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SPECIAL FEATURE: ORIGINAL ARTICLE

Plastic flow and its management

Assessment of microplastic pollution in agricultural soil of Bhopal, Central India

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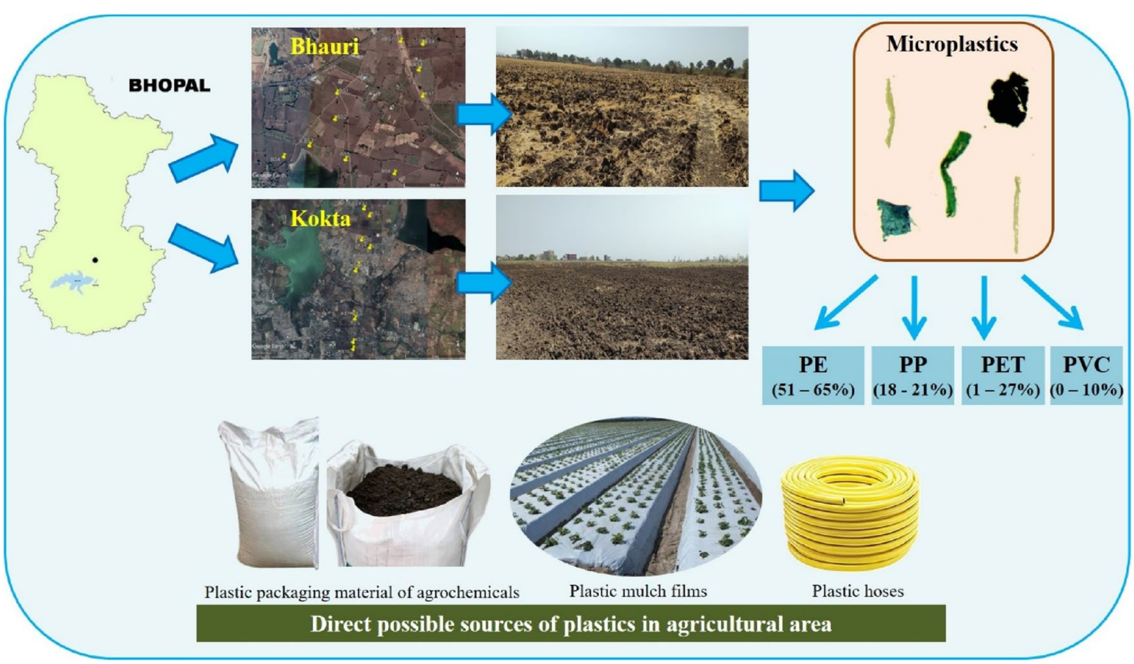
Abstract
Occurrence of microplastics in various environmental matrices is a global reality. Considering the significance of this fact, scientists are trying to identify and characterize this emerging contaminant in a variety of abiotic as well as biotic matrices, so that effective preventive measures may be adopted. Increasing plastic usage in agricultural practices in the form of packaging, mulching etc. have introduced this contaminant in agricultural soil as well. Therefore, present study was carried out in agricultural soil of Bhopal, Central India. Microplastics in agricultural soil were identified and characterized using FTIR spectroscopy, and further assessed for possible ecological risks. An amount of 307.5 ± 9.19 and 69.5 ± 4.95 particles were found in the 10 soil samples collected from each of the Bhauri and Kokta agricultural areas of Bhopal, respectively. Polyethylene and polypropylene were the most abundant microplastic polymers. Presence of these particles resulted in 'very-low' to 'low' hazard to the soil. Presence of plastic particles in agricultural soil of Bhopal was attributed to the littering of plastic packaging materials of various agrochemicals, and atmospheric deposition. Presence of microplastics may pose considerable risk to the agricultural soil, crop health, and subsequently to human health. Therefore, control measures to minimize plastic pollution need to be adopted.

Graphical abstract



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Keywords Agriculture · Central India · Microplastics · Risk assessment · Soil

Introduction

Agriculture is one of the fundamental requirements for the sustenance of human lives. Moreover, agriculture is also one of the most important components of Indian economy since India serves as the world's largest producer of pulses, jute, and spices [1, 2]. Besides, India is the second largest producer of rice, wheat, cotton, sugarcane, tea, groundnut, fruits, and vegetables [1]. Considering the role of agriculture in the human lives and economy, it is of utmost importance to keep the quality of soil intact and free from any kind of pollutants. Nevertheless, United Nations' sustainable development goals (SDGs) also emphasize upon ending hunger, achieving food security, improved nutrition, and promoting sustainable agriculture [3]. However, in present times, various emerging contaminants have been found to affect the physico-chemical and microbiological quality of the soil [4–6]. Microplastics are one of such contaminants which have been shown to negatively affect the quality of soil [4, 7]. Microplastics, the tiny plastic particles in the size range of 1 µm–5 mm [8]; are mostly the outcome of improper management of plastic waste [9]. Being small in size, these plastic particles are able to travel long distances in the environment and contaminate almost every kind of matrix, such as, air [10, 11], water [12], soil [7, 13], glaciers [14–16], deep ocean [17] etc. Despite having significant contaminating potential of microplastics, research in this direction has progressed in the present decade only. Most of the researches till date have focused on the marine water [18, 19], surface water [20, 21], groundwater [22, 23], drinking water [9, 12], wastewater [24, 25], air [10, 11], and biotic species [26–29]. However, microplastic research in the area of soil is rather limited [7]. As soil does make an important part of the entire ecosystem, research in this area needs to be focused upon.

Presence of microplastics in the soil may be sourced through various means, such as, packaging material of fertilizers and pesticides [30, 31], plastic mulching films [32], application of groundwater/wastewater/sludge contaminated with microplastics [33], dumping of municipal solid waste, atmospheric deposition [34], etc. These microplastic particles upon mixing with the soil disturb the natural soil composition and properties [35]. As plastic particles are carbon rich polymers, these also have the potential to influence the carbon and nitrogen ratio of the soil [7]. Further, microplastic particles also disrupt the growth of microbial species in the root zone area, which ultimately affects the crop growth [13, 36]. Effects on crop growth and/or crop's nutritional properties are expected to negatively affect human health as well. Besides, it is also noteworthy that microplastic particles are the efficient carriers of a number of environmental contaminants, such as, metals/metalloids, chemicals, pigments, additives, and microbes which further enhance the risk posed by these particles onto soil, crop, and ultimately on human health [9, 37, 38]. Upon reaching into deeper layers of soil, these microplastic particles may also contaminate the groundwater resources [39].

