to become double by 2034. As per estimation the global market for plastic will be 643.37 billion USD by 2029 from 439.28 USD in 2021. Globally more than one million plastic bottles are produced per minute and only 22% are recycled. Recycling of the plastic waste globally is only 9%, while global mismanagement of the plastic waste is 22%. The Ministry of Environment, Forest and Climate Change has reported that in India 25,000 tons of plastic are used every day and only 28-30% is recycled.

The studies have shown that globally all the water bodies' i.e., surface water of the entire ocean McEachern et al. (2019), the deep sea Chiba et al. (2018), estuaries Gray et al. (2018), storm water runoff, freshwater bodies, and wastewater Kole et al. (2017) besides deep-sea sand, coastal sediments are contaminated by the microplastic passing through the terrestrial environment. Soil acts as a sink for microplastics. Several researchers Yu et al. (2022), Horton et al. (2017), De Souza et al. (2018) have reported that soil pollution by microplastics is more than the pollution of the water bodies by the microplastics, the contamination of soils by microplastics is 4-23 times than the ocean contamination Nizzetto et al. (2016). UN Environmental Programme (UNEP) 2014 has listed soil pollution by microplastics among the top ten environmental problems. World Health Organisation (WHO) during the meeting of Scientists on March 2-3, 2020, discuss the impact of these pollutants on humans and other organisms and laid down the guidelines for the appropriate application of plastic in the agriculture sector so that the adverse effects of plastic in the agricultural sector can be minimized.

German Scientist Rillig (2012) was the first researcher who reported that microplastic in the soil environment impacts the physicochemical properties of the soil, soil functions such as soil bulk density, soil biophysical environment, microbial activities in the soil and plant growth and maturity. Li et al. (2022), Moller et al. (2020) during their studies found that urban and agricultural soils are more vulnerable to microplastic pollution as these soils are more exposed to artificial activities. Soil scientists De Souza et al. (2018), De Souza et al. (2019), Hodson et al. (2017) during their studies found that the microplastic particle in soils adsorbs the persistent organic pollutants (polycyclic aromatic hydrocarbons), potentially toxic metals and endocrine-disrupting chemicals which not only deteriorate the soil health but passes to the food chain. Microplastic in the soil also decreases the soil microbial diversity Kong et al. (2018).

This review summarizes the type and concentration of the microplastic in the soils, sludge and food material and their health impact on humans.

2. CLASSIFICATION OF MICROPLASTIC

Microplastics present in the natural environment can be categorized into two:

1) Primary Microplastics

These are those which are originally manufactured in micro-sized particles and are released directly into the environment from domestic and industrial effluents, sewage discharge, spills etc. A few common examples are microbeads in cosmetics, airborne microplastic from textile industries and other industrial abrasives, pellets, film, and fragments Galloway et al. (2017).

2) Secondary Microplastics

A major part of the microplastic present on the earth is of this type. This type of microplastics is generated due to the gradual degradation and /or fragmentation of larger plastic particles such as discarded tires, clothing, disposables, and electronic items Townsend et al. (2019) present in the environment by the environmental weathering (such as photo-oxidation, thermal degradation, biodegradation, thermo-oxidation, mechanical transformation, hydrolysis, wind, wave action and abrasion) Auta et al. (2017), Sharma and Chatterjee (2017). The wastewater from washing machines which contain synthetic fibres is another source of secondary microplastic.

3. MAJOR SOURCES OF ENVIRONMENTAL MICROPLASTICS

Environmental contamination of the microplastic is due to anthropogenic activities i.e., domestic, industrial, coastal, and agricultural activities.

The Major Sources Are:

1) Plastic Pellets

Plastic pellets, the primary microplastic are of 2.5 mm diameter or in powder form and are transported to different industries to form plastic products. During transport, manufacturing, processing, and recycling these pellets are spilt in the environment. Several scientific studies have reported the presence of plastic pellets in the environment Essel et al. (2015).

2) Personal Care Products (PCCP) and cosmetics

About 80% of the personal care products and cosmetics such as face wash, facial scrubbers, shower gel, toothpaste, shaving cream, nail polish, sunscreen, deodorant, mascara, hair colour and make-up foundation contain one or more types of microbeads as ingredients Auta et al. (2017). The concentration of these microbeads in a few PCCP and cosmetics ranged up to 10% of the product weight. Studies have shown that 50% of marketed facial washes and 67% of facial scrubs contain microbeads. It is reported that in the European environment 7 kg of microplastic per minute enters due to PCCP and cosmetics. Microplastic due to PCCP and Cosmetics is reported in the wastewater streams from households, hotels, hospitals, and sports facilities including beaches Leal Filho et al. (2022), Habib et al. (2020), Bansal (2020), Boucher and Friot (2017).

3) Abrasion of Tyres

The mechanical abrasion of tyres (Poly Styrene-butadiene rubber, polyisoprene and other additives form the outer layer of tyres) produces tyre wear particles and/or tyre and road wear particles. Khan et al. (2019) have reported that the approximate annual production of tyres is 2.7 billion pieces. Approximately 6 million tonnes of tyre-wear particles are generated globally Khan et al. (2019), out of which approximately 1.3 million tonnes are produced by European countries Bänsch-Baltruschat et al. (2020). The tyre wear particles contribute 30-50% of total microplastic pollution. The tyre-wear particles are reported by researchers in water bodies, soil, and ocean Xia (2019).

