Chapter 3
Abundance and Distribution of MPs and NPs in Soil: A Global Scenario

Mahir Tajwar, Shamiha Shafinaz Shreya, Md. Yousuf Gazi, and Md. Bayazid Hossain

Abstract The worldwide abundance of microplastics (MP) and nanoplastics (NP) is generally identified as a persistent problem to the marine environment and is already deemed a silent threat in aquatic environments. However, their presence in agricultural soil and terrestrial environment has largely been overlooked, and our understanding of its effect on the terrestrial ecosystem is not fully understood. This chapter addressed the global accumulation and abundance of MP and NP in terrestrial ecosystems. Furthermore, the factors contributing to their distribution and widespread presence in terrestrial soil have been evaluated for better insights in microplastic studies. Based on the limited studies done on terrestrial soil, the abundance of MP and NP varies geographically with high concentrations being detected in the regions of China, Pakistan, Canada, the USA, Spain, Italy, and Australia whereas comparatively, a lower amount has been detected in France, Germany, and Antarctica. This chapter intends to (1) summarize the accumulation and distribution of MPs and NPs in the terrestrial ecosystem and (2) evaluate the factors regulating the distribution of MPs and NPs as environmental pollutants on territorial soil system. The prospects for future research include an in-depth investigation of the concentration and characterization of MPs and NPs in the terrestrial soil of various countries and analysis of different factors controlling its distribution and its potential impact.

Keywords Microplastics · Nanoplastics · Soil · Spatial Distribution · Abundance · Agriculture

---

M. Tajwar
Department of Geosciences, Auburn University, Auburn, AL, USA

S. S. Shreya
Department of Oceanography, University of Dhaka, Dhaka, Bangladesh

M. Y. Gazi (✉)
Department of Geology, University of Dhaka, Dhaka, Bangladesh
e-mail: yousuf.geo@du.ac.bd

M. B. Hossain
Department of Soil, Water & Environment, University of Dhaka, Dhaka, Bangladesh

N. R. Maddela et al. (eds.), *Micro and Nanoplastics in Soil*,
https://doi.org/10.1007/978-3-031-21195-9_3

3.1 Introduction

Since the mass production of plastic started, the biosphere of the earth has been confronting a steadily increasing threat. Cumulative thrust for convenient yet cheaper products and modern lifestyle has boosted the annual production of plastic materials by leaps and bounds which is estimated to be about 34,000 million tons by 2050 (Plastics Europe, 2019; Maity & Pramanick, 2020). Trends of overdependence, indiscriminate utilization, less recycling propensity (only 9%), improper management of used products, etc. are leading the global annual plastic waste production to 6300 million tons approximately; a lion's share of this finds a way to the terrestrial ecosystem (Geyer et al., 2017; Van Sebille et al., 2015). Consequently, soil possesses a far greater concentration of plastic materials than aquatic sediments as reported by Horton et al. (2017a, b) and Fischer et al. (2016). Furthermore, agroecosystem was reported as the most plastic contaminated terrestrial ecosystem by Nizzetto et al. (2016a, b). However, the distributive nature and interaction with components in the terrestrial ecosystem, specifically in agricultural soils, are still unclear.

Plastic products have gained universal popularity; hence widespread occurrence and distribution of plastic materials can be traced easily. Worldwide contamination of soil by smaller plastic particles has been mentioned by several studies (Fuller & Gautam, 2016; Scheurer & Bigalke, 2018; Koutnik et al., 2021). Zhang et al. (2021) identified the variation in abundance of global soil MPs which is thought to be connected with the physiographical nature, development activities, population densities, soil properties, and other features of that area (Harms et al., 2021; Kim et al., 2015). Recently, detection of plastic particles has been confirmed in distant places like the Polar Regions and the Tibetan Plateau where anthropogenic interference is severely less (Jiang et al., 2019; Peeken et al., 2018). Upon deposition on surface soil, plastics undergo disintegration and degradation processes resulting in smaller MPs and even NPs (Rocha-Santos & Duarte, 2015; Cole & Galloway, 2015; Barnes et al., 2009). Meanwhile, previously generated MPs can also directly enter the terrestrial ecosystem as primary MPs (Napper et al., 2015) (Fig. 3.1).

Previous studies have identified the sources and pathways of MP contamination in farmland soil and reported plastic mulch, application of compost and sludge, irrigation with untreated and partially treated water, plastic container, atmospheric deposition, etc. as the main sources (Corradini et al., 2019; Blasing & Amelung, 2018; Rillig, 2012; Sanchez-Hernandez et al., 2018).

Once entered the agricultural soils, MPs and NPs can be transferred both vertically and horizontally through soil pore spaces (Zhang et al., 2019; Lwanga et al., 2017a, b; Horton et al. 2017a, b; Rillig et al., 2017b) or can be bioaccumulated into the human food chain and endanger health (Zhang et al., 2019; Machado et al., 2019). Hence, a detailed understanding of the distribution and transportation of MP and NP in soil may serve as a vital factor for controlling plastic contamination. Unfortunately, the scarcity of published reports on the movement and transportation nature of MPs in the terrestrial ecosystem reveals the fact that it has gained less

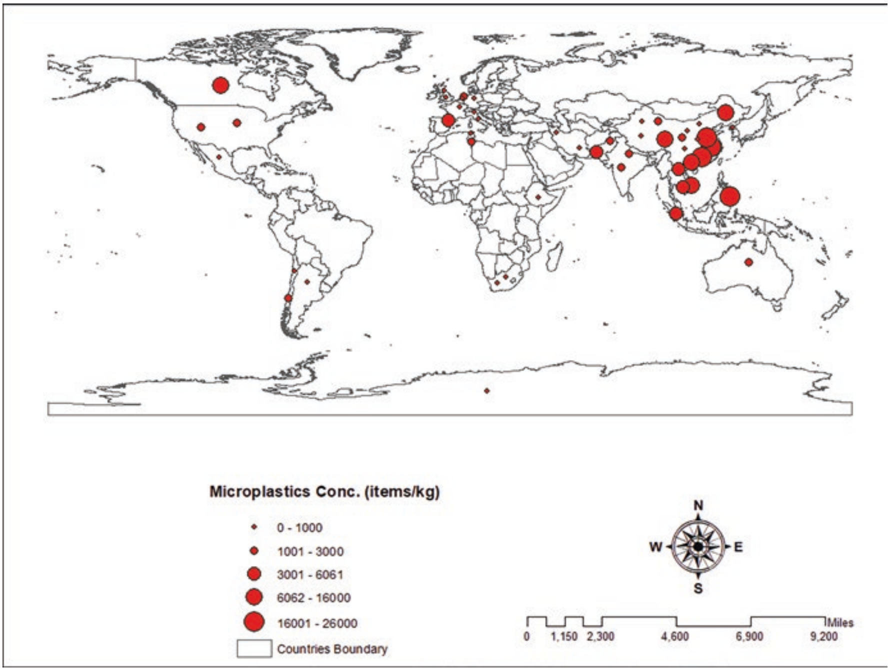

Fig. 3.1 Showing the global abundance and distribution of microplastics on the agricultural soil

attention from the researcher community, compared to aquatic systems (Möller et al., 2020; Brady & Weil, 2000). As a result, several information gaps need to be addressed. Consequently, a knowledge gap has been created.

This review study aims to gather data about the global trend of accumulation and abundance of MPs and NPs in the terrestrial ecosystem. Moreover, several factors which control the distribution behavior of MPs and NPs in farmland soils have been discussed with a view to providing a base material for the better realization of transportability of smaller plastic particles in agro-ecosystem.

3.2 Factors Controlling the Distribution of MPs and NPs in Soil

Since plastic has got an overwhelmingly ubiquitous nature, it is obvious that MPs and NPs will be found in the terrestrial ecosystem. Smaller plastic materials enter into the agro-ecosystem as manufactured MPs and NPs primarily or secondarily as produced from the bigger plastic materials (Rillig, 2012; Duis & Coors, 2016; Koelmans et al., 2015). Plastic mulch, greenhouse materials, atmospheric deposition, etc. are considered as direct sources, while indirect sources include application of organic amendments, irrigation with wastewater, application of sludge, etc. (Ng et al., 2018; Duis & Coors, 2016; Horton et al. 2017a, b). Once entered, plastic materials may undergo disintegration and degradation processes, generating MPs and NPs eventually (Napper & Thompson, 2019; Chamas et al., 2020). Having convenient size compared to the pores of the soil, MPs and NPs can be distributed spatially and horizontally. This phenomenon of movement in agro-ecosystem is governed by several factors: morphology of the plastic, precipitation, properties of soil, cultivation, etc. (Zhang et al., 2018).

3.2.1 Properties of Soil

Physicochemical properties of soil such as texture, moisture content, temperature, soil reaction, etc. directly affect the movement of MPs and NPs in soil. Soil texture straightly determines the pore space distribution which is very crucial for the translocation of smaller plastic particles within the layers of soil (Rahmatpour et al., 2018; Cey et al., 2009). Light textured soil (containing higher sand percentage) tends to have bigger pore spaces (macropores) which will enable the soil to permit more vertical movement of microplastics (Rillig et al., 2017b) than soils with higher clay and silt content, respectively. In addition, Ding et al. (2021) recently studied the abundance of MP in soils of three sites, and they found that sand soil had higher MP content than grassland and woodland.