Considering the significance of soil microplastics and research gap in this area, present study was conducted in one of the important agricultural belts of India viz. Bhopal. Nevertheless, majority of the microplastic studies in India have focused only in the coastal environments [40–44], while a few have been carried out in the air [45, 46]. Therefore, it was considered necessary to estimate the occurrence of microplastics in Indian agricultural soil along with their characterization and risk assessment. This is the first study about the estimation of microplastics in agricultural soil of the Central Indian region and therefore, it would certainly help other researchers to further assess the impact of microplastics onto physico-chemical/microbiological properties of the soil.

Materials and methods

Study site

This study was carried out in Bhopal situated across the geographical coordinates of 23.4884°N and 77.4243°E. Bhopal is the capital city of the Indian state of Madhya Pradesh (Central India) (Fig. 1a) [7]. Out of the 52 administrative districts of Madhya Pradesh, Bhopal is one of the districts having population of approximately 23,68,145 [7, 47]. Although, the major portion of Bhopal's economy is dependent on industrial and tourism activities [48]; agriculture is also practiced in the peripheral areas of the city. As per the records, Bhopal generates approx. 112 tons of plastic waste per day, out of the total 800 tons of solid waste generated in the city [49]. In order to estimate the occurrence of microplastics in agricultural lands of Bhopal, soil samples were collected from two agricultural areas, namely Bhauri

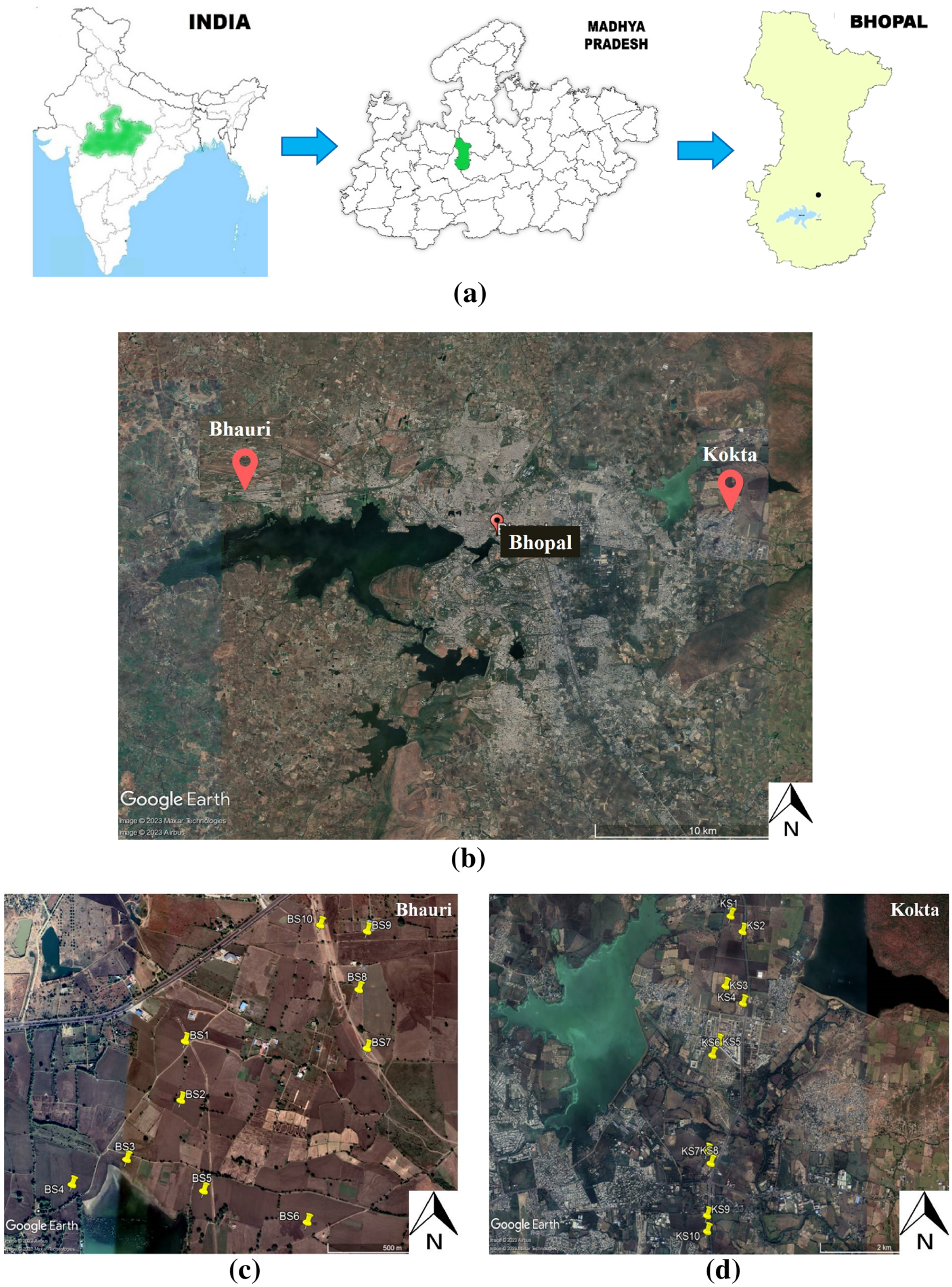

Fig. 1 **a** Location of Bhopal in Madhya Pradesh, India; **b** sampling areas in Bhopal city, Central India for agricultural soil collection; **c** sampling sites in two distinct selected areas

and Kokta, situated opposite to each other at either ends of the city (Fig. 1b). A total of 20 samples (10 from each of the chosen agricultural area) were collected randomly. The specific locations of the sampling sites are shown in Fig. 1c–d.