4) Synthetic Textiles

In the year 2020 synthetic fibre production globally was 68 million tonnes (approximately 62% of all the fibres) and is expected to grow by 7.4% annually for the period 2021-2025. It is reported that the contribution of synthetic fibre to environmental microplastic pollution is approximately 35%. Entry of the synthetic textiles a primary microplastic in the environment is due to abrasion and shedding of fibres (polyester, acrylic, polyethene or elastane) during household and industrial washing of synthetic textiles. 124-308 mg of microfiber per kg of washed fabric corresponding to 640,000 to 1,500,000 microfibres per kg of fabric enters the environment De Falco et al. (2019). Several researchers Hamid et al. (2018), Boucher et al. (2016), Magnusson et al. (2016) have reported the presence of fibres in each compartment of the environment.

5) Abrasion of Road Markings

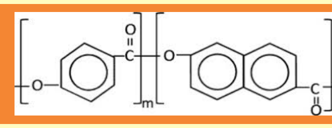
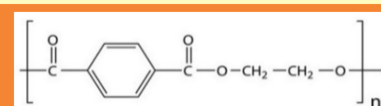
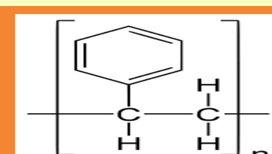
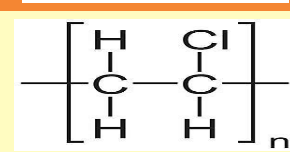
Road markings, the basic road safety measures are required for both human drivers and automated vehicles. Paints, glass beads, thermoplastic, polymer tape and epoxy resins (the primary microplastic) are used for the road marking system. Abrasion of these materials due to road vehicles and weathering is 5-10%. Burghardt et al. (2020) have reported that road Markings contribute 2.3-7% of total environmental microplastic pollution. Soil and water bodies are contaminated by these particles via rain and wind.

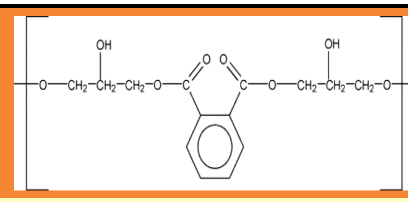
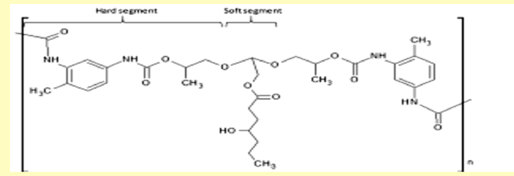
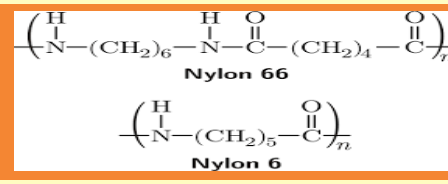
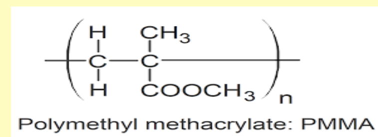
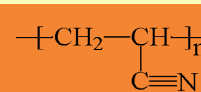
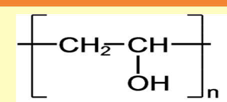
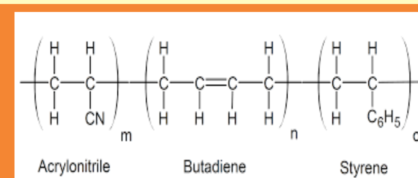
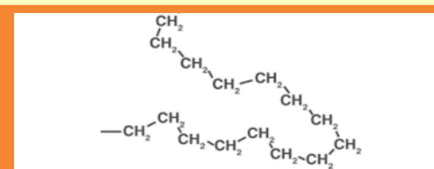
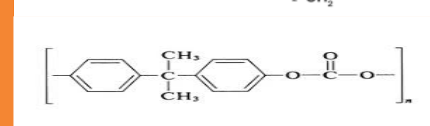
6) City Dust

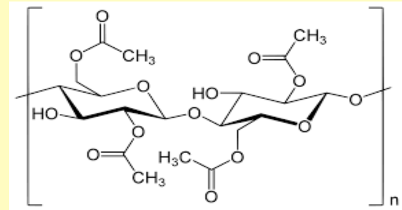
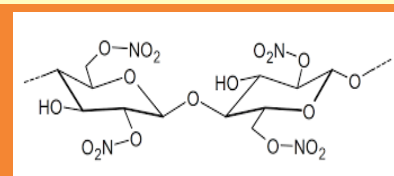
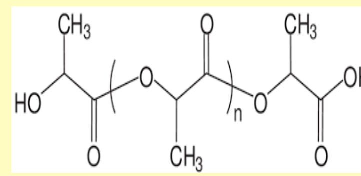
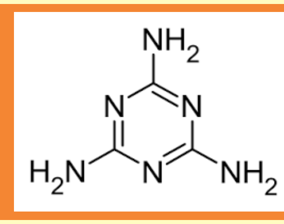
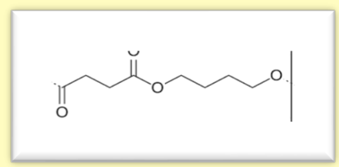
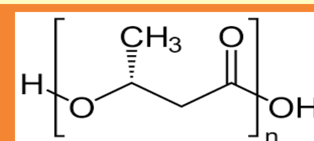
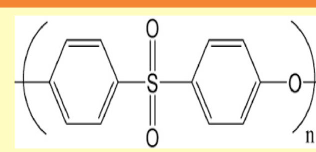
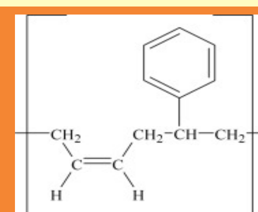
Dust produced in the cities due to abrasion of infrastructure (household dust, building coating, and artificial turf), footwear's synthetic soles, synthetic cooking utensils and detergents contain 4% microplastics Magnusson et al. (2016). These microplastics settle in the soil, water bodies and ocean. Table 1

Table 1

Table 1 Most commonly used plastic polymers their applications and chemical structures are as