Soils containing a greater amount of montmorillonite and other expanding clay minerals will generate cracks and fissures upon drying. These cracks can pave the way for massive transportation of plastic particles of various sizes directly at the deeper part of the soil profile very quickly (Rillig & Lehmann, 2020). Similar findings were observed in several other studies (O’Connor et al. 2019a, b; El-Farhan et al., 2000; Majdalani et al., 2008) implying the significant effects of interconnected pore space pathways and wet-dry cycles on the transport of MPs in a terrestrial ecosystem. Meanwhile, previous experiments reported the significant reduction of microplastic movement with increasing ionic attachment in a media of quartz sand (Treumann et al., 2014; Pelley & Tufenkji, 2008). Moreover, chemical properties of soil, namely, soil pH and Fe/Al content, influence the distribution of MPs and NPs as mentioned by some studies (Wu et al., 2020; Scheurer & Bigalke, 2018).

3.2.2 Morphology of MP and NP

The distribution of MP and NP in the soil is most reliant on their various morphological characteristics, such as size, density, shape, hydrophobicity, etc. (Rillig et al., 2017a). Previous several studies have enlightened on the influence of size and hydrophobicity of plastic materials upon their movement in the terrestrial ecosystem (O’Connor et al. 2019a, b; Pelley & Tufenkji, 2008). David O’Connor et al. (2019a, b) studied the mobility of five different MPs and found that mobility of smaller-sized PE-MP was greater than any other with the longest penetration. A same observation regarding the size-mobility inverse relation of MPs has also been reported by Rillig et al. (2017b). Furthermore, Liu et al. (2018) investigated arable soils around the suburbs of Shanghai and noticed relatively larger MPs in topsoil varying significantly from deeper soil (Hurley & Nizzetto, 2018).

Shape is another morphological factor that affects the fate of mobility of plastic materials in a terrestrial system. MPs and NPs are found with various shapes in soil, for instance, sphere, particle, fiber, and film mostly. Among them, sphere and particle are being widely used for recent relevant researches showing that microplastic particles of these two shapes can easily translocate to the deeper part of the soil (Lwanga et al., 2017a, b; Rillig et al., 2017b; Treumann et al., 2014; Zhuang et al., 2005). On the other hand, in a review study, Rillig et al. (2017b) assumed different distributive behavior of other shapes such as film, fiber, etc. from the sphere. They predicted that fiber and film-shaped smaller plastic particles have a possibility to be trapped in the soil matrix and can become surrounded by an eco-corona likewise aquatic system (Galloway et al., 2017). In addition, the reviewers also reported that the movement of MPs and NPs in the soil system would be substantially influenced by eco-corona. Their findings are consistent with Zhang et al. (2019). Meanwhile, low-density microplastics had fewer tendencies to move downward as mentioned by O'Connor et al. (2019a, b).

After the entrance, MPs and NPs confront several processes like attachment, sedimentation, etc. which can hinder the strolling of plastic particles in soil (Zhang & Liu, 2018; Rillig et al., 2017a). Previous experiments on movement behavior of colloids in different media found straining, attachment at the solid-liquid interface, pore exclusion, and air-water interfacial bond as the significant factors in particle movements through soil (Zhuang et al., 2005; Bradford & Torkzaban, 2012; Bradford et al., 2002).

3.2.3 Soil Biota

Previous experiments have mentioned that biogenic activities could instigate the transfer of smaller particles from the surface into the deeper part of the soil by creating interconnected pore space pathways (Blasing & Amelung, 2018; Zubris & Richards, 2005). In a review study, Rillig et al. (2017b) reported earthworms and roots as the most important producers of bio-macrospores in soil. They expected similar results from micro arthropods. Moreover, Huerta Lwanga et al. (2016) reported that earthworms can contribute to microplastic movement from the surface soil to the deep soil by ingestion/excretion mechanism. The capability of the conversion of primary MPs to secondary MPs and NPs through ingestion by earthworms and some other soil-dwelling organisms, for instance, burrowing mammals, collembolan, mites, etc., has been reported in some studies as well (Zhu et al., 2019; Rillig, 2012).

Previous studies found evidence of vertical and horizontal movement of LDMPs in soil facilitated by collembolan, earthworms, and other organisms (Maaß et al., 2017; Rillig et al., 2017b; Lwanga et al., 2017a, b). Besides, direct transportation of LDMPs by preferential flow through the pore space pathways was mentioned by Yu et al. (2019). Moreover, Zhang et al. (2019) conducted a study combining field investigations and laboratory simulations to examine LDMP distribution and controlling factors in agricultural soils. They found evidence of vertical as well as horizontal movement of LDMPs along with water through pore space pathways of soil. Maaß et al. (2017) conducted a study with two species of collembola and confirmed the movement and distribution of MPs by both species. In another study, Zhu et al. (2018) mentioned that mites can also disperse commercial PVC particles.

Root penetration, expansion, and water extraction create pores and channels within soils which facilitate downward translocation of smaller particles as reported by Gabet et al. (2003). In addition, the decomposition of roots produces macropores of nearly the same size, which can distribute MPs in soils (Li et al. 2019a, b). Another study revealed that fungal hyphae might facilitate MP movement by serving as preferential paths (Wick et al., 2007). Leaching contributes significant microplastic transportation vertically in soils through pore spaces created by naturally or biogenic activities (Cey et al., 2009). However, there is no comparative analysis of microplastic particles movement by earthworm or other soil biota and leaching in soil.

3.2.4 Cultivation

Agronomic activity such as plowing, mulching with plastics, application of sludge, application of organic amendments, irrigation with wastewater, etc. cause the mobilization of MP and NP in surface soil and subsurface soil. The findings of several recent pieces of research have proven the fact that cultivation activities help to spread around plastic particles in any agro-ecosystem (Nizzetto et al., 2016b; Zhang et al., 2019). Ding et al. (2020) found a significantly higher number of MPs in orchards which they thought for massive utilization of plastic for packaging. Rillig and Lehmann (2020) reviewed the effect of different tillage practices on microplastic incorporation in different depths of agricultural soil. They noted that mould board plowing brings most of the MPs present on the soil surface at the plowing depth. Besides, they noted that other tillage practices would show mixing effects throughout the tillage layer.

Mulching with plastics, a widely practiced trend of modern farming, has been established as a major source of plastic materials in agro-ecosystem by numerous studies (Sintim & Flury, 2017; Zhou et al. 2019a, b; Gao et al., 2019). Once embedded in the soil, it can be converted into MPs and NPs (Blasing & Amelung, 2018). Wang et al. (2021) studied samples of different land-use patterns from five provinces of China and found significantly higher particle abundance where plastic mulching was used. Furthermore, they noticed that the MP abundance of paddy fields was significantly higher than wheat lands. Plastic mulch affects the agro-ecosystem inversely since plastic covering can raise both soil temperature and moisture which can intensify the degradation and transportation rate of MPs (Subrahmaniyan et al., 2006). Moreover, decomposition of other agricultural plastic materials such as seed bags, packaging materials, agricultural plastic tools, etc. can add MP in farmlands (Antunes et al., 2013). Chen et al. (2020) added polytunnels, bale twines, fertilizer bags, containers, and nets to the list which can be a source factor of plastic materials in agro-ecosystem.

Application of sludge to amend the soil is reported by many studies to be a significant input pathway of smaller fractions of plastics in farmland soil (Ziajahromi et al., 2016; Zhou et al., 2020; Nizzetto et al., 2016b). An estimation made by Nizzetto et al. (2016b) revealed that about 4.4×10^4–3×10^5 tons and about 6.3×10^4–4.3×10^5 tons of MPs enter arable soil annually because of use as the amendment in North America and Europe, respectively. The findings of Chen et al. (2020) are consistent with this. Meanwhile, organic farming involves the utilization of organic fertilizers (namely composts) which are commonly produced from household waste or municipal waste. These composts may have a MP concentration of 895 items kg^{-1} as reported by Weithmann et al. (2018). On the other hand, irrigation with wastewater can serve as a source and distributor of plastic materials both spatially and vertically in agricultural soil (Scheurer & Bigalke, 2018). Mintenig et al. (2017) showed that about 20 million hectares of arable land worldwide are irrigated with untreated or partially treated sewage water on which about 10% of the world's population depends on the food. On the other hand, Rillig and Lehmann (2020) considered bio-pores created by decomposed roots after harvesting as a massive transport pathway of MPs and NPs in agricultural systems. They also reported that harvesting submerged parts of plants beneath the surface (carrots, potatoes, etc.) can also facilitate to incorporation and transportation of microplastics in farmland. Li et al. (2019a, b) also attributed that harvesting of rhizome may serve the downward movement of microplastics.

3.2.5 Weather Pattern

The weather pattern of an area can affect the distribution and accumulation of MPs and NPs significantly. An area with annual heavy rainfall may experience surface runoff which can mobilize plastic materials spatially over a huge area. With the flow coming from the source, plastic materials can be floated away to distant locations. Previous studies indicated that flow length and catchment size showed a positive correlation with the number of possible plastic sources and distribution (Klein et al., 2015; Tibbetts et al., 2018; Fischer et al., 2016; Ballent et al., 2016). A study on the abundance of plastics in the Swiss floodplain was carried out by Scheurer and Bigalke (2018). They identified the distribution of plastic as diffuse and found a linkage of the lateral distribution process with flood dynamics. Moreover, such flushing movement of water determined by topographical and weather factors can carry smaller plastic materials even through soil pores spaces of soil horizontally and vertically (Zhang et al., 2017; Zhang et al., 2011). Meanwhile, O'Connor et al. (2019a, b) reported upward migration of MPs if saturation prevails in soil pore spaces since MPs have relatively low specific density. On the contrary, during hot days with no precipitation, dry soils will likely have natural cracks, which can serve as entryways for microplastics to deeper soils (Li et al. 2019a, b). In addition, dry hot days will intensify MP conversion to NP with the help of UV radiation and elevated temperature (Horton et al. 2017a, b).