Sampling

Samples of 1 kg. weight were collected from the top 5 cm surface soil of agricultural areas in duplicates during May–June 2022. Quadrate method (size 1 m × 1 m) was used to delineate the area for sample collection. For digging and collection of soil, spade (metallic), scoop (stainless steel), and measuring tape were used [7]. Samples were transferred to the cotton bags, marked, and brought to the laboratory for analysis [42].

Experimental procedure

The collected soil samples were in dried condition owing to collection in the month of summer (mean temperature of 41 °C); however, these were further dried at 40ºC for 48–72 h to avoid any possibility of humidity. The bigger soil lumps were crushed to small pieces and grinded for obtaining homogeneous sample. Samples were then sieved using stainless steel sieves in which mesh size varied from 5 mm to 500 µm. The fraction of soil and plastic particles beyond 5 mm size was discarded. The remaining soil fractions were kept segregated as per their size and checked for the presence of microplastic particles in each of the fractions. Wet peroxide oxidation (using $FeSO_4$ and H_2O_2) and density separation (using conc. NaCl solution of density 1.2 g/mL) were performed. The resulted microplastic particles were evaluated to know the physical characteristics viz. size, shape, and color using stereomicroscope (Make: Zeiss, Model: Stemi 305) with magnification variable between 8× and 40×, and zoom ratio of 5:1 [7]. In order to chemically characterize the particles, Fourier transform infrared (FTIR) spectroscopy (Make: Perkin Elmer, Model: Spectrum Two) having attenuated total reflectance (ATR) accessory was utilized.

The experimental procedures were carefully carried out following necessary precautions to avoid any mishandling and contamination in the samples. Gloves and cotton lab coats were worn all the time. Samples were collected in glass Petri-dishes and covered with aluminium foil. It was speculated that air-borne microplastic particles might contaminate the samples resulting in overestimation [19, 50]. However, this possibility was overruled in present study, owing to the fact that the minimum size of the microplastic particles was considered to be 500 µm.

Risk assessment

The assessment methodologies for ecological risk estimation of microplastics vary among researchers as there is no consensus achieved on a single standard method. Some researchers follow the Håkanson's method of estimating risk which depends upon the degree of microplastic pollution over a period of time [51]; while others estimate risk based on the concentration of microplastics in the given environmental matrix at any particular time-frame [52]. In this study, the later method has been followed and ecological risk estimation was carried out considering the concentration of microplastics and their respective hazard scores (toxicity level), as shown in Eq. 1.

$$\mathrm{H} = \sum \mathrm{P_n} \times \mathrm{S_n} \tag{1}$$

where, H is the Microplastics' induced risk index, P_n is the Percent of microplastic polymer type collected at the individual sampling site, S_n is the Hazard score of plastic polymers based on the Lithner et al. [53]

Results

Identification and quantitative estimation of microplastic particles

Upon analyzing the agricultural soil samples, it was found that almost all the samples were contaminated with the microplastic particles. The particles varied significantly in size and shape, however; colour for most of the particles was found to be white/transparent. The shape of the particles ranged from fiber to fragments, the former being the most common type among all the particles detected. All the plastic particles below the size range of 5 mm were considered for quantitative estimation, as 5 mm has been defined as the upper size limit for microplastics [8]. A total of 307.5 ± 9.19 particles and 69.5 ± 4.95 particles were found in the 10 soil samples collected from each of the Bhauri and Kokta agricultural areas, respectively (Fig. 2). Figure 2a shows that the site no. # 5, 6, 7, and 10 are comparatively more contaminated than rest of the sites in the Bhauri agricultural area. Further, site no. # 1–5 and 7 were found to be more contaminated in the Kokta area (Fig. 2b).

As soil samples were fractioned in different size ranges viz. 5–2 mm, 2–1 mm, and 1–0.5 mm; the microplastic particles obtained were also categorized into these size ranges, as represented in Fig. 3. The obtained particles can be seen