Polymer	Nature and applications	Chemical Structure
Polyester	Density is 1.24-2.3 so sinks in water and is non-biodegradable. These are used in textiles, fibres, recording tape etc.	
Polyethene (PE)	Density is 0.91-0.97 so floats on water and is non-biodegradable, are used in packing, in bags, wire insulation, and squeeze bottles	---[CH_2-CH_2] n---- (where n may be 1000 to 20,000)
Polyetheneterephthalate (PET)	Density is 1.37-1.45 so sinks in water and cannot be biodegraded. Packing materials, Bottles for soft drinks and other beverages are composed of polyethene terephthalate	
Polypropylene (PP)	The polypropylene floats on water (as density is 0.91) and is non-biodegradable. These are used in Packing materials, Fibres, indoor-outdoor carpets, bottles, Heavy-duty microwavable containers	---[CH(CH_3)-CH_2] n----
Polystyrene (PS)	Polystyrenes are non-biodegradable with a density of 1.01-1.04 (sinks in water). These are used in Packing, Styrofoam, moulded objects such as tableware (forks, knives, and spoons), trays, video cassette cases, Beverage/foam cups, toys and window in envelopes.	
Polyvinyl chloride (PVC)	PVC is used in Building and construction, Clear food wrap, bottles, floor covering, synthetic leather, water, and drainpipe. These are non-biodegradable with a density ranging from 1.16-1.584 i.e., heavier than water and cannot be easily biodegraded.	

Alkyd	Alkyld which has applications in Paints, fibres are non-biodegradable having a density of 1.67-2.1 and sinks in water. The rate of biodegradation is very slow.	
Polyurethane (PUR)	The density of polyurethane ranges from 0.03-0.1 so these substances float on water. These are used in Building and construction, Foams, rigid and flexible fibres. These compounds can be biodegraded with the help of naturally occurring microorganisms.	
Nylon (Polyamide) (PA)	Nylon which is used in the Automobile industry, Textiles Fibres and moulded objects have a density of 1.02-1.05 so does not float on water. These compounds can be biodegraded.	
Polymethyl methacrylate (PMMA)	PMMA are heavier than water with a density of 1.17-1.20 and are mainly used in Electronics, Glass replacement, paints, and household products. These are non-biodegradable and can be recycled.	
Polyacrylonitrile (PAN)	PANs have applications in Textiles Fibres and are used in knit shirts, sweaters, blankets, and carpets. The density of PANs ranges from 1.09-1.20 so these compounds sink in water. Polyacrylonitriles cannot be biodegraded.	
Polyvinyl alcohol (PVA)	Polyvinyl alcohols which have applications in textiles possess a density of 1.19-1.31 so sink in water. Polyvinyl alcohol can be biodegraded with the help of fungi, Gram-negative and Gram-positive bacteria.	
Poly Acrylonitrile-butadiene-styrene (PABS)	Acrylonitrile-butadiene-styrene has applications in the electronics industry. The density of acrylonitrile-butadiene-styrene ranges from 1.06-1.08. Due to their stronger physical structure, these compounds cannot be biodegraded.	
High-density polyethene (HDPE)	High-density polyethenes are non-biodegradable their density ranges from 0.96-0.97 so float on water. These are used in Containers for milk and other beverages, squeeze bottles	
Polycarbonate (PC)	Polycarbonates are used in electronic components, Construction materials, Automotive, aircraft, railway, and security components, Data storage. The density of polycarbonate varies from 1.20-1.22. Due to the presence of phenyl group on either side of the carbonate bond enzymes cannot biodegrade the polycarbonates.	

Cellulose acetate	Cellulose acetate is an eco-friendly material with a density of 1.28 and can be very easily biodegraded. Cellulose acetate is used for Cigarette filters and fabric fibres.	
Cellulose nitrate	Cellulose nitrate is used in printing inks, nail polish and foils and has a density of 1.35. The biodegradation of the cellulose nitrate occurs very slowly.	 Nitro Cellulose (NC)
Polylactic acid (PLA)	Polylactic acid has a density of 1.38 and is eco-friendly as can be very easily biodegraded. It is used in Packaging, cups	Density is 1.38 so sink in water 
Melamine	Melamine has a density of 1.57 and cannot be biodegraded or recycled. Melamine is used for Flooring, dinnerware, dry boards	
Polybutylene succinate (PBS)	Polybutylene succinate is a very easily biodegraded material with a density of 1.26. It is processed into films, bags, and boxes, for food and cosmetic packaging. PBS is also used in the biomedical industry for prosthetic materials, contact lenses, wound dressings, dental materials, implants, and medical disposables.	
Polyhydroxyalkanoates	Polyhydroxyalkanoates are eco-friendly materials which can be very easily biodegraded. The density is 1.25. These compounds are used for packaging, latex, Bio-implant material, heat-sensitive adhesives, as a therapeutic carrier	
Polyethyl Sulphones (PES)	PESs are high performance thermoplastic and are resistant to acids, alkalis, oils, greese and aliphatic hydrocarbons with a density 1.31-1.34. These compounds have a good optical clarity, insulation properties, moderate rigidity even at a high temperature and used in the medical appliances.	
Styrene-butadiene rubber (SBR)	SBR is the synthetic rubber containing 75% butadiene and 25% styrene. The SBRs are high crack and abrasion resistant. The density of SBR is 0.98. It is used in the manufacturing of conveyor belts, shoe soles and heels, adhesives, roll coverings car tires, drive couplings and haul-off pads etc.	
Polyvinyl acetate (PVA)	The PVA is also called as wood glue with a density of 1.19. The PVA is used as adhesive for wood, wallpaper, envelopes, cigarette packing. The PVA is the gum base of the Chewing gum.	$[-CH_2-CHOOCCH_3-]_n$