Ding et al. (2020) conducted a research with agricultural soils from nine sites across Shaanxi province, and they observed that in northern Shaanxi, MPs were not gone by surface runoff, causing massive accumulation while the situation appeared reverse in the case of southern Shaanxi, where they found degraded smaller MPs. They explained their findings focusing on the weather pattern difference between northern and southern Shaanxi since the northern part had the temperate monsoon climate and less rainfall for the southern Shaanxi; it was just the opposite.

Weather patterns involving subsequent cycles of rainfall events and dry periods may have an impact on the mobility of MPs into the soil (O'Connor et al. 2019a, b; McCarthy & McKay, 2004). O'Connor et al. (2019a, b) studied the mobility of five different MPs in sand soil column experiments. They found a significant positive relationship between MP penetration and wet-dry cycles. However, more research should be carried out for a better understanding of the effects of weather patterns on the distribution of MPs and in soil.

3.3 Summary of Regional MP and NP Abundance in Soil

3.3.1 Africa

The first report on the abundance and occurrence of microplastic in the African continent was done by Ryan in 1988 where the accumulation of pieces of plastic at the seafloor of the southwestern Cape Province of South Africa was studied from August 1977 to August 1978. After 27 years of the first study done in Africa, microplastic in the surface water of south-eastern major bays of South Africa was evaluated (Nel & Froneman, 2015).

In the region of South Africa, an extent of 13.3–563.8 items/kg of microplastic and nanoplastic have been detected in the river sediments of Eastern Cape Town (Nel et al., 2018), and the concentration in the region of Braamfontein Spruit, Johannesburg, has been found to be 166.8 items/kg (Dahms et al., 2020). Particles identified in the Lake Ziway sediments of Ethiopia have a range from 6.3 to 115.9 items per kg of freshwater sediments (Merga et al., 2020).

Comparatively, a high concentration of MP and NP has been found in Tunisia where an amount of more than 6920 particles has been reported in the region of

Table 3.1 Distribution of microplastics and nanoplastic in terrestrial ecosystems across Africa

Countries	Location	Concentration (items/kg)	Sample type	References
Tunisia	Bizerte	2340 ± 227.15–6920 ± 395.98	Freshwater sediment	Toumi et al. (2019)
Tunisia	South/North Lake of Tunis	316.03 ± 123	Sediment	Abidli et al. (2019)
Ethiopia	Lake Ziway	6.3–115.9	Freshwater sediment	Merga et al. (2020)
South Africa	Eastern Cape Town	13.3–563.8	River sediment	Nel et al. (2018)
South Africa	Braamfontein Spruit, Johannesburg	166.8	Stream sediment	Dahms et al. (2020)

Bizerte (Toumi et al., 2019). A much lower distribution (316.03 ± 123 items/kg) has been detected in the sediments of Tunis lake (Abidli et al., 2019) (Table 3.1).

3.3.2 America

Several pieces of research have been gathered in this study to give an overview of the abundance of microplastics in the soil of the Americas. These researches looked at the usage of sewage sludge and biosolids as a source of microplastics. In a study, it has been estimated that biosolid applications might provide up to 300,000 tons of MPs to farmed soils in North America each year (Nizzetto et al., 2016a, b). In Ontario, Canada, microplastic abundance is found to be at a range of 8700–14,000 MPs/kg in biosolid samples (Crossman et al., 2020).

A study had been conducted in the city of New York, USA, where samples were collected from four sites, and the findings revealed MP concentration ranged from 370 to 2060 items/kg^{-1} with a mean of 1235 items per kg. This result is comparable to the amount of sewage sludge applied to worldwide soils (Zubris & Richards, 2005).

A study (Corradini et al., 2019) of 31 agricultural fields in Chile found that the concentrations of those areas range from 0.6 to 10.4 MPs/g. But it revealed that after five sewage sludge applications, the concentration amount increased to 3600 items/kg from 1200 items/kg.

In Brazil, it has been found that the sediments near municipal dumping sites have a significant concentration of MP (Neto et al., 2019), and the study also expressed that the presence of MP was detected in 100% of the samples; however, no specific data on agricultural soil was obtained.

Another study (Lwanga et al., 2017a, b) measured plastic particles in a rural field on the Yucatán Peninsula of Mexico where a total of 870 ± 1900 items/kg of microplastics were discovered (Table 3.2).

Table 3.2 Distribution of microplastics and nanoplastic in terrestrial ecosystems across America

Region	Countries	Location	Sample type	Concentration (unit)	References
South America	Chile	–	Agricultural soil	184–306 pieces/kg	Corradini et al. (2021)
	Chile	Mellipill	Agricultural soil	2010 items/kg	Corradini et al. (2019)
	Mexico	Yucatán Peninsula	Home garden soil	870 ± 1900 items/kg	Lwanga et al. (2017a, b)
	Argentina		Farmland soil	30 ± 19 kg/ha	Ramos et al. (2015)
North America	USA	Washington, D.C.	Vegetated wetland soil	1270 pieces/kg	Helcoski et al. (2020)
		New York	Soil	1235 items/kg	Zubris and Richards (2005)
	Canada	Ontario	Biosolid samples	8700–14,000 MPs/kg	Crossman et al. (2020)

3.3.3 Asia

In Asian countries, the pervasiveness of microplastics (MP) is a severe environmental concern. According to the literature, Asia is home to seven of the top ten trash-dumping countries (Jambeck et al., 2015). To acquire an overview of the abundance and distribution of microplastics across Asia, a variety of studies have been collated and discussed.

Southern Asia

In Southern Asia, the highest abundance is found in Pakistan. A study was carried out in Pakistan to map out the regional dispersion of microplastics in the topsoil Lahore, Pakistan. The distribution of MPs in topsoil throughout the Lahore district was discovered to range from 1750 to 12,200 MPs per kg, with a mean of 4483 ± 2315 items/kg. In agricultural soil MP concentration was found in the range of 2200–6875 MPs per kg with a mean concentration of 3712 ± 2156 MPs per kg of soil (Rafique et al., 2020). In India, MPs were identified in soils collected from electronic waste-dumping sites. In Bangalore and Chennai, the average MP estimates were 302 and 1908 items/kg, respectively (Tun et al., 2022). Traditional plasticizers like dibutyl phthalate, dimethyl phthalate, and di(2-ethylhexyl) phthalate were detected in high abundance (Chakraborty et al., 2019). PE was also found to be a dominated polymer in Indian soils of dumping sites which account for 55% of total MP (Chai et al., 2020a, b).

In the case of Bangladesh, most of the recent studies have reported the abundance of microplastic in the sediments of the coastal environment (Rahman et al., 2020; Tajwar et al., 2021, 2022a, b; Rakib et al., 2021), where MP concentration had been found about 8.1 ± 2.9 particles/kg. However, the concentration of MP & NP based on the terrestrial ecosystem is yet to be evaluated (Table 3.3).

Table 3.3 Distribution of microplastics and nanoplastic in terrestrial soil across Southern Asia

Countries	Location	Sample Type	Concentration (items/kg)	References
India	Chennai	Soil of e-waste dumping sites	1908	Tun et al. (2022)
	Bangalore	Soil of e-waste dumping sites	302	
Pakistan	Lahore	Agricultural soil	3712 ± 2156	Rafique et al. (2020)
		Topsoil	4483 ± 2315	

South-eastern Asia

MPs have also been discovered in alarming figures in the countries of Southeast Asia. In Indonesia, many areas continue to operate open dumping sites, which are a potential source of MPs (The Jakarta Post, 2019). In one Indonesian sampling site, MP distribution was highest at 43,704 particles per kg, followed by 16,842 and 11,111 pieces/kg in two other sites. The dumping site's entrance revealed a significant MP abundance (16,842 pieces/kg). The median number of MPs in the soil is 6061 pieces/kg (Tun et al., 2022).

According to research in Cambodia, the median MP concentration in Cambodian soils was determined to be 4360 pieces per kilogram. It demonstrated the maximum abundance of MP (218,182 pieces/kg) in one Cambodian sampling site, with 48 MP found in only 0.22 g of soil (Tun et al., 2022). From a study on Asian countries, it is found that the average value of microplastic was highest in the Philippines counted for 24,000 pieces/kg. MP levels were found to be high in soils from two sampling sites of the Philippines, containing 31,000 and 24,000 pieces/kg, respectively (Tun et al., 2022). In Vietnam, the median of MPs in soils was about 11,337 pieces/kg, but the highest abundance is found about 83,606 pieces/kg, followed by 28,358 pieces/kg and 26,768 particles per kg. Soil samples accumulated from two e-waste recycling areas close to Ho Chi Minh City showed high abundance of MP, containing 17,568 and 26,761 items per kg (Tun et al., 2022). In Laos, the highest MP abundance was accounted for 22,222 pieces/kg from a dumping site. MPs were detected from the other three sampling sites ranging from 893 to 4651 items per kg, and the samples had been taken from a rice field near a landfill area. The median value of MPs in soils of Laos was 4651 pieces/kg (Tun et al., 2022) (Table 3.4).

Middle East

Rezaei et al. (2019) investigated the transmission of MPs by wind erosion measuring the abundance of MPs (low-density) in the soils of Iran's Fars province. 1.2 ± 0.6 and 205 ± 186 mg per kg had been identified at agriculture-based locations, but only 0.2 ± 0.1 and 38 ± 17 particles per kg were found on rangelands. The primary source of MPs in these areas was assumed to be insufficient removal of plastic mulch films (Büks & Kaupenjohann, 2020) (Table 3.5).