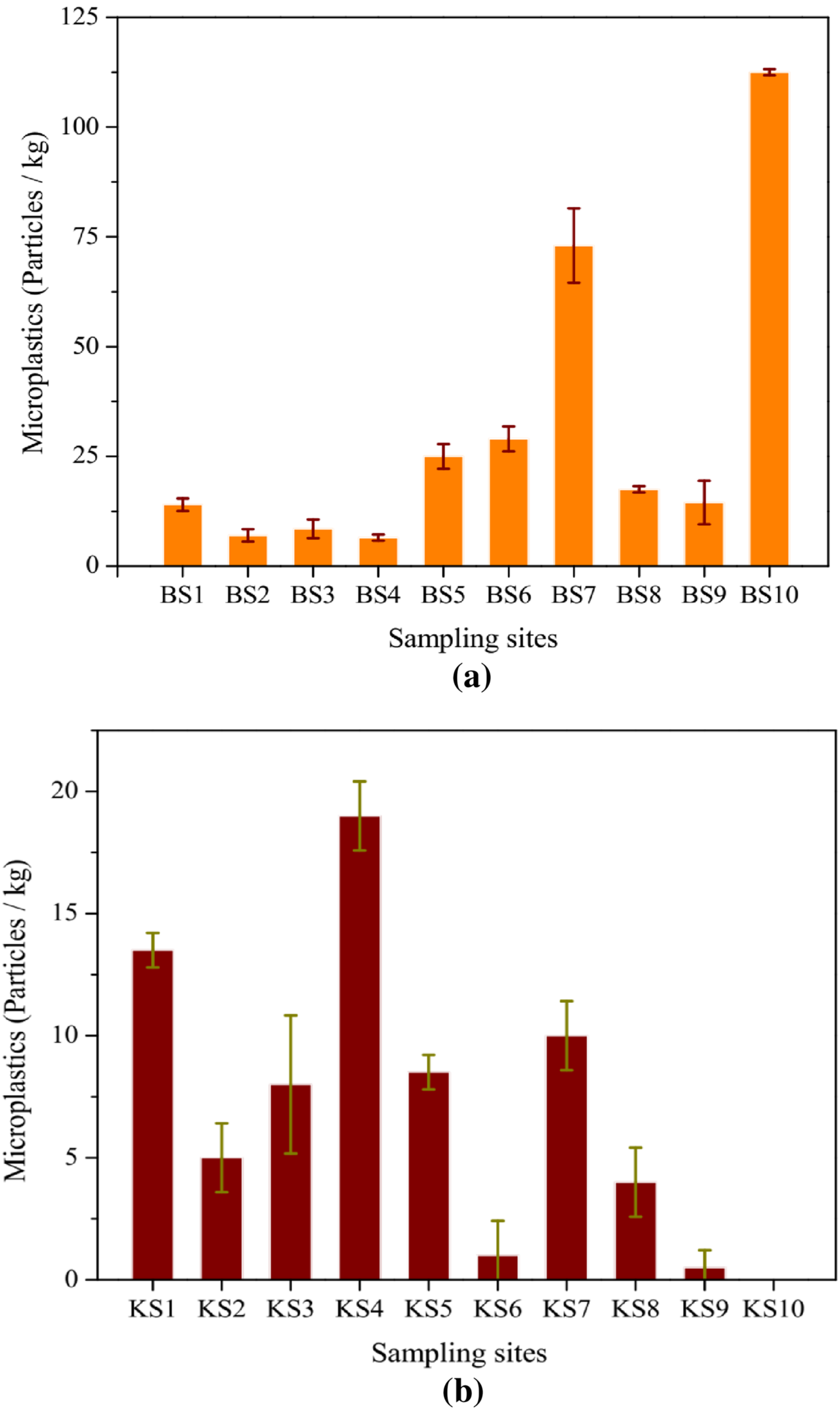

Fig. 2 Quantitative estimation of microplastics in **a** Bhauri and **b** Kokta agricultural areas in Bhopal, Central India

to be dominantly present in the size range of 5–2 mm and 2–1 mm, while smaller size particles were few. However, in due course of time, these larger size particles are expected to be broken down into smaller pieces upon action by the environmental agencies, which may pose comparatively higher risk to the soil [35].

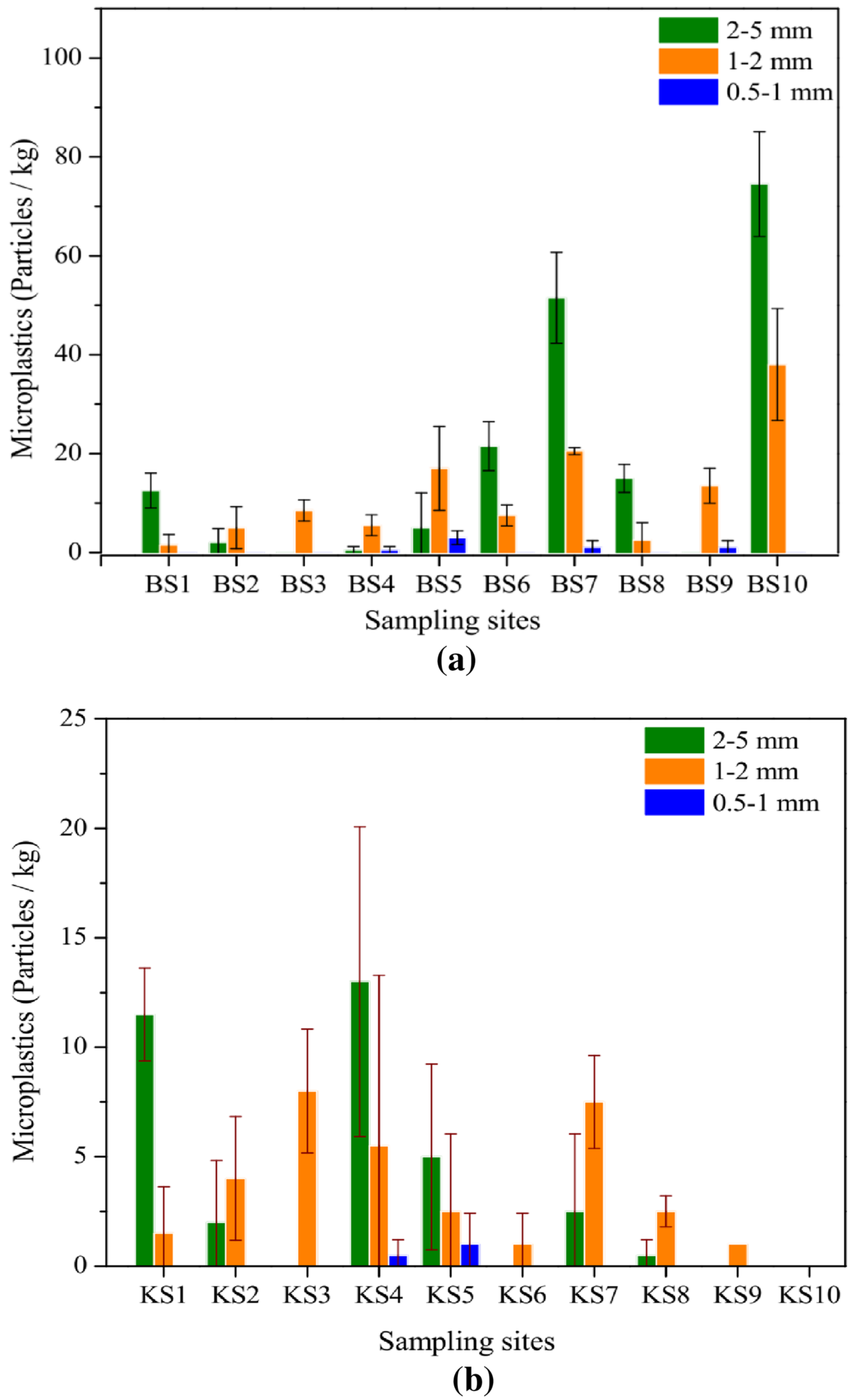

Fig. 3 Size based distribution of microplastics across the selected sampling sites in agricultural soils of **a** Bhauri and **b** Kokta in Bhopal, Central India