4. ROUTES OF EXPOSURE TO MICROPLASTIC

Most commonly used synthetic plastics are polythene (low and high density), polystyrene, polyvinyl chloride, polypropylene, polyethene terephthalate

4.1. TO SOIL

The microplastic in the soil ecosystem is due to:

1) Agricultural Films/mulching

Agricultural mulching technology in recent years has been widely used for cultivation as it provides better fruit quality, greater yield and provides improved water utilization. Polyvinyl chloride, polypropylene, polyethene and ethylene-vinyl acetate copolymer are widely used plastics for mulching. About 4.5 million tonnes of plastic has been used in 2019 for mulching and is expected to become 5.6 million tonnes by 2030 Huang et al. (2020). Globally this technology is used in approximately 20 million hectares of agricultural land. Removing all the mulching films from the agricultural lands after harvesting is not practically feasible so a part of the film is left in the field. Due to the low rate of recycling a large amount of plastic mulch debris remain on the surface of the agriculture field which became fragile after some time due to photo degradation by UV light and when fields are ploughed these films are fragmented and buried in the soil. Ren et al. (2021) during their research studies have found that the contribution of mulching to soil microplastic is 10-30%.

2) Sewage sludge

Sewage sludge which is rich in organic matter and essential nutrients are applied as fertilizer to agricultural fields for the improvement of soil productivity and agricultural growth for the last 50 years. It is estimated that approximately 50% of sewage sludge produced is applied to agricultural fields. The sewage sludge obtained either from domestic wastewater (microbeads derived from PCCP and cosmetics, polymer fibres from the washing of clothes) or from industrial waste; or due to abrasion of tyres, contains the microplastic. When sewage sludge is applied to the soil these pollutants are accumulated in soils. Van den et al. (2020) have reported that sewage sludge contains 280-430 items per kg.

3) Irrigation water

In developed countries, most of the agricultural lands are irrigated by the water obtained from rivers, lakes, groundwater, and reservoirs, while in some developing countries due to scarcity of water sewage water is also used for irrigation of soils. A survey of the literature Choi et al. (2021), Jian et al. (2020), Qi et al. (2020) reveals that all these water resources contain high levels of microplastics. These concealed microplastic particles are transferred to soils via irrigation.

4) Compost

Compost an eco-friendly soil nutrient prepared from organic wastes and biological waste has been used since the early days of agricultural activities globally. Due to improper disposal, the organic compost prepared from biological wastes contains microplastic Bläsing and Amelung (2018). As organic compost is world widely used as an organic fertilizer microplastics are transported into the soil from the compost

5) **Atmospheric Deposition**

Deposition from the atmosphere is the source of the entry of microplastics into the agricultural soils. Dris et al. (2016) during their research work reported that 29280 pc/m2 of microplastic particles are deposited in the atmosphere of Paris city daily. A review of the literature denotes that atmospheric deposition is one of the major sources of microplastic deposition in agricultural soil.

4.2. TO HUMANS AND OTHER ORGANISMS

The exposure of microplastic to humans and other organisms is via:

1) **Ingestion:** means uptake by mouth i.e., intake via the gastrointestinal route. Drinking water, beverages, beer, eating food, honey, vegetables, fruits, and seafood including fish and salts are some sources from which ingestion of microplastics occurs.
2) **Dermal:** Absorption via skin/gills is termed dermal uptake. Human skin absorbs these pollutants by using facial soaps and body scrubbers and during bathing and washing with contaminated water Hernandez et al. (2017). The aquatic animals' including fish bio accumulates these microplastic or Nano plastic via gills.
3) **Inhalation:** The city dust, air and dust fumes at the workplace contain fibres/particles of microplastic and Nano plastic which are inhaled by the human via respiration.

5. MICROPLASTIC IN THE SOIL ENVIRONMENT

During the 1970s microplastics were considered an aquatic environment and marine pollutant and research was made to study the impact of these pollutants on aquatic organisms, and the impact of these pollutants on the terrestrial ecosystem started in the last decade with the work Rillig (2012).

Environmental scientists have found that the environmental pollutant microplastics cycles from one ecosystem to another Rodrigues et al. (2018), Sun et al. (2022) and soil not only acts as a natural sink of microplastic but also acts as a carrier of microplastic to groundwater and ocean Qi et al. (2020). The microplastic which enters the soil became permanent in the environment as the soil can sorbs them, can accumulate them or transport them through the soil matrix Xu et al. (2020a).

A review of the literature Ziajahromi et al. (2017), Huerta-Lwangaet al. (2022), Piehl et al. (2018), Van Schothorst et al. (2021) reveals that microplastic in soils is due to direct and indirect sources. The direct sources are agricultural mulching films, greenhouses (which are made from plastic films and/or plastic-based non-woven fabrics), shade nets, polytunnels and wind barriers and the indirect sources are sewage sludge, compost, and irrigation by contaminated water. The concentration of microplastic in agricultural soils ranges from 0 to 165000 pieces per kg of soil. The maximum concentration of the microplastic is reported in the agricultural soil of Pakistan and is 675 mg/kg Sajjad et al. (2022). The review of the literature also denotes that the soils which are continuously amended with sewage sludge or irrigated with sewage water have more amounts of microplastic pieces per kg of soil.

The belowground transport of microplastic in soils occurs via bioturbation by plant roots and soil fauna; ploughing, tillage, burrowing, crop harvesting (agricultural practices), water infiltration and/or soil cracks Luo et al. (2018), Rillig et al. (2019), Zhang et al. (2018a). The microplastic in the soil is also dispersed and redistributed by soil biotas such as mites, larvae of mosquitoes and collembolan by their feeding activities and burrowing Al-Jaibachi et al. (2019)

Based on the report of Horton et al. (2017) and others that the concentration of microplastic in the terrestrial environment is many folds than in the ocean the United Nations Environment Programme (UNEP) in its meeting dated June 5, 2018, called for more research studies on the effects of microplastic pollution on the soil environment.