Table 3.4 Distribution of microplastics and nanoplastic in terrestrial soil across South-eastern Asia

Countries	Location	Sample type	Concentration (items/kg)	References
Indonesia	–	Dumping sites soils	6061	Tun et al. (2022)
Philippines	Smokey Mountain, Manila	Soils	24,000	
Vietnam	Ho Chi Minh City	Soils	11,337	
Cambodia	–	Soils	4360	
Laos	–	Soils	4651	

Table 3.5 Distribution of microplastics and nanoplastic in terrestrial soil across the Middle East

Country	Location	Sample type	Concentration	References
Iran	Fars Province	Rangeland soils	38 ± 17 items/kg	Büks and Kaupenjohann (2020)
		Agricultural soils	205 ± 186 mg / kg	

Eastern Asia

In Eastern Asia, China is the only country that performed MP measurement in more than 15 regions, and from those researches, it is found that MPs are highly distributed all over China. As significant amounts of plastics are manufactured, consumed, and discharged in China each year, soil microplastic pollution deserves special attention (Gourmelon, 2015). In China, the amount of plastic garbage that had been improperly managed was found to be the highest in 2010, at 8.82 million tons (Jambeck et al., 2015). Ding et al. (2020) examined the abundance of MPs in the agriculture-based sites of Shaanxi Province, China. They discovered that MPs were present in all agricultural soils. MP concentrations in soil ranged from 1430 to 3410 items/kg. The findings of this research validated the existence of a high concentration of MPs in farmland soil and demonstrated that activities related to agriculture could have contaminated the soil with MPs. If we look carefully, it will be observed that soils with a history of sewage sludge application, wastewater irrigation, and mulching contain more MPs (Zhang & Liu, 2018). It is estimated that sludge application in China contributes approximately 1.56×10^{14} sludge-based MPs to the natural ecosystem (Liu et al., 2018).

A distant agricultural area in China's Loess Plateau consisted only of 0.54 mg of MPs per kg of a soil sample, whereas the use of sewage sludge to agricultural soil enhanced the MPs concentration to 15,800 MPs/kg (Mahon et al., 2017; Zhang et al., 2018). Huang et al. (2020) investigated agricultural soils by examining 384 sediment samples gathered from 19 provinces across China. In places where plastic mulching was employed consistently, microplastic particle abundance rose over time, with an amount of 80.3 49.3, 308138.1, and 1075.6346.8 items per kg soil in fields with 5, 15, and 24 years of continuous mulching, respectively.

Zhang and Liu (2018) took polymer samples from one untreated afforested site close to Kunming and four farmland locations with sewage sludge and wastewater application. They discovered average concentrations of 26,070 items/kg with a minimum concentration of 13,470 items/kg and a maximum concentration of 42,960 particles per kg in farmland Gleysol, 14,440 particles per kg (min, 8180 particles/kg; max, 18,100 particles/kg) in an afforested Gleysol and 12,050 particles per kg (min, 7100 particles/kg; max, 26,630 particles /kg) in farmland Nitsol. This suggests that not only the plastic load but also the soil type are considered as factors in MP concentrations in soils. Zhou et al. (2019a, b) investigated the prevalence and quantity of MPs, as well as their interactions with heavy metals, across three different subareas in central China. The concentration of MPs ranged from 2.2×10^4 to 6.9×10^5 items/kg according to the findings. MP distribution was much greater in the forest (4.1×10^5 items/kg) compared to the vegetable land (1.6×10^5 items/kg) or barren land (1.2×10^5 items/kg) (Table 3.6).

Another study on Yunnan, China, showed MP concentrations ranged from 7100 to 42,960 particles/kg with an average concentration of 18,760 particles/kg in cropped soils (Zhang & Liu, 2018). In Shanghai, the abundance of microplastics in shallow and deep soils was 78.00 ± 12.91 and 62.50 ± 12.97 items/kg, respectively. Furthermore, topsoil had a higher amount and greater sizes of micro(meso)plastics

Table 3.6 Distribution of microplastics and nanoplastic in terrestrial soil across Eastern Asia

Countries	Location	Sample type	Concentration (items/kg)	References
China	Shanghai	Vegetable farmland	70	Liu et al. (2019)
	Nanjing and Wuxi	Agricultural land soil	855	Li et al. (2019a, b)
	Wuhan	Vegetable plots soil	16,000	Zhou et al. (2019a, b)
	Wuhan	Vegetable Farmland	2020	Chen et al. (2020)
	Hangzhou	Agricultural soils	503.3	Zhou et al. (2020)
	Shaanxi	Agricultural soils	2420	Ding et al. (2020)
	Xinjiang	Agricultural soils	308 ± 138.1	Huang et al. (2020)
	Heilongjiang	Farmland Mollisol	107	Zhang et al. (2020)
	Hebei	Beach soils	317/500 g	Zhou et al. (2016)
	Shangdong	Beach soils	1.3–14712.5	Zhou et al. (2018)
	Loess plateau	Agricultural field	<0.54 mg/kg	Zhang et al. (2018)
	Yunnan	Tree-planted soils	7100–42,960	Zhang et al. (2018)
	Dagoujian and Shangusan	Cropland soils	12,960	Zhang et al. (2018)
	Kunming	Farmland Gleysols	26,070	Zhang et al. (2018)
		Farmland Nitisols	12,050	
		Afforested Gleysols	14,440	
Korea	Yeoju City	Agricultural soils	664	Choi et al. (2021)

compared to deep soil, according to this study (Liu et al., 2018). Chai et al. (2020a, b) studied 33 samples of soil collected from an e-waste disposal region in China's Guangdong Province. MP was found in 30 soils, with a maximum distribution of 34,100 items/kg, indicating that an e-waste disposal location has developed into a hotspot for MP. In another study, MP abundance is found in soils from an e-waste recycling facility ranging from 600 to 14,200 pieces/kg (Zhang et al., 2021).

According to a Korean study, the soils of Yeoju had a mean of 700 items/kg of microplastics, with the highest amount of microplastics detected from upland soil (3440 items/kg). Though the average dispersion of microplastics in soils samples of agricultural land was 664 pieces/kg, this varied by farming type; orchard sites had the highest abundance, followed by greenhouse, upland, and paddy field sites (Choi et al., 2021). The high concentration of microplastics in agricultural soils (664 ± 83 pieces/kg) highlighted the influence of agricultural activities on soil microplastic contamination, which is likely related to the mulching and usage of vinyl films (Rodríguez-Seijo & Pereira, 2019).

3.3.4 Antarctica

Analysis of the abundance of MPs & NPs has been done along the nearshore region of Ross Sea, Antarctica, where the range has been detected to be 0.0032 to 1.18 particles/m^3 with an average amount of 0.17 ± 0.34 particles/m^3 (Cincinelli et al., 2017) (Table 3.7).

3.3.5 Australia

The concentration of MPs and NPs in soils near an industrial facility has been detected to be of the amount 2400 mg/kg on an average in Sydney of Australia. The min amount has been found to be 300 mg/kg, and the max amount has been recorded to be 67,500 mg/kg, which can be considered as a high contamination region. (Fuller & Gautam, 2016) (Table 3.8).

Table 3.7 Distribution of microplastics and nanoplastic in terrestrial ecosystems across Antarctica

Countries	Location	Concentration (items/kg)	Sample type	References
Antarctica	Ross Sea	0.17 ± 0.34	Sediment	Cincinelli et al. (2017)

Table 3.8 Distribution of microplastics and nanoplastic in terrestrial ecosystems across Australia

Countries	Location	Concentration (mg/kg)	Sample Type	References
Australia	Sydney	2400	Sediment	Fuller and Gautam (2016)

3.3.6 Europe

According to several studies, MPs and NPs have been found in sediments, seawater, and freshwater across Europe. The Table 3.9 represents the distribution of MP and NP in the terrestrial ecosystem across Europe. Italy, Spain, the Netherlands, and the UK recorded the presence of a high amount of MPs and NPs within the sediments with Spain showing the highest amount MP and NP of 3330 items/kg detected in the croplands of the rural areas of Valencia (van den Berg et al., 2020).

The highest amount of MPs and NPs has been found to be 1108 ± 983 items/m^2 in the sediments of the Lake Garda (Imhof et al., 2017). Concentration in the regions of Lake Bolsena and Lake Chiusi has been detected to be 112 and 234 items/kg (Fischer et al., 2016). The distribution of MPs and NPs in the country of Italy has been found to be directly proportionate to the presence of industries and human-induced contamination. Human activities, tourism, industrial activities, and urban development are directly related to the pollution of MPs and NPs (Frère et al., 2017; Gündoğdu & Çevik, 2017; Tubau et al., 2015; de Lucia et al., 2014; Barnes et al., 2009). MP and NP contamination in sediment is found to be higher where there's a high human settlement (Collet & Engelbert, 2013).

A higher concentration of MPs and NPs has been reported in the sediments of the Meuse River (1400 items/kg) of the Netherlands compared to the abundance detected in the sewage sludge (650 items/kg) by Leslie et al. (2017). A high concentration of MP and NP (660 and 300 items/kg) has also been recorded in the regions of River Thames Basin and Edgbaston Pool, Birmingham, of the UK (Horton et al. 2017a, b; Vaughan et al., 2017).