Qualitative characteristics of microplastic particles

In order to further characterize, microplastic particles were subjected to spectroscopic analysis through ATR-FTIR for chemical characterization. The obtained absorbance spectra of microplastic particles were compared with the characteristic absorbance bands of various polymers of plastic category. It was revealed that particles majorly belonged to five different polymer classes, viz. polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), and polystyrene (PS). The characteristic absorbance bands of each type of

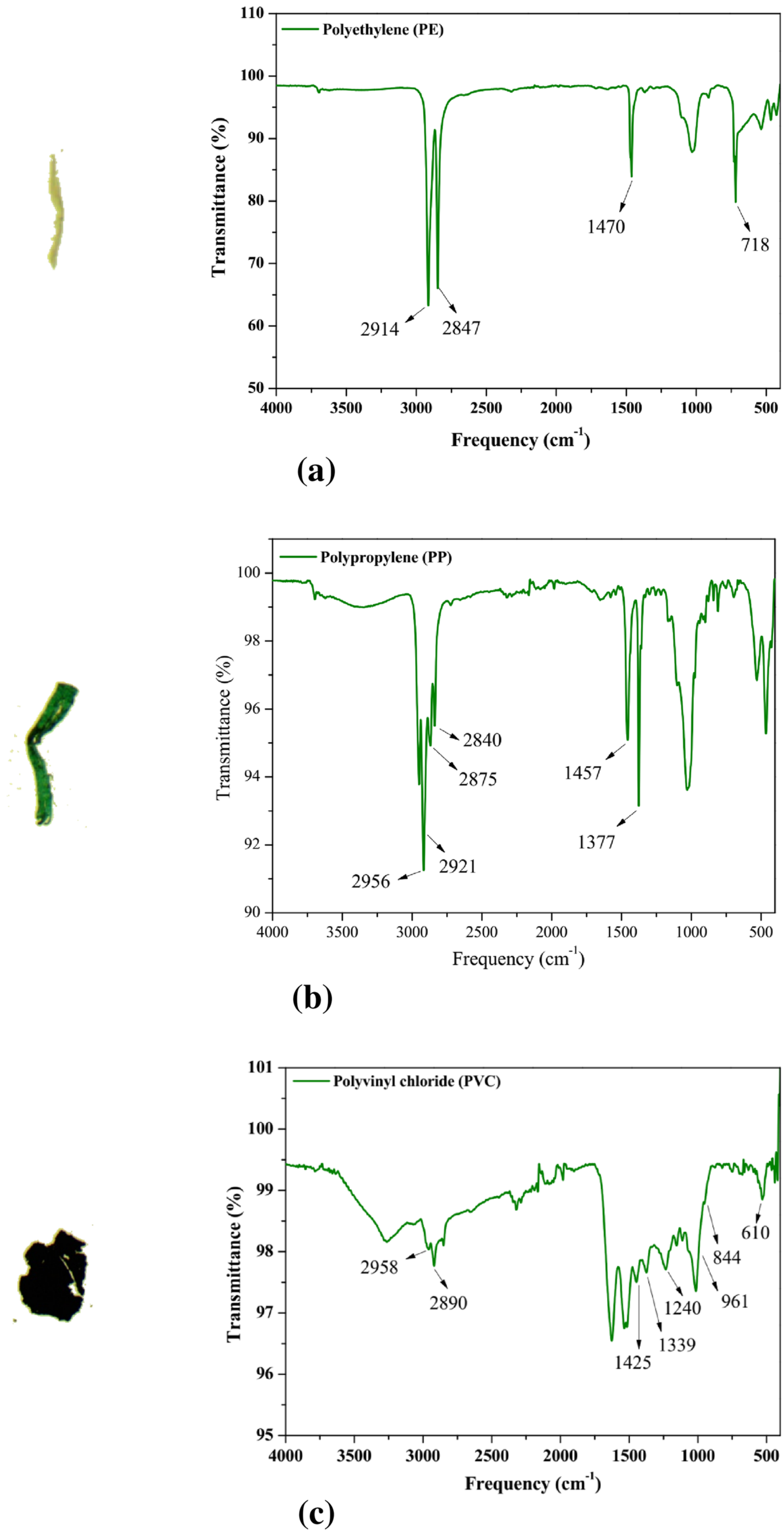

Fig. 4 Chemical characterization of microplastics across the selected sampling sites in agricultural soils of Bhopal, Central India; **a** PE, **b** PP, **c** PVC, **d** PET, **e** PS