Figure 1

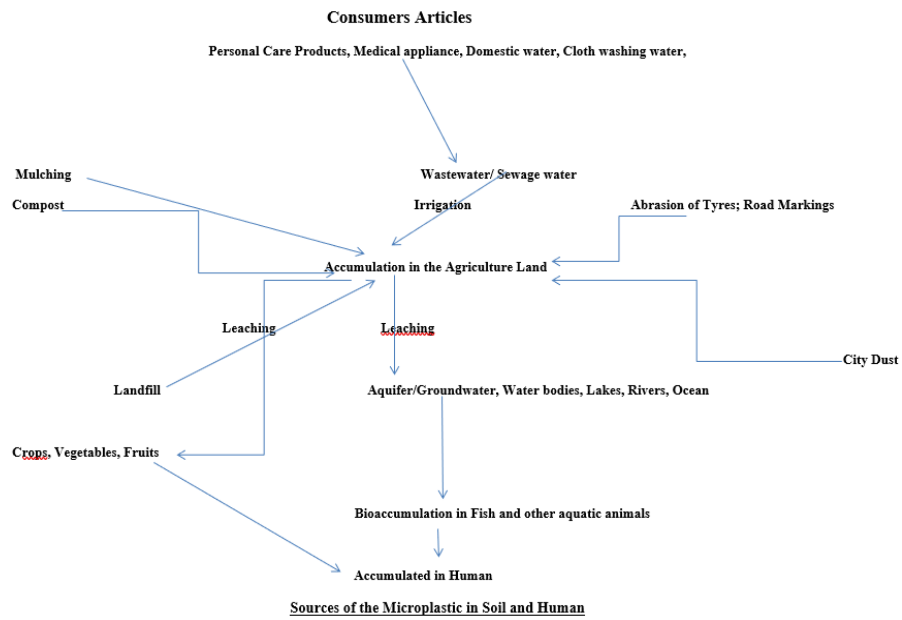


Figure 1 Consumers Articles

The concentration of the microplastic in soils, sewage sludge and some food products are documented in Table 2.

Table 2

Table 2 Microplastics in Soils, Sewage Sludge and Food Material

Source	Country	Quantity per kg of soil	Composition	Reference
Soils				
Paddy soil	China	10.3	PE, PP	Lv et al. (2019)
Vegetable fields	China	62.5-78.0	PE, PP, PES	Liu et al. (2018)
Agricultural field	China	40-320	PE, PP	Zhang et al. (2018b)
Farmland Soils	Germany	0.0-1.3	PE, PP, PS	Piehl et al. (2018)
Agricultural Soils	Chile	60-10400	PE, PP, PES, PS	Corradini et al. (2019)
Industrial Soils	Australia	300-67500 mg/kg	PVC, PE, PS	Fuller and Gautam (2016)

Agricultural Soil	Denmark	0-165000 53000-528000	PP, PE, Nylon, PS	Vollertsen and Hansen (2017)
Agricultural Soil	China	7100-42960	Fibres, films etc	Zhang and Liu (2018)
Home Garden Soil	Mexico	1900-2770	PE, PS	Huerta et al. (2017)
Floodplain soil	Switzerland	0-593	PP, PE, PES	Scheurer and Bigalke (2018)
Coastal Soil	Hebei China	634	Foams, flakes,fibres	Zhou et al. (2016)
Coastal Soil	Shandong China	13-14713	PE, PP, PS	Zhou et al. (2018)
Agricultural Soil	Netherland	664	PE, PP, SBR	Choi et al. (2021)
Roadside soil		1104	PE, PVC, PET	
Cropland soil	Chile	0-306	PE, PP, PES, PS	Corradini et al. (2021)
Agricultural Soils	China	143-3410	PE, PP, PS. fibre	Ding et al. (2020)
Soil of Tibetan Plateau	Tibet	2-43	PE, PP	Feng et al. (2020)
Agricultural Soils	Germany	0-218	PE, PP, PVC	Harms et al. (2021)
Agricultural Soils	China	1-324 80.3-1075.6	PP, PE, Nylon, PS	Huang et al. (2020)
Agricultural Soil	Korea	10-7630	PE, PP, PS, PET	Kim et al. (2021)
Agricultural soil	China	40.35 mg/kg	PE, PP, PS	Li et al. (2020)
Agricultural Soil	Argentina	125 mg /kg	PE, PP, PS. fibre	Rodriguez-Seijo et al. (2017)
Agricultural Soil	Pakistan	675 mg/kg	PE, PP, PES, PS, PVC	Sajjad et al. (2022)
Agricultural Soil	Canada	4-541	PS, PE, PP, PUR, Polyester,	Crossman et al. (2020)
Roadside Soil	Germany	915	PE, PP, PS	Dierkes et al. (2019)
Agricultural Soil	Sweden	0.3-3.4 mg/kg	PS, PE, PP, PUR, Polyester	Ljung et al. (2018)
Agricultural Soil	Spain	8652	PE, PP, PS, Film, Fibre	Van den Berg et al. (2020)
Agricultural Soil	China	0-2760	PE, PP, PES, PS	Zhou et al. (2020)
Semi-arid Soils	Iran	1.2-2.5 mg/kg	PE, PP, polyester, PS	Rezaei et al. (2019)
Agricultural Soil	China	900-2200	PE, LDPE, PP, PS	Meng et al. (2020)
Agricultural	Spain	1994	PE, PP, PS, PVC	Beriot et al.