Table 3.9 Distribution of microplastics and nanoplastic in terrestrial ecosystems across Europe

Countries	**Location**	**Concentration (items/kg)**	**Sample type**	**References**
UK	River Thames Basin	660	Sediment	Horton et al. (2017a, b)
UK	Edgbaston Pool, Birmingham	250–300	Sediment	Vaughan et al. (2017)
Netherlands	Dutch	650	Sewage sludge	Leslie et al. (2017)
Netherlands	Meuse River	1400	Sediment	Leslie et al. (2017)
Italy	Lake Bolsena	112	Sediment	Fischer et al. (2016)
Italy	Lake Chiusi	234	Sediment	Fischer et al. (2016)
Spain	Valencia	3330	Sediment	Van den Berg et al. (2020)
Countries	**Location**	**Concentration (items/m^2)**	**Sample type**	**References**
Italy	Lake Garda	1108 ± 983	Sediment	Imhof et al. (2017)
France	Rhône River	0.06 to 1	Sediment	Schmidt et al. (2018)
Germany	Rhine	0.892777	Sediment	Mani et al. (2015)

However, the distribution of detected MP and NP has been found to be significantly low compared to the other studied regions in the terrestrial ecosystem of France and Germany where the amount has been reported to be 0.06 to 1 and 0.892777 items/kg, respectively (Schmidt et al., 2018; Mani et al., 2015).

The presence of buoyant MPs and NPs detected in the sediment serves as a testament to the existence of different types of microplastic getting trapped in sediment during the process of sedimentation (Chae et al., 2015). The deposition of these sorts of MPs within the sediments relates to the extent of maturity which modifies the item thickness, shape, and the improvement of surface biofilm (Long et al., 2015; Cózar et al., 2014).

References

Abidli, S., Lahbib, Y., & El Menif, N. T. (2019). Microplastics in commercial molluscs from the lagoon of Bizerte (Northern Tunisia). *Marine Pollution Bulletin, 142*, 243–252. https://doi.org/10.1016/j.marpolbul.2019.03.048

Antunes, J. C., Frias, J. P. G. L., Micaelo, A. C., & Sobral, P. (2013). Resin pellets from beaches of the Portuguese coast and adsorbed persistent organic pollutants. *Estuarine, Coastal and Shelf Science, 130*, 62–69.

Ballent, P. L., Corcoran, M., Odile, H., Paul, A., & Longstaffe, F. J. (2016). Sources and sinks of microplastics in Canadian Lake Ontario nearshore, tributary and beach sediments. *Marine Pollution Bulletin, 110*, 383e395. https://doi.org/10.1016/j.marpolbul.2016.06.037

Barnes, D. K., Galgani, F., Thompson, R. C., et al. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*, 1985–1998. https://doi.org/10.1098/rstb.2008.0205

Blasing, M., & Amelung, W. (2018). Plastics in soil: Analytical methods and possible sources. *Science of the Total Environment, 612*, 422–435.

Bradford, S. A., & Torkzaban, S. (2012). Colloid adhesive parameters for chemically heterogeneous porous media. *Langmuir, 28*, 13643–13651.

Bradford, S. A., Yates, S. R., Bettahar, M., & Simunek, J. (2002). Physical factors affecting the transport and fate of colloids in saturated porous media. *Water Resources Research, 38*, 63–61.

Brady, N. C., & Weil, R. R. (2000). *Nature and properties of soils*. Macmillan Publishing Company.

Büks, F., & Kaupenjohann, M. (2020). Global concentrations of microplastics in soils–a review. *The Soil, 6*(2), 649–662. https://doi.org/10.5194/soil-6-649-2020

Cey, E. E., Rudolph, D. L., & Passmore, J. (2009). Influence of macro porosity on preferential solute and colloid transport in unsaturated field soils. *Journal of Contaminant Hydrology, 107*, 45–57.

Chae, D. H., Kim, I. S., Kim, S. K., et al. (2015). Abundance and distribution characteristics of microplastics in surface seawaters of the Incheon/Kyeonggi coastal region. *Archives of Environmental Contamination and Toxicology, 69*, 269–278. https://doi.org/10.1007/s00244-015-0173-4

Chai, B., Li, X., Liu, H., Lu, G., Dang, Z., & Yin, H. (2020a). Bacterial communities on soil microplastic at Guiyu, an E-Waste dismantling zone of China. *Ecotoxicology and Environmental Safety, 195*, 110521. https://doi.org/10.1016/j.ecoenv.2020.110521

Chai, B. W., Wei, Q., She, Y. Z., Lu, G. N., Dang, Z., & Yin, H. (2020b). Soil microplastic pollution in an e-waste dismantling zone of China. *Waste Management, 118*, 291–301.

Chakraborty, P., Mukhopadhyay, M., Sampath, S., Ramaswamy, B. R., Katsoyiannis, A., Cincinelli, A., & Snow, D. (2019). Organic micropollutants in the surface riverine sediment along the lower stretch of the transboundary river Ganga: Occurrences, sources and ecological risk assessment. *Environmental Pollution, 249*, 1071–1080. https://doi.org/10.1016/j.envpol.2018.10.115

Chamas, A., Moon, H., Zheng, J., Qiu, Y., Tabassum, T., Jang, J. H., Abu-Omar, M., Scott, S. L., & Suh, S. (2020). Degradation rates of plastics in the environment. *ACS Sustainable Chemistry & Engineering, 8*(9), 3494–3511. https://doi.org/10.1021/acssuschemeng.9b06635

Chen, Y., Leng, Y., Liu, X., & Wang, J. (2020). Microplastic pollution in vegetable farmlands of suburb Wuhan, Central China. *Environmental Pollution, 257*, 113449. https://doi.org/10.1016/j.envpol.2019.113449

Choi, Y. R., Kim, Y. N., Yoon, J. H., Dickinson, N., & Kim, K. H. (2021). Plastic contamination of forest, urban, and agricultural soils: A case study of Yeoju City in the Republic of Korea. *Journal of Soils and Sediments, 21*(5), 1962–1973. https://doi.org/10.1007/s11368-020-02759-0

Cincinelli, A., Scopetani, C., Chelazzi, D., Lombardini, E., Martellini, T., Katsoyiannis, A., Fossi, M. C., & Corsolini, S. (2017). Microplastic in the surface waters of the Ross Sea (Antarctica): Occurrence, distribution, and characterization by FTIR. *Chemosphere, 175*, 391–400. https://doi.org/10.1016/j.chemosphere.2017.02.024

Cole, M., & Galloway, T. S. (2015). Ingestion of Nanoplastics and Microplastics by Pacific Oyster Larvae. *Environmental Science & Technology, 49*(24), 14625–14632. https://doi.org/10.1021/acs.est.5b04099

Collet, I., & Engelbert, A. (2013). Coastal regions: People living along the coastline, integration of NUTS 2010 and latest population grid. *Statistics in Focus, 30*. ISSN:2314-9647.

Corradini, F., Meza, P., Eguiluz, R., Casado, F., Huerta-Lwanga, E., & Geissen, V. (2019). Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal. *Science of the Total Environment, 671*, 411–420. https://doi.org/10.1016/j.scitotenv.2019.03.368

Corradini, F., Casado, F., Leiva, V., Huerta-Lwanga, E., & Geissen, V. (2021). Microplastics occurrence and frequency in soils under different land use on a regional scale. *Science of the Total Environment, 752*, 141917. https://doi.org/10.1016/j.scitotenv.2020.141917

Cózar, A., Echevarría, F., González-Gordillo, J. I., et al. (2014). Plastic debris in the open ocean. *Proceedings of the National Academy of Sciences, 111*, 10239–10244. https://doi.org/10.1073/pnas.1314705111

Crossman, J., Hurley, R. R., Futter, M., & Nizzetto, L. (2020). Transfer and transport of microplastics from biosolids to agricultural soils and the wider environment. *Science of the Total Environment, 724*, 138334. https://doi.org/10.1016/j.scitotenv.2020.138334

Dahms, H. T. J., van Rensburg, G. J., & Greenfield, R. (2020). The microplastic profile of an urban African stream. *Science of the Total Environment, 731*, 138893. https://doi.org/10.1016/j.scitotenv.2020.138893

De Lucia, G. A., Caliani, I., Marra, S., et al. (2014). Amount and distribution of neustonic micro-plastic off the western Sardinian coast (Central-Western Mediterranean Sea). *Marine Environmental Research, 100*, 10–16. https://doi.org/10.1016/j.marenvres.2014.03.017

Ding, L., Zhang, S., Wang, X., Yang, X., Zhang, C., Qi, Y., & Guo, X. (2020). The occurrence and distribution characteristics of microplastics in the agricultural soils of Shaanxi Province, in north-western China. *Science of the Total Environment, 720*, 137525. https://doi.org/10.1016/j.scitotenv.2020.137525

Ding, L., Wang, X., Ouyang, Z., Chen, Y., Wang, X., Liu, S., Yang, X., Jia, H., & Guo, X. (2021). The occurrence of microplastic in Mu Us Sand Land soils in northwest China: Different soil types, vegetation cover and restoration years. *Journal of Hazardous Materials, 403*, 123982.

Duis, K., & Coors, A. (2016). Microplastics in the aquatic and terrestrial environment: Sources (with a specific focus on personal care products), fate and effects. *Environmental Sciences Europe, 28*, 1–25. https://doi.org/10.1186/s12302-015-0069-y

El-Farhan, Y. H., DeNovio, N. M., Herman, J. S., & Hornberger, G. M. (2000). Mobilization and transport of soil particles during infiltration experiments in an agricultural field, Shenandoah valley, Virginia. *Environmental Science & Technology, 34*, 3555e3559.