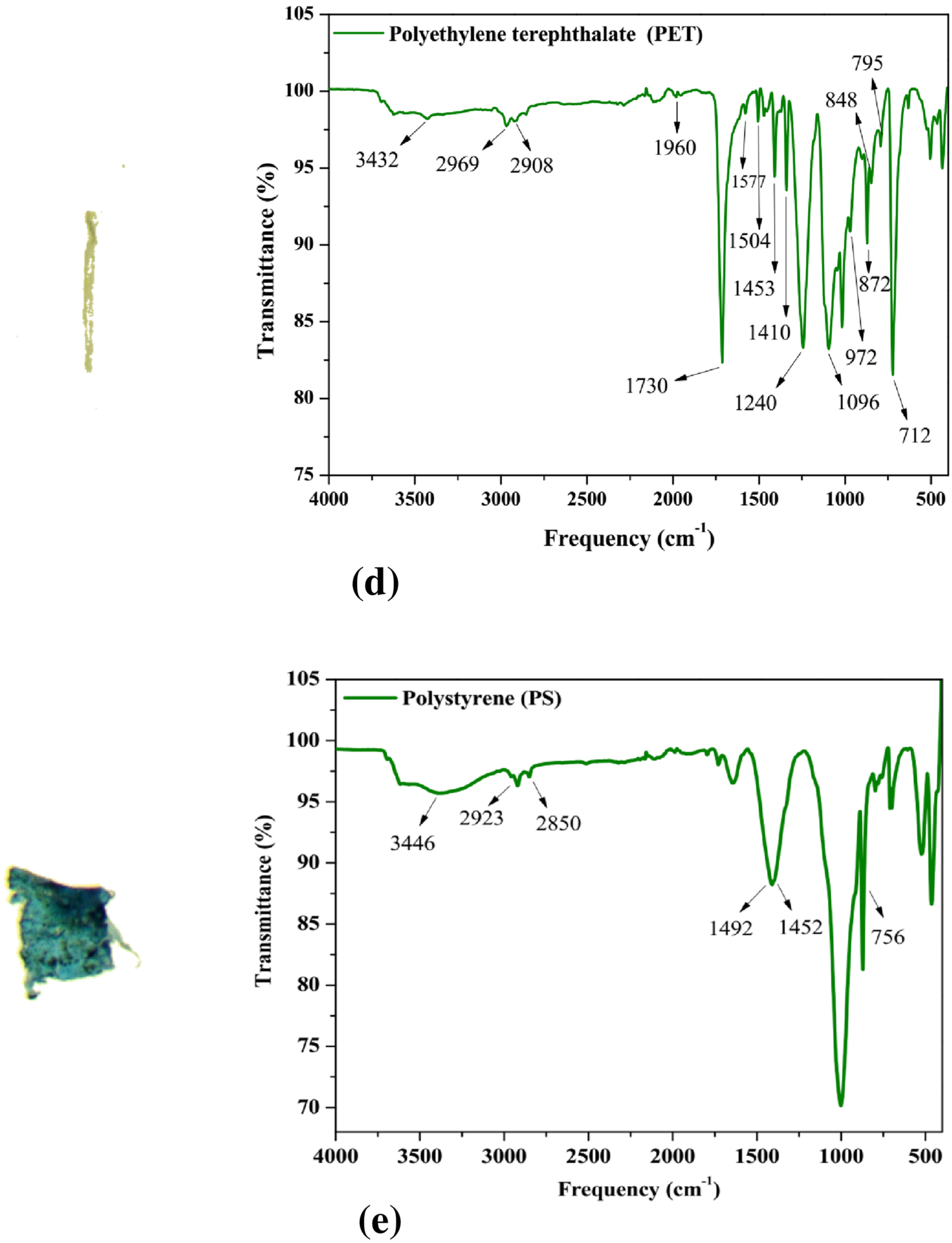

Fig. 4 (continued)

plastic polymer are shown in Fig. 4a–e. Corresponding peak position of bands for PE, PP, PVC, and PET has been discussed elsewhere [7]. Additionally, presence of PS was confirmed through the two saturated C–H stretching peaks present at 2923 cm^{-1} and 2850 cm^{-1}. Further, peaks at 1492 cm^{-1}, 1452 cm^{-1}, and 756 cm^{-1} are also the characteristic peaks of polystyrene (Fig. 4e). In many of the cases, such peaks were also found which are not characteristic of that particular polymer class, such as, broad peak present at 3423 cm^{-1} and another peak at 1032 cm^{-1}

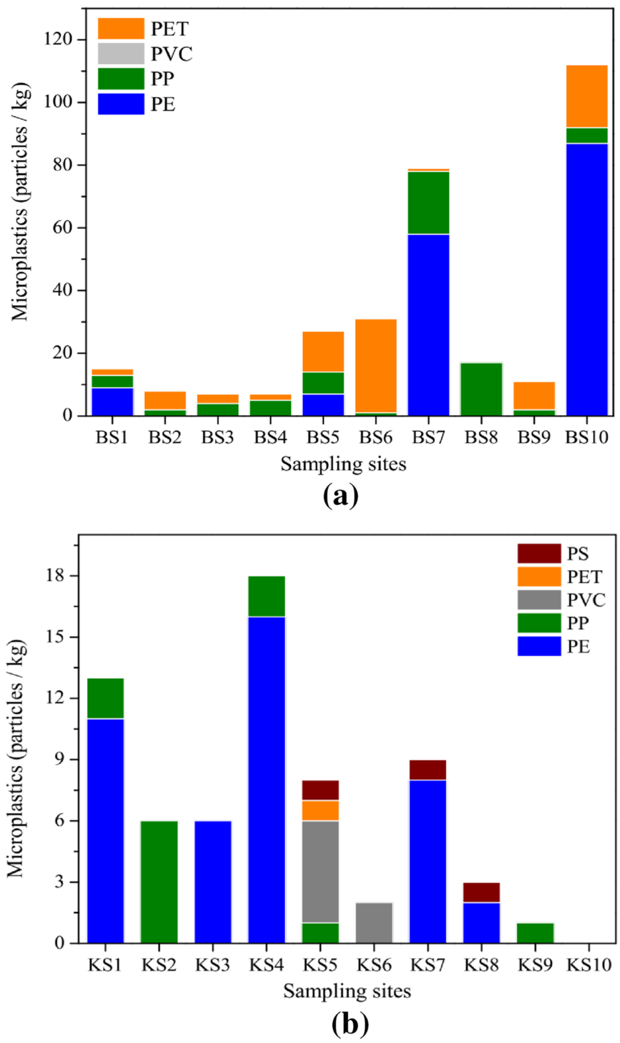

Fig. 5 Chemical characteristics-based microplastics' distribution across the selected sampling sites in agricultural soils of **a** Bhauri and **b** Kokta in Bhopal, Central India

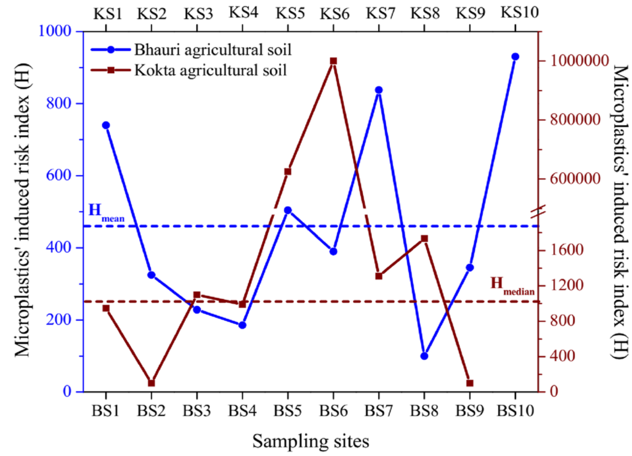

Fig. 6 Microplastics' induced risk index in agricultural soils of Bhauri and Kokta in Bhopal, Central India

in the spectrum of polypropylene (Fig. 4b). These peaks refer to the degradation of polymers in the soil matrix in presence of moisture, biotic agencies, human interferences etc. [54]. It has also been proposed that these peaks may be the result of various additives/plasticizers added during the plastic manufacturing processes [55]. Similarly, in the spectrum of polyvinyl chloride, absorbance peaks may be seen at 1643 cm^{-1} and 1032 cm^{-1} (Fig. 4c) which depict the degradation of the particles in soil [7, 54, 56].