Soil				(2021)
Agricultural soil	Netherlands	888	PE, PP	Van Schothorst et al. (2020)
	Spain	2242	PE, PP, PS, PVC	
Agricultural soil	China	310-5698	PP, PE, Ethylene-propylene copolymer	Yu et al. (2020)
Vegetable Farmland	Wuhan China	320-12560	PE, PP, PES, PET	Chen et al. (2020)
Greenhouse soil	China	1000-3786	PE, PP, PS, Phthalate derivatives	Li et al. (2021a)
Agricultural Land	Wuxi China	420-1290	PE, PP, PS, PET	Li et al. (2019a)
Woodland	Wuhan	410000	PE, PP, PS, PET, fibres	Zhou et al. (2019)
Vegetable Land	China	160000	PE, PP, PS, PET	
Vacant Land		120000	PE, PP, PS, PET, fibres, films	
Agricultural soils	Lahore	2200-6875	PE, PP, PS, PET,	Rafique et al. (2020)
Parks soils		4125-9340	PE, PP, PVC, Nylon	
Industrial areas soil		4580-9890	PE, PP, PS, LDPE, PET, Fibres, PVC	
Antarctica Soil	Antarctica	4-37 / 50 mL	PET, fibres	Perfetti-Bolaño et al. (2022)
Antarctica Snow	Ross Island Antarctica	29/ L	PET	Aves et al. (2022)
Sewage Sludge				
Sewage Sludge	Mexico	18000-41000	PE, PP, PES, PS	Corradini et al. (2019)
Sludge	Canada	541	PS, PE, PP, PUR, Polyester,	Crossman et al. (2020)
Sewage sludge	Spain	5190	PE, PP, PS, Film, Fibre	Van den Berg et al. (2020)
Sludge	USA	37.6-545.9	PE, PP, PES, PS	Zhang et al. (2020)
Anaerobic digested Sludge	Ireland	4196-15385	PE, PS, PET	Mahon et al. (2017)
Wastewater Sludge		5000	PE, PP, PES, PS	Carr et al. (2016)
Mixed Sewage Sludge	Argentina	274000	Filaments, Fibres, Pellets	Reis (2019)
Sewage Sludge	Canada	4400-14900	PP, PE, Fibres	Gies et al. (2018)
Sludge	China	1600-56400	Polyolefins, PA, Acrylic fibres	Li et al. (2018a)
Mixed Sewage Sludge	UK	2000	PE, PP, PA, Fibre	Murphy et al. (2016)
Sewage Sludge	Spain	314000	PUR, PE, PET,	Edoet al.

			Polyester	(2019)
Sewage Sludge	Spain	50070	PS, PUR, PMMA	Van den Berg et al. (2020)
Sewage Sludge	Norway	1700-19837	PET, PE, Microbeads	Lusher et al. (2017)
Anaerobic digested Sludge	China	4010	SBR, PVC, PUR, PE, PABS, PBMA	Xu et al. (2020b)
Sewage Sludge from secondary tanks	Italy	113000	PMMA, Polyester, Polyamide, PE, PP, PUR	Magni et al. (2019)
Sewage Sludge	Germany	1000-24000	PE, PP, PA, PVC, PS	Mintenig et al. (2017)
Anaerobic digested Sludge	Finland	8.2-301.4	PUR, PET, PVA, PE, Polyester, PET	Lares et al. (2018)
Sludge	USA	0-12 g/kg	PET, PC	Zhang et al. (2019)
Sewage Sludge	France	14930-17330	PS, PET, PE, PP, PVC	Kazour et al. (2019)
Sludge	China	1565-271700	PE, PA, PP, PVC, PAN,	Liu et al. (2018), Li et al. (2019a)
Sludge	Poland	6700-62600	PE, PS, PP, PVC	Wisniowska et al. (2018)
		Composts		
Composts from green	Netherlands	1253	PE, PP	Van Schothorst et al. (2022)
waste	Spain	2800	PE, PP, PS, PVC	
Composts of rural domestic waste	China	2400	PP, PE, PES, PVPC, PS, PUR	Gui et al. (2021)
Composts from Bio waste	Germany	70-146	PE, PES, PS, PP, PA, PUR, PET, PVC, Cellulose based polymer,	Weithmann et al (2018)
Composts from pig manure	China	43.8	PE, PS, PET	Yang et al. (2021)
Composts from sheep faeces	Spain	0-5000	PE, PP, PS, microbeads	Beriot et al. (2021)
Composts from green waste	Lithuania	5733-6433	PP, PE, PAN, PES	Sholokhova et al. (2022)
Composts from green waste	Germany	12-46	PP, PE, PAN,	Braun et al. (2020)
Composts from Bio waste	Netherland	82800	PLA	Huerta-Lwanga et al. (2021)
Composts from food waste	Lithuania	3783-4066	PS, PE, PET, PP	Sholokhova et al. (2022)
		Food Products		
Fish of Urbanised estuary	Australia	0.2-4.6 items/fish	PET, PP, PES, PAN, Nylon, PVC	Halastead et al. (2017)