Fischer, E. K., Paglialonga, L., Czech, E., et al. (2016). Microplastic pollution in lakes and lake shoreline sediments – A case study on Lake Bolsena and Lake Chiusi (central Italy). *Environmental Pollution, 213*, 648–657. https://doi.org/10.1016/j.envpol.2016.03.012

Frère, L., Paul-Pont, I., Rinnert, E., et al. (2017). Influence of environmental and anthropogenic factors on the composition, concentration and spatial distribution of microplastics: A case study of the Bay of Brest (Brittany, France). *Environmental Pollution, 225*, 211–222. https://doi.org/10.1016/j.envpol.2017.03.023

Fuller, S., & Gautam, A. (2016). A procedure for measuring microplastics using pressurized fluid extraction. *Environmental Science & Technology, 50*(11), 5774–5780. https://doi.org/10.1021/acs.est.6b00816

Gabet, E. J., Reichman, O. J., & Seabloom, E. W. (2003). The effects of bioturbation on soil processes and sediment transport. *Annual Review of Earth and Planetary Sciences, 31*, 249–273.

Galloway, T. S., Cole, M., & Lewis, C. (2017). Interactions of microplastic debris throughout the marine ecosystem. *Nature Ecology & Evolution, 1*, 0116. https://doi.org/10.1038/s41559-017-0116

Gao, F. L., Li, J. X., Sun, C. J., Zhang, L. T., Jiang, F. H., Cao, W., & Zheng, L. (2019). Study on the capability and characteristics of heavy metals enriched on microplastics in marine environment. *Marine Pollution Bulletin, 144*, 61–67.

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances, 3*(7), e1700782. https://doi.org/10.1126/sciadv.1700782

Gourmelon, G. (2015). Global plastic production rises, recycling lags. *Vital Signs, 22*, 91–95.

Gündoğdu, S., & Çevik, C. (2017). Micro- and mesoplastics in Northeast Levantine coast of Turkey: The preliminary results from surface samples. *Marine Pollution Bulletin, 118*, 341–347. https://doi.org/10.1016/j.marpolbul.2017.03.002

Harms, I. K., Diekoetter, T., Troegel, S., & Lenz, M. (2021). Amount, distribution and composition of large microplastics in typical agricultural soils in Northern Germany. *Science of The Total Environment, 758*, 143615.

Helcoski, R., Yonkos, L. T., Sanchez, A., & Baldwin, A. H. (2020). Wetland soil microplastics are negatively related to vegetation cover and stem density. *Environmental Pollution, 256*, 113391. https://doi.org/10.1016/j.envpol.2019.113391

Horton, A. A., Svendsen, C., Williams, R. J., et al. (2017a). Large microplastic particles in sediments of tributaries of the River Thames, UK – Abundance, sources and methods for effective quantification. *Marine Pollution Bulletin, 114*, 218–226. https://doi.org/10.1016/j.marpolbul.2016.09.004

Horton, A. A., et al. (2017b). 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*, 127–141.

Huang, Y., Liu, Q., Jia, W., Yan, C., & Wang, J. (2020). Agricultural plastic mulching as a source of microplastics in the terrestrial environment. *Environmental Pollution, 260*, 114096. https://doi.org/10.1016/j.envpol.2020.114096

Huerta Lwanga, E., Gertsen, H., Gooren, H., Peters, P., Salánki, T., van der Ploeg, M., Besseling, E., Koelmans, A. A., & Geissen, V. (2016). Microplastics in the terrestrial ecosystem: Implications for *Lumbricus terrestris* (Oligochaeta, Lumbricidae). *Environmental Science & Technology, 50*(5), 2685–2691. https://doi.org/10.1021/acs.est.5b05478

Hurley, R. R., & Nizzetto, L. (2018). Fate and occurrence of micro(nano)plastics in soils: Knowledge gaps and possible risks. *Current Opinion in Environmental Science & Health, 1*, 6–11.

Imhof, H. K., Sigl, R., Brauer, E., et al. (2017). Spatial and temporal variation of macro-, meso- and microplastic abundance on a remote coral island of the Maldives, Indian Ocean. *Marine Pollution Bulletin, 116*, 340–347. https://doi.org/10.1016/j.marpolbul.2017.01.010

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science, 347*(6223), 768–771. https://doi.org/10.1126/science.1260352

Jiang, X., Chen, H., Liao, Y., Ye, Z., Li, M., & Klobucar, G. (2019). Ecotoxicity and genotoxicity of polystyrene microplastics on higher plant Vicia faba. *Environmental Pollution, 250*, 831–838.

Kim, I. S., Chae, D. H., & Kim, S. K. (2015). Factors influencing the spatial variation of microplastics on high-tidal coastal beaches in Korea. *Archives of Environmental Contamination and Toxicology, 69*, 299–309. https://doi.org/10.1007/s00244-015-0155-6

Klein, S., Worch, E., & Knepper, T. P. (2015). Occurrence and spatial distribution of microplastics in river shore sediments of the Rhine-Main area in Germany. *Environmental Science & Technology, 49*(10), 6070–6076. https://doi.org/10.1021/acs.est.5b00492

Koelmans, A. A., Besseling, E., & Shim, W. J. (2015). Nanoplastics in the aquatic environment. In M. Bergmann, L. Gutow, & M. Klages (Eds.), *Critical review BT – Marine anthropogenic litter* (pp. 325–334). Springer International Publishing. https://doi.org/10.1007/978-3-319-16510-3_12

Koutnik, V. S., Leonard, J., Alkidim, S., Deprima, F. J., Ravi, S., Hoek, E. M. V., & Mohanty, S. K. (2021). Distribution of microplastics in soil and freshwater environments: Global analysis and framework for transport modeling. *Environmental Pollution, 274*, 116552.

Leslie, H. A., Brandsma, S. H., van Velzen, M. J. M., et al. (2017). Microplastics en route: Field measurements in the Dutch river delta and Amsterdam canals, wastewater treatment plants, North Sea sediments and biota. *Environment International, 101*, 133–142. https://doi.org/10.1016/j.envint.2017.01.018

Li, J., Song, Y., & Cai, Y. (2019a). Focus topics on microplastics in soil: Analytical methods, occurrence, transport, and ecological risks. *Environmental Pollution, 257*, 113570.

Li, Q., Wu, J., Zhao, X., Gu, X., & Ji, R. (2019b). Separation and identification of microplastics from soil and sewage sludge. *Environmental Pollution, 254*, 113076. https://doi.org/10.1016/j.envpol.2019.113076

Liu, M., Lu, S., Song, Y., Lei, L., Hu, J., Lv, W., Zhou, W., Cao, C., Shi, H., Yang, X., & He, D. (2018). Microplastic and mesoplastic pollution in farmland soils in suburbs of Shanghai, China. *Environmental Pollution, 242*, 855–862. https://doi.org/10.1016/j.envpol.2018.07.051

Liu, M., Song, Y., Lu, S., Qiu, R., Hu, J., Li, X., Bigalke, M., Shi, H., & He, D. (2019). A method for extracting soil microplastics through circulation of sodium bromide solutions. *Science of the Total Environment, 691*, 341–347. https://doi.org/10.1016/j.scitotenv.2019.07.144

Long, M., Moriceau, B., Gallinari, M., et al. (2015). Interactions between microplastics and phytoplankton aggregates: Impact on their respective fates. *Marine Chemistry, 175*, 39–46. https://doi.org/10.1016/j.marchem.2015.04.003

Lwanga, E. H., Gertsen, H., Gooren, H., Peters, P., Salanki, T., van der Ploeg, M., et al. (2017a). Incorporation of microplastics from litter into burrows of Lumbricus terrestris. *Environmental Pollution, 220*, 523–531.

Lwanga, E. H., Vega, J. M., Quej, V. K., de los Angeles Chi, J., Del Cid, L. S., Chi, C., Segura, G. E., Gertsen, H., Salánki, T., van der Ploeg, M., & Koelmans, A. A. (2017b). Field evidence for transfer of plastic debris along a terrestrial food chain. *Scientific Reports, 7*(1), 1–7. https://doi.org/10.1038/s41598-017-14588-2

Maaß, S., Daphi, D., Lehmann, A., & Rillig, M. C. (2017). Transport of microplastics by two collembolan species. *Environmental Pollution, 225*, 456–459.

Machado, A. A. D., Lau, C. W., Kloas, W., Bergmann, J., Bacheher, J. B., Faltin, E., Becker, R., Gorlich, A. S., & Rillig, M. C. (2019). Microplastics can change soil properties and affect plant performance. *Environmental Science & Technology, 53*, 6044–6052.

Mahon, A. M., O'Connell, B., Healy, M. G., O'Connor, I., Officer, R., Nash, R., & Morrison, L. (2017). Microplastics in sewage sludge: Effects of treatment. *Environmental Science & Technology, 51*(2), 810–818. https://doi.org/10.1021/acs.est.6b04048

Maity, S., & Pramanick, K. (2020). Perspectives and challenges of micro/nano plastics induced toxicity with special reference to phytotoxicity. *Global Change Biology, 26*, 3241–3250.

Majdalani, S., Michel, E., Di-Pietro, L., & Angulo-Jaramillo, R. (2008). Effects of wetting and drying cycles on in situ soil particle mobilization. *European Journal of Soil Science, 59*, 147–155.

Mani, T., Hauk, A., Walter, U., et al. (2015). Microplastics profile along the Rhine River. *Scientific Reports, 5*, 17988. https://doi.org/10.1038/srep17988

McCarthy, J. F., & McKay, L. D. (2004). Colloid transport in the subsurface. *Vadose Zone Journal, 3*, 326–337.