The proportion of various types of polymers in the collected microplastic particles is shown in Fig. 5. It can be seen that polyethylene is present in the highest amount in both the areas. In case of Bhauri agricultural area, the polyethylene was found to be 51.3%, followed by PET (27.4%), PP (21.3%), and PVC (0%) (Fig. 5a). However, the proportion of polymers in the soil of Kokta agricultural area was slightly different, viz. PE (65.2%) > PP (18.2%) > PVC (10.6%) > PS (4.6%) > PET (1.5%) (Fig. 5b).

Ecological risk estimation

Ecological risk posed by microplastics was calculated using the formula shown in Eq. 1. For Bhauri agricultural soil, the risk index varied between 100 and 838 having the mean value of 458.7 among the sites; while for Kokta agricultural soil, it varied between 100 and 1,000,100 having median value of 1044.4 (Fig. 6). The considerable difference in the risk indices of the two areas, and among the different sites in the same area was attributed to the difference in number and types of microplastic particles. More number of microplastic particles will certainly result in higher risk compared to sites having less number of particles. Additionally, there is considerable variation among the hazard scores of different polymers [53]. Thus, polymer having high hazard score may result in higher risk index in spite of minimal presence quantitatively. For example, the presence of PVC type of plastic particles in Kokta agricultural area is reported only at two sites, namely #KS5 and #KS6, having the amount as 5 and 2 particles/kg, respectively (Fig. 5b). However, PVC's hazard score of 10,001 [53] renders the risk index to be increased significantly (Fig. 6). Here it is to be mentioned that present study has considered only 10 samples in the respective areas; and hence, the risk estimation needs to be interpreted with caution.

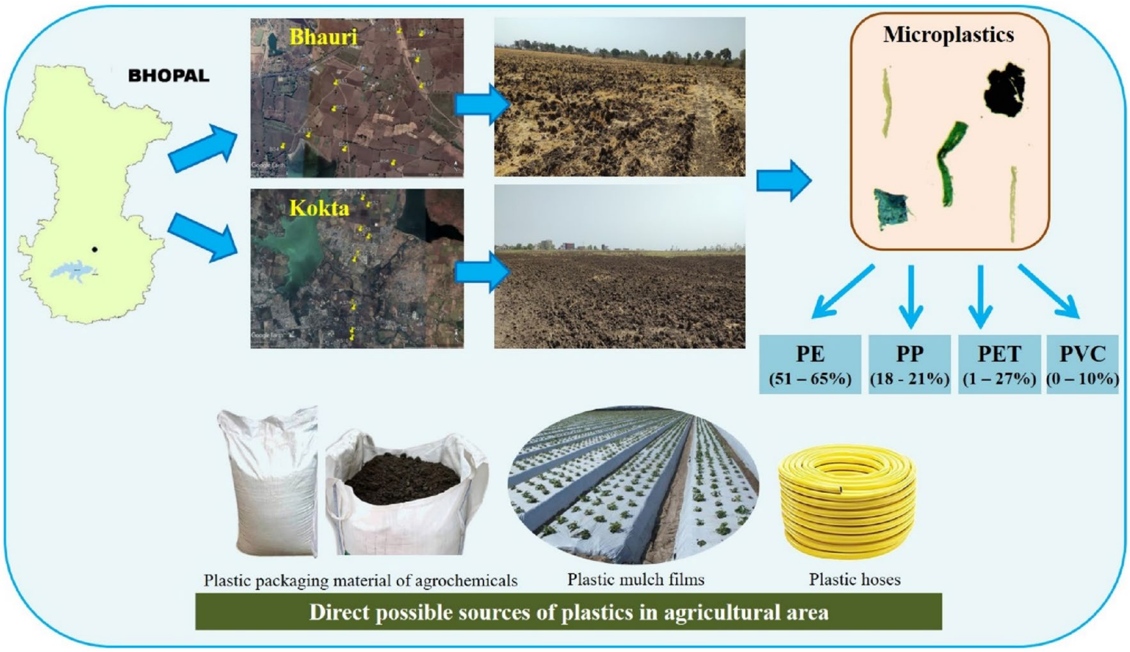

Fig. 7 Schematic representation of the microplastics' occurrence in agricultural soils of Bhopal, Central India

Discussion

Presence of microplastics and probable sources in the agricultural soil

This investigation first time reports the occurrence of microplastics in the soil of agricultural area in the Central Indian region. Moreover, microplastics' research in India is in its early stages, and mainly limited to the eastern and western Indian coastal regions [41–44]. Research in the soil matrix is minimal [7, 57] and therefore, present study bears a special significance in order to understand the level of contamination due to microplastics in soil. Generally, occurrence of microplastic particles in the Indian agricultural soils may be attributed to the littering of agrochemicals' packaging materials in field, use of plastic mulching films, atmospheric deposition, use of sewage sludge as fertilizers, irrigation using wastewater having microplastics, and dumping of municipal waste (as shown in Online Resource 1) etc. [23, 57, 58].

Occurrence of microplastics in the agricultural soil of Bhopal region indicates the exposure of soil to a variety of plastic litter. With time, the bigger plastic pieces breakdown into smaller ones resulting in microplastics. Since, microplastics originate from the larger plastic particles, these maintain the physico-chemical properties of the plastics. Besides, microplastics develop certain other unique features as well being small in size and varied in dimensions. Among all the selected sampling sites in two different agricultural areas, microplastics have been reported from each site except one, viz. #KS10. The highest amount of microplastics in Bhauri area was 112.5 ± 0.707 particles/kg (site no. #BS10); while it was 19 ± 1.414 particles/kg in the Kokta agricultural area (site no. #KS4). Majority of the particles were found in ruptured and disturbed condition (Fig. 4), representing that abiotic/biotic factors and human interferences are breaking these down to further smaller pieces.