Marine fish	Australia	1.58 item/fish	PE, PP, PS,	Wootton et al. (2021)
Marine fish	Fiji	0.86 items/fish	Polyolefins, Synthetic rubber	
Marine Fish	North-East Atlantic Ocean	1.3 items/fish;54 items/kg of fish	PP, PET, fibres, Nylon	Barboza et al. (2020)
River fish	Michigan, USA	19 items/fish	PE, PAN, PVA, Polyacetate	McNeish et al. (2018)
Marine Fish	Adriatic Sea	4.11items/fish;	PP, PET, PE Nylon	Mistri et al. (2022)
Marine Fish	Malaysia sea	5-6.5 items/fish	PE, PET, fibres, Nylon	Foo et al. (2022)
River Fish	Bangladesh	1.85-3.5 items/fish	Fibber, film, foam	Khan and Setu (2022)
Marine fish	Southeastern Black Sea	0.81-2.06 items/fish	PP, fibre	Aytan et al. (2022)
Marine fish	Turkish Coast	1.1-1.9 items/fish	PP, fibre	Gundogdu et al. (2020)
Marine fish	Yellow sea	0.41-1.2 items/fish	PET, PE	Sun et al. (2019)
Marine fish	South Africa	3.72 items/fish	PET, PP, PE	Sparks and Immelman (2020)
Fish from Mondega Estuary	Portugal	1.67-3.41 item/fish	PET	Bessa et al. (2018)
Marine fish	Mediterranean Sea	1.36-2.36 items/fish	copolymers	Güven et al. (2017)
Marine Fish	Northern Ionian Sea Coast	1.5-1.9 items/fish	PE, PP, PVC, PUR, Polyamide	Digka et al. (2018)
Mussels	Giglio island Italy	1.0-2.0 items/ mussel	PP, PE, PET, PA, PUR	Avio et al. (2017)
Mussels	Coastal water, UK	1.1-6.4 items/ mussel	PP, PE, LDPE, fibres, PVC	Li et al. (2018b)
Mussels	Northern Ionian Sea Coast	1.7-5.26 items/ mussel	PP, PE, LDPE, fibres	Digka et al. (2018)
Mussels		2.7-3.7 items/ mussel	PET, PUR, Poly ester	Catarino et al. (2018)
Shellfish	India	1000-10000 particles/kg	PVC, Polyamide, Polyacrylamide, polyacetylene	Saha et al. (2021)
Finfish		3000-14000 particles/kg		
Oysters	Coastal water, UK	1.4-7 items/oyster	PET, PP, PE, PS, PVC, PA	Li et al. (2018c)
Edible sea salt	India	1400-1900 particles /kg	PE, PP, PET, nylon, PS	Yaranal (2021)

Rock Salt		200-400 particles /kg		
Natural Salt		7-681 items/kg	PET, PES, PE, PP, PB	Iñiguez et al. (2017)
Commercial Salt		1-10 items/kg	PE, PET, PS, PAN	Karami et al. (2017)
Compost from pulped food waste	Italy	1400	PP, PE, PS, Cellulose derivatives	Ruggero et al. (2021)
Compost from grocery store	USA	300000	PES, PET, PE, PA, fibres	Golwala et al. (2021)
Street Dust	Xinjiang China	307-1526 particles	PE, PP, Flakes, Fibres	Li et al. (2022)

6. IMPACT OF MICROPLASTIC ON SOIL QUALITY

Microplastic in soil due to its large surface area and small particle size adsorbs other organic and inorganic pollutants affecting the health of the soil ecosystem. An increase in soil water availability, decrease in water evaporation and a decrease in soil bulk density and water-stable aggregates in presence of microplastic were reported by De Souza Machado et al. (2019), Wan et al. (2019). Microplastic also affects the porosity of the soil Jiang et al. (2017). Boots et al. (2019) found that HDPE decreases the soil pH by 0.62 units. The concentration of the dissolved organic C, ammonium-N, and nitrate –N and total phosphorous in soil significantly increase on microplastic amendments Liu et al. (2017), while Dong et al. (2015) during their research studies found that residues of plastic mulching negatively affect soil fertility and plant growth. Several researchers Li et al. (2021b), De Souza Machado et al. (2019), Awet et al. (2018), Liu et al. (2018) have reported that microplastic in soil significantly alters the soil enzymatic activities.

7. IMPACT OF MICROPLASTIC ON SOIL ORGANISMS

Microplastics in soil impact the feeding habits of soil animals causing a nutritional imbalance which results in growth and reproduction reduction, organ damage and disorder in the immune response and metabolism Lahive et al. (2019), Wang et al. (2019). Cao et al. (2017) during their studies found that microplastic in soil affects the growth of the earthworm as it causes histopathological and immune damage to earthworms. Microplastic in soils causes intestinal and oxidative damage to nematodes Liu et al. (2018), Zhu et al. (2018) which results in a decrease in body length, survival rate and reproductive capacity of the nematodes. In presence of microplastic the reproduction of mesofauna, *Folsomia candida* decreases and microplastic alters the microbial community in the gut of collembolan Ju et al. (2019). The health of Macrofauna (earthworms, snails) which converts organic matter and nutrients into a form which can be utilised by plants is negatively impacted by the microplastics present in the soil Sun et al. (2019).

8. IMPACT OF MICROPLASTIC ON PLANTS

Microplastics in soil indirectly affect seed germination and plant growth Ng et al. (2018). The translocation of the microplastic depends on the shape, size, and chemical properties of the microplastic Bosker et al. (2019). Reviews of the reported data denote that the entry of microplastic in a plant is through the free space between root cells Meng et al. (2021). Polystyrene (PS) in the onion increases the root biomass and total root length, while polyamide and polyester fibres significantly impact soil microbial activity and tissue elemental composition De Souza Machado et al. (2019). The increase in total biomass, root biomass, root length and root-soil microbial activity in onion was reported by De Souza Machado et al. (2019) in presence of polyester sulphone. In corn plant, PS and polylactic acid decreases the root biomass Wang et al. (2020a), and PE retards the nutrient uptake and plant growth Urbina et al. (2020). In the wheat plant, PS increases the root length and root biomass and decreases the root/shoot ratio Lian et al. (2020), low-density polyethene (LPDE) decreases the number of leaves and fruit biomass affecting vegetative growth Li et al. (2019) and polyethene (PE) affects the root antioxidant system Liu et al. (2021). Jiang et al. (2019) found that PS in broad beans decreases the biomass and activity of enzyme catalase and retards the transport of nutrients to the roots by blocking the pores of the cell walls. In carrots, the particles of PS enter the root and translocate to the leaves Dong et al. (2021). Lozano et al. (2021). Microplastic Shape, Polymer Type, and Concentration Affect Soil Properties and Plant Biomass. Front Plant Science, 12. reported that PP and LDPE decrease root mass and above-ground biomass of the carrot plants. In presence of high-density polyethene (HDPE) the shoot height and biomass of the carrot plant decrease, and the germination of seeds is also retarded Boots (2019).