Merga, L. B., Redondo-Hasselerharm, P. E., Van den Brink, P. J., & Koelmans, A. A. (2020). Distribution of microplastic and small macroplastic particles across four fish species and sediment in an African lake. *Science of the Total Environment, 741*, 140527. https://doi.org/10.1016/j.scitotenv.2020.140527

Mintenig, S. M., Int-Veen, I., Löder, M. G. J., Primpke, S., & Gerdts, G. (2017). Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-Fourier transform infrared imaging. *Water Research, 108*, 365–372.

Möller, J. N., Lö der, M. G. J., & Laforsch, C. (2020). Finding microplastics in soils: A review of analytical methods. *Environmental Science & Technology, 54*, 2078–2090.

Napper, I. E., Bakir, A., Rowland S. J., & Thompson, R. C. (2015). Characterisation quantity and sorptive properties of microplastics extracted from cosmetics. *Marine Pollution Bulletin, 99*(1–2), 178–185. S0025326X1500449X. https://doi.org/10.1016/j.marpolbul.2015.07.029

Napper, I. E., & Thompson, R. C. (2019). Environmental deterioration of biodegradable, oxo-biodegradable, compostable, and conventional plastic carrier bags in the sea, soil, and open-air over a 3-year period. *Environmental Science & Technology, 53*(9), 4775–4783. https://doi.org/10.1021/acs.est.8b06984

Nel, H. A., & Froneman, P. W. (2015). A quantitative analysis of microplastic pollution along the south-eastern coastline of South Africa. *Marine Pollution Bulletin, 101*(1), 274–279. https://doi.org/10.1016/j.marpolbul.2015.09.043

Nel, H. A., Dalu, T., & Wasserman, R. J. (2018). Sinks and sources: Assessing microplastic abundance in river sediment and deposit feeders in an Austral temperate urban river system. *Science of the Total Environment, 612*, 950–956. https://doi.org/10.1016/j.scitotenv.2017.08.298

Neto, J. A. B., de Carvalho, D. G., Medeiros, K., Drabinski, T. L., de Melo, G. V., Silva, R. C. O., Silva, D. C. P., de Sousa Batista, L., Dias, G. T. M., da Fonseca, E. M., & dos Santos Filho, J. R. (2019). The impact of sediment dumping sites on the concentrations of microplastic in the inner continental shelf of Rio de Janeiro/Brazil. *Marine Pollution Bulletin, 149*, 110558. https://doi.org/10.1016/j.marpolbul.2019.110558

Ng, E. L., Lwanga, E. H., Eldridge, S. M., Johnston, P., Hu, H. W., Geissen, V., & Chen, D. L. (2018). An overview of microplastic and nanoplastic pollution in agroecosystems. *Science of the Total Environment, 627*, 1377–1388.

Nizzetto, L., Bussi, G., Futter, M. N., Butterfield, D., & Whitehead, P. G. (2016a). A theoretical assessment of microplastic transport in river catchments and their retention by soils and river sediments. *Environmental Science: Processes & Impacts, 18*, 1050–1059.

Nizzetto, L., Futter, M., & Langaas, S. (2016b). Are agricultural soils dumps for microplastics of urban origin? *Environmental Science & Technology, 50*, 10777–10779. https://doi.org/10.1021/acs.est.6b04140

O'Connor, D., Pan, S., Shen, Z., Song, Y., Jin, Y., Wu, W., & Hou, D. (2019a). Microplastics undergo accelerated vertical migration in sand soil due to small size and wet-dry cycles. *Environmental Pollution, 249*(2019), 527–534.

O'Connor, D., Hou, D., Ok, Y. S., Mulder, J., Duan, L., Wu, Q., Wang, S., Tack, F. M. G., & Rinklebe, J. (2019b). Mercury speciation, transformation, and transportation in soils, atmospheric flux, and implications for risk management: A critical review. *Environment International, 126*, 747–761.

Peeken, I., Primpke, S., Beyer, B., Guetermann, J., Katlein, C., Krumpen, T., Bergmann, M., Hehemann, L., & Gerdts, G. (2018). Arctic sea ice is an important temporal sink and means of transport for microplastic. *Nature Communications, 9*, 1505.

Pelley, A. J., & Tufenkji, N. (2008). Effect of particle size and natural organic matter on the migration of nano- and micro scale latex particles in saturated porous media. *Journal of Colloid and Interface Science, 321*, 74–83.

Plastics Europe. (2019). *Plastics – the facts, 2019. An analysis of European plastics production, demand and waste data*.

Rafique, A., Irfan, M., Mumtaz, M., & Qadir, A. (2020). Spatial distribution of microplastics in soil with context to human activities: A case study from the urban center. *Environmental Monitoring and Assessment, 192*(11), 1–13. https://doi.org/10.1007/s10661-020-08641-3

Rahman, S. M. A., Robin, G. S., Momotaj, M., Uddin, J., & Siddique, M. A. M. (2020). Occurrence and spatial distribution of microplastics in beach sediments of Cox's Bazar, Bangladesh. *Marine Pollution Bulletin, 160*, 111587. https://doi.org/10.1016/j.marpolbul.2020.111587

Rahmatpour, S., Mosaddeghi, M. R., Shirvani, M., & Simunek, J. (2018). Transport of silver nanoparticles 794 in intact columns of calcareous soils: The role of flow conditions and soil texture. *Geoderma, 322*, 79589–79100.

Rakib, M., Jahan, R., Al Nahian, S., Alfonso, M. B., Khandaker, M. U., Enyoh, C. E., Hamid, F. S., Alsubaie, A., Almalki, A. S., Bradley, D. A., & Mohafez, H. (2021). Microplastics pollution in salt pans from the Maheshkhali Channel, Bangladesh. *Scientific Reports, 11*(1), 1–10. https://doi.org/10.1038/s41598-021-02457-y

Ramos, L., Berenstein, G., Hughes, E. A., Zalts, A., & Montserrat, J. M. (2015). Polyethylene film incorporation into the horticultural soil of small periurban production units in Argentina. *Science of the Total Environment, 523*, 74–81. https://doi.org/10.1016/j.scitotenv.2015.03.142

Rezaei, M., Riksen, M. J. P. M., Sirjani, E., Sameni, A., & Geissen, V. (2019). Wind erosion as a driver for transport of light density microplastics. *Science of the Total Environment, 669*, 273–281.

Rillig, M. C. (2012). Microplastic in terrestrial ecosystems and the soil? *Environmental Science & Technology, 46*, 6453–6454. https://doi.org/10.1021/es302011r

Rillig, M. C., & Lehmann, A. (2020). Microplastic in terrestrial ecosystems. *Science, 368*(6498), 1430–1431. https://doi.org/10.1126/science.abb5979

Rillig, M. C., Ziersch, L., & Hempel, S. (2017a). Microplastic transport in soil by earthworms. *Scientific Reports, 7*, 1362.

Rillig, M. C., Ingraffia, R., & Machado, A. A. S. (2017b). Microplastic incorporation into soil in agroecosystems. *Frontiers in Plant Science, 8*, 1805. https://doi.org/10.3389/fpls.2017.01805

Rocha-Santos, T., & Duarte, A. C. (2015). A critical overview of the analytical approaches to the occurrence, the fate and the behavior of microplastics in the environment. *TrAC – Trends in Analytical Chemistry, 65*, 47. https://doi.org/10.1016/j.trac.2014.10.011

Rodríguez-Seijo, A., & Pereira, R. (2019). Microplastics in agricultural soils: Are they a real environmental hazard? In *Bioremediation of agricultural soils* (pp. 45–60). CRC Press. eBook ISBN9781315205137.

Sanchez-Hernandez, J. C., Del Pino, J. N., Capowiez, Y., Mazzia, C., & Rault, M. J. S. O. T. T. E. (2018). Soil enzyme dynamics in chlorpyrifos-treated soils under the influence of earthworms. *Science of the Total Environment, 612*, 1407–1416. https://doi.org/10.1016/j.scitotenv.2017.09.043

Scheurer, M., & Bigalke, M. (2018). Microplastics in Swiss floodplain soils. *Environmental Science & Technology, 52*, 3591–3598.

Schmidt, N., Thibault, D., Galgani, F., et al. (2018). Occurrence of microplastics in surface waters of the Gulf of Lion (NW Mediterranean Sea). *Progress in Oceanography, 163*, 214–220. https://doi.org/10.1016/j.pocean.2017.11.010

Sintim, H. Y., & Flury, M. (2017). Is biodegradable plastic mulch the solution to agriculture's plastic problem? Environ. *Environmental Science & Technologyy, 51*, 1068–1069.

Subrahmaniyan, K., Kalaiselvan, P., Balasubramanian, T. N., & Zhou, W. (2006). Crop productivity and soil properties as affected by polyethylene film mulch and land configurations in groundnut (Arachis hypogaea L.). *Archives of Agronomy and Soil Science, 52*(1), 79–103.