9. IMPACT ON HUMAN

Human exposure to microplastics and other additive chemicals occurs via (a) skin (b) Lungs and (c) the digestive system. Microplastic particles enter the human body by two most common methods (i) Endocytosis and (ii) persorption Kor and Mehdinia (2020). Senathirajah et al. (2021) reported that global human consumption of microplastic is 0.1-5 g per week i.e., average consumption is 100,000 pieces of plastic or 250 g every year. The average global consumption of microplastic is 35 kg per capita. As per the estimation of FCCI, an Indian consumes 11 kg of plastic products per year, while in other Asian countries the average consumption is 36 kg per year. Approximately 92 kg of plastic per capita is consumed in Western Europe. An American consumes 140 kg of plastic per year, as per estimation in America half a billion drink straws are consumed daily. As per inferences of Cox et al. (2019), 39,000 - 52,000 plastic particles are consumed by each citizenry every year and 25000 particles are inhaled in a year. Those citizens who drink only bottled water consume additional 9000 particles every year (while 4000 particles are consumed by the human who drinks tap water only). The microplastic in drinking water became more harmful as besides microplastic particles microbial pathogens are also developed in the biofilms.

The adverse direct effects of the microplastic particles on humans/mammals (distribution pattern, accumulation kinetics) depend on the shape, size, chemical structure and surface area of the particles, the smaller particles are easily sorbed and transported into the lymphatic system through human and other mammalian circulatory systems Lusher et al. (2017). These particles are accumulated in the liver, kidney, and intestine Revel et al. (2018). The adverse effects of microplastic in mammals are due to oxidative stress with inflammation. The microplastic particles produce more reactive oxygen species and are more easily translocated Eerkes-Medrano et al. (2019). Zhang et al. (2021) have reported these particles due to oxidative stress causes respiratory toxicity in humans. Microplastic particles of size 10 um produce reactive oxygen species of high levels which causes oxidative stress on the human brain and epithelial cells Schirinzi et al. (2017).

Liang et al. (2021) reported that microplastic in the human body causes apoptosis, necrosis, and fibrosis and even can damage the tissue. Immunotoxicity i.e., autoimmune disorders and/or immunosuppression in humans by microplastic particles has been reported by Prata et al. (2020), Sun et al. (2021). The carcinogenicity of these particles in humans has been reported by Lusher et al. (2017), Martin et al. (2017). Sobhani et al. (2021) have also found reproductive toxicity due to these particles. More accumulation of microplastic particles of 0.5-5 um in children enhances the chances of the metabolic disorder Wang et al. (2020b)

Organic compounds Bisphenol A (BPA), bisphenone, PFAS and phthalates are found in commercial plastics as these compounds are used as additives during the manufacturing process. Due to the large surface area, hazardous pollutants such as PAH; PCB, DDT and potentially toxic metals are sorbed on microplastic particles. When mammals/human uptake these particles via food those are biomagnified in mammals including humans. On the surface of microplastic, a biofilm is formed by non-pathogenic microorganisms. Pathogenic microbes' viz., *Pseudomonas aeruginosa*, *Legionella* spp., non-*Mycobacterium* spp. And *Naegleriafowleri* on biofilm have also been found Science Advice for Policy by European Academies (SAPEA) (2019).

The rate of mortality of the immune cells became 2 to 3 folds in presence of microplastics (University Medical Centre (UMC) Utrecht). Bisphenol A affects the endocrine system and reduces fertility in men and women. Polychlorinated biphenyls sorbed on microplastic particles in humans affect the reproductive system and immune system and are carcinogenic Flaws (2019). Microplastic particles via the bloodstream can even cross the brain protecting the hardy membrane and the placenta; these particles are passed to the foetus from the mother (Rutgers Centre for Urban Environmental Sustainability). Microplastic particles are also reported in the faeces of humans. Citizenry who are more exposed to plastic became more prone to plastic-like air pollution or harmful construction materials Cox et al. (2019)

10. SMALL STEPS TO CURTAIL THE RISKS OF PLASTIC

In the 21 plastic is an essential part of human life so cannot be completely avoided but for better future living few small steps will be useful.

1) The production and use of single-use plastic must be completely banned and production of other types of plastics must be reduced in place of plastic packing glass packing may be used.
2) The use of plastic microbeads in personal care products and cosmetics must be phased out and banned.
3) In mulching biodegradable films must be used.
4) Drink water from your tap: If in place of plastic bottled water tap water is used for drinking and other purposes the consumption of plastic may be reduced (plastic is present in bottled water, beer, and sea salt).
5) Avoid plastic food containers and not heat food in plastic: The use of recycled plastic containers must be avoided as they contain harmful chemicals such as phthalates; styrene and bisphenols A. Plastic materials must be avoided for heating the food as the hazardous chemicals associated with plastic material leaches to the food. In America, it is advised by the American Academy of Paediatrics not to wash plastic wares in dishwashers.
6) To avoid unnecessary exposure to plastic fresh food must be used.

7) As household dust contains hazardous chemicals such as phthalates, per- and polyfluoroalkyl substances proper and regular vacuum cleaning is essential.

CONFLICT OF INTERESTS

None.

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DECLARATION

No original data have been used in this review all information is accessed from published work.

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