Tajwar, M., Gazi, M. Y., & Saha, S. K. (2021). Characterization and spatial abundance of microplastics in the coastal regions of Cox's Bazar, Bangladesh: An integration of field, laboratory, and GIS techniques. *Soil and Sediment Contamination: An International Journal, 31*, 1–25. https://doi.org/10.1080/15320383.2021.1910622

Tajwar, M., Shreya S. S., Gazi, M. Y., Hasan, M., & Saha, S. K. (2022a). Microplastic contamination in the sediments of the Saint Martin's Island Bangladesh. *Regional Studies in Marine Science* 53102401-S2352485522001232 102401. https://doi.org/10.1016/j.rsma.2022.102401

Tajwar, M., Shreya S. S., Hasan M., Hossain M. B., Gazi M. Y., & Sakib N. (2022b). Assessment of microplastics as contaminants in a coal mining region. *Heliyon 8*(11), e11666-S2405844022029541 e11666. https://doi.org/10.1016/j.heliyon.2022.e11666

The Jakarta Post. (2019). *Inadequate landfills worsen Indonesia's waste problems*. https://www.thejakartapost.com/news/2019/03/03/inadequate-landfills-worsen-indonesias-waste-problems.html

Tibbetts, J., Krause, S., Lynch, I., & Sambrook Smith, G. (2018). Abundance, distribution, and drivers of microplastic contamination in urban river environments. *Water, 10*(11), 1597. https://doi.org/10.3390/w10111597

Toumi, H., Abidli, S., & Bejaoui, M. (2019). Microplastics in freshwater environment: The first evaluation in sediments from seven water streams surrounding the lagoon of Bizerte (Northern Tunisia). *Environmental Science and Pollution Research, 26*(14), 14673–14682. https://doi.org/10.1007/s11356-019-04695-0

Treumann, S., Torkzaban, S., Bradford, S. A., Visalakshan, R. M., & Page, D. (2014). An explanation for differences in the process of colloid adsorption in batch and column studies. *Journal of Contaminant Hydrology, 843164*, 219–229.

Tubau, X., Canals, M., Lastras, G., et al. (2015). Marine litter on the floor of deep submarine canyons of the Northwestern Mediterranean Sea: The role of hydrodynamic processes. *Progress in Oceanography, 134*, 379–403. https://doi.org/10.1016/j.pocean.2015.03.013

Tun, T. Z., Kunisue, T., Tanabe, S., Prudente, M., Subramanian, A., Sudaryanto, A., Viet, P. H., & Nakata, H. (2022). Microplastics in dumping site soils from six Asian countries as a source of plastic additives. *Science of the Total Environment, 806*, 150912. https://doi.org/10.1016/j.scitotenv.2021.150912

van den Berg, P., Huerta-Lwanga, E., Corradini, F., & Geissen, V. (2020). Sewage sludge application as a vehicle for microplastics in eastern Spanish agricultural soils. *Environmental Pollution, 261*, 114198. https://doi.org/10.1016/j.envpol.2020.114198

Van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B. D., Van Franeker, J. A., Eriksen, M., Siegel, D., Galgani, F., & Law, K. L. (2015). A global inventory of small floating plastic debris. *Environmental Research Letters, 10*(12). https://doi.org/10.1088/1748-9326/10/12/124006

Vaughan, R., Turner, S. D., & Rose, N. L. (2017). Microplastics in the sediments of a UK urban lake. *Environmental Pollution, 229*, 10–18. https://doi.org/10.1016/j.envpol.2017.05.057

Wang, J., Li, J. Y., Liu, S. T., Li, H. Y., Chen, X. C., Peng, C., Zhang, P. P., & Liu, X. H. (2021). Distinct microplastic distributions in soils of different land-use types: a case study of Chinese farmlands. *Environmental Pollution, 2021*(269), 116199.

Weithmann, N., Moller, J. N., Loder, M. G. J., Piehl, S., Laforsch, C., & Freitag, R. (2018). Organic fertilizer as a vehicle for the entry of microplastic into the environment. *Science Advances, 4*, eaap8060.

Wick, L. Y., Remer, R., Würz, B., Reichenbach, J., Braun, S., Schäfer, F., et al. (2007). Effect of fungal hyphae on the access of bacteria to phenanthrene in soil. *Environmental Science & Technology, 41*, 500–505. https://doi.org/10.1021/es061407s

Wu, X., Lyu, X., Li, Z., Gao, B., Zeng, X., Wu, J., & Sun, Y. (2020). Transport of polystyrene nanoplastics in natural soils: Effect of soil properties, ionic strength and cation type. *Science of the Total Environment, 707*, 136065.

Yu, M., van der Ploeg, M., Lwanga, E. H., Yang, X. M., Zhang, S. L., Ma, X. Y., Ritsema, C. J., & Geissen, V. (2019). Leaching of microplastics by preferential flow in earthworm (Lumbricus terrestris) burrows. *Environmental Chemistry Letters, 16*, 31–40.

Zhang, G. S., & Liu, Y. F. (2018). The distribution of microplastics in soil aggregate fractions in southwestern China. *Science of the Total Environment, 642*, 12–20. https://doi.org/10.1016/j.scitotenv.2018.06.004

Zhang, S. L., Zhang, X. Y., Huffman, T., Liu, X. B., & Yang, J. Y. (2011). Influence of topography and land management on soil nutrients variability in Northeast China. *Nutrient Cycling in Agroecosystems, 89*, 427–438.

Zhang, S. L., Huang, J., Wang, Y., Shen, Q. S., Mu, L. L., & Liu, Z. H. (2017). Spatiotemporal heterogeneity of soil available nitrogen during crop growth stages on mollisol slopes of Northeast China. *Land Degradation and Development, 28*, 856–869.

Zhang, S., Yang, X., Gertsen, H., Peters, P., Salánki, T., & Geissen, V. (2018). A simple method for the extraction and identification of light density microplastics from soil. *Science of the Total Environment, 616–617*, 1056–1065. https://doi.org/10.1016/j.scitotenv.2017.10.213

Zhang, S., Liu, X., Hao, X., Wang, J., & Zhanget, Y. (2019). Distribution of low-density microplastics in the mollisol farmlands of northeast China. *Science of the Total Environment, 708*. https://doi.org/10.1016/j.scitotenv.2019.135091

Zhang, D., Ng, E. L., Hu, W., Wang, H., Galaviz, P., Yang, H., Sun, W., Li, C., Ma, X., Fu, B., & Zhao, P. (2020). Plastic pollution in croplands threatens long-term food security. *Global Change Biology, 26*(6), 3356–3367. https://doi.org/10.1111/gcb.15043

Zhang, Z., Cui, Q., Chen, L., Zhu, X., Zhao, S., Duan, C., Zhang, X., Song, D., & Fang, L. (2021). A critical review of microplastics in the soil-plant system: Distribution, uptake, phytotoxicity and prevention. *Journal of Hazardous Materials, 424*, 127750. https://doi.org/10.1016/j.jhazmat.2021.127750

Zhou, Q., Zhang, H., Zhou, Y., Li, Y., Xue, Y., Fu, C., Tu, C., & Luo, Y. (2016). Separation of microplastics from a coastal soil and their surface microscopic features. *Chinese Science Bulletin, 61*(14), 1604–1611. https://doi.org/10.1360/N972015-01098

Zhou, B. Y., Wang, J. Q., Zhang, H. B., Shi, H. H., Fei, Y. F., Huang, S. Y., Tong, Y. Z., Wen, D., Zhou, Q., Zhang, H., Fu, C., Zhou, Y., Dai, Z., Li, Y., Tu, C., & Luo, Y. (2018). The distribution and morphology of microplastics in coastal soils adjacent to the Bohai Sea and the Yellow Sea. *Geoderma, 322*, 201–208. https://doi.org/10.1016/j.geoderma.2018.02.015

Zhou, B., Wang, J., Zhang, H., Shi, H., Fei, Y., Huang, S., Tong, Y., Wen, D., Luo, Y., & Barceló, D. (2019a). Microplastics in agricultural soils on the coastal plain of Hangzhou Bay, east China: Multiple sources other than plastic mulching film. *Journal of Hazardous Materials, 388*, 121814.

Zhou, Y., Liu, X., & Wang, J. (2019b). Characterization of microplastics and the association of heavy metals with microplastics in suburban soil of central China. *Science of the Total Environment, 694*, 133798. https://doi.org/10.1016/j.scitotenv.2019.133798

Zhou, B., Wang, J., Zhang, H., Shi, H., Fei, Y., Huang, S., Tong, Y., Wen, D., Luo, Y., & Barceló, D. (2020). Microplastics in agricultural soils on the coastal plain of Hangzhou Bay, east China: Multiple sources other than plastic mulching film. *Journal of Hazardous Materials, 388*, 121814. https://doi.org/10.1016/j.jhazmat.2019.121814

Zhu, D., Bi, Q. F., Xiang, Q., Chen, Q. L., Christie, P., Ke, X., et al. (2018). Trophic predator-prey relationships promote transport of microplastics compared with the single Hypoaspis aculeifer and Folsomia candida. *Environmental Pollution, 235*, 150–154.

Zhu, F., Zhu, C., Wang, C., & Gu, C. (2019). Occurrence and ecological impacts of microplastics in soil systems: A review. *Bulletin of Environmental Contamination and Toxicology, 102*(6), 741–749. https://doi.org/10.1007/s00128-019-02623-z

Zhuang, J., Qi, J., & Jin, Y. (2005). Retention and transport of amphiphilic colloids under unsaturated flow conditions: Effect of particle size and surface property. *Environmental Science & Technology, 39*, 7853–7859.

Ziajahromi, S., Neale, P. A., & Leusch, F. D. L. (2016). Wastewater treatment plant effluent as a source of microplastics: Review of the fate, chemical interactions and potential risks to aquatic organisms. *Water Science and Technology, 74*, 2253–2269.

Zubris, K. A. V., & Richards, B. K. (2005). Synthetic fibers as an indicator of land application of sludge. *Environmental Pollution, 138*(2), 201–211. https://doi.org/10.1016/j.envpol.2005.04.013