In the sampled sites, presence of microplastics is primarily expected to originate from the use of agricultural items packaged in plastics, such as fertilizers, pesticides; use of plastic hoses etc. (Fig. 7) Fertilizers and pesticides are often packed in high-density polyethylene or polypropylene materials, as these packaging materials provide impermeability, resistance to microbes, and water-proofing. After the use of these agrochemicals, packaging materials are often left in the soil; either whole or in part, which keeps on breaking down under the influence of environmental and human factors. Similarly, hoses (made up of PE/PP/PVC) are generally left in the soil once their application is over. Excess presence of polyethylene and polypropylene in this study corroborates this fact. Moreover, studies also report that polyethylene, polypropylene, polyethylene terephthalate are the most common plastic polymers in the agricultural sector [57]. Another important source of microplastics in the region is the atmospheric deposition which serves to be one of the important factors for transporting plastic particles up to distant places [7, 14, 16].

Table 1 Published literature on the occurrence of microplastics in agricultural soil

Country	Type of soil	Depth of soil (cm)	Abundance of microplastics (particles/kg)	Type of microplastics	Major source	References
China	Vegetable farmlands	0–3	78 ± 12.91	Polypropylene, polyethylene	Plastic mulching, compost	[34]
		3–6	62.50 ± 12.97			
India	Agricultural soil (Maharashta)	15	40.46 (mulched soil)	Polyacrylamide, polyethylene, polypropylene, cellulose, and polyethylene terephthalate	Plastic mulching, irrigation, heavy rainfall	[57]
		15	20.54 (un-mulched soil)			
	Agricultural soil (Karnataka)	30	8.45 (mulched soil)			
		15	2.83 (un-mulched soil)			
China	Soil amended with sewage sludge compost	0–5	35.5	Polyethylene, polypropylene, polyethylene terephthalate, polybutylene, ethylene vinyl acetate	Sewage-sludge based fertilizers (30 tonnes/hectare)	[58]
		5–15	330.4			
		15–25	180			
		0–5	27.6		Sewage-sludge based fertilizers (15 tonnes/hectare)	
		5–15	45			
		15–25	15			
China	Agricultural soil	0–40	1075.6 ± 346.8	Polyethylene	Plastic mulching films	[59]
Qinghai—Tibet	Farmland soil	0–3	53.2 ± 29.7	Polyester, polypropylene	Plastic mulching films	[60]
		3–6	43.9 ± 22.3			
China	Agricultural soils in arid regions	20	40.35 mg/kg	Polyethylene	Plastic mulching films	[61]
China	Agricultural soil	0–10	571 (mulched soil)	polyethylene, polypropylene, polyester, rayon, and polyamide	Plastic mulching, irrigation water, plastic waste, and compost	[62]
			263 (non-mulched soil)			
India	Agricultural soil (Bhauri)	0–5 cm	307.5 ± 9.19 particles/10 kg	Polyethylene, polypropylene,	Agricultural items packaged in plastics, such as fertilizers, pesticides; plastic hoses; atmospheric deposition	This study
	Agricultural soil (Kokta)		69.5 ± 4.95 particles/10 kg			

Comparison with other studies

There are not many studies in the area of soil microplastics, *esp*. agricultural; however, a few studies may be quoted (Table 1). Huang et al. reported microplastics in agricultural soil of China. It was found in the study that soil under the influence of plastic mulching films for long time had more amount of microplastics. A total number of 1075.6 ± 346.8 pieces/kg of soil were reported from the soil which was under mulching for 24 years [59]. Impact of mulching and land-use on the presence of microplastics has also been studied by Feng et al. It was demonstrated that microplastic particles emerged from the fragmentation of plastic mulch in farmland soil resulting in 53.2 ± 29.7 items/kg and 43.9 ± 22.3 items/kg in shallow (0–3 cm) and deep (3–6 cm) soils, respectively [60]. The characteristic polymer types were reported to be of polyester and polypropylene. Presence of microplastics was also reported from the vegetable farmlands in suburbs of Shanghai [34]. On an average, 78 ± 12.91 items/kg and 62.50 ± 12.97 items/kg were reported from the shallow (0 ~ 3 cm) and deep (3 ~ 6 cm) soils, respectively. Chemical composition analysis showed the presence of polypropylene (50.51%) and polyethylene (43.43%) [34]. Li et al. demonstrated the impact of mulching in agricultural soils *esp*. in arid regions. Microplastics' abundance of 40.35 mg/kg, having size range of 0.9–2 mm, was reported from the soils which were under the continuous practice of mulching for approximately 30 years [61]. Zhou et al. studied the agricultural soil on one of the coastal plains in China. Here, mulched soils were found to have 571 pieces/kg of microplastics, compared to 263 pieces/kg in the non-mulched soils [62]. However, apart from mulching; irrigation water, plastic waste, and compost were also recognized as the probable sources of microplastics in agricultural soil. As far as type of microplastic particles are concerned, dominance of polyethylene, polypropylene, polyester, rayon, and polyamide was reported [62]. Similarly, microplastics were also found in the Chinese soil where sewage-sludge based fertilizers were applied. Quantitatively, 545.9 and 87.6

Table 2 Information about the microplastic polymers found in the study

Polymer	Monomer	Abbreviation	Hazard score (S_n)	Utility
Polyethylene	Ethylene	PE	11	Packaging film, garbage bags
Polypropylene	Propylene	PP	1	Packaging, ropes, twines
Polyethylene terephthalate	Terephthalic acid and ethylene glycol	PET	4	Bottles, bags
Polyvinyl chloride	Vinyl chloride	PVC	10,001	Packaging, hoses
Polystyrene	Styrene	PS	30	Packaging

microplastic items/kg of soil were reported after the application of 30 tonnes/hectare and 15 tonnes/hectare of sludge composts, respectively [58].

Studies in the context of Indian agricultural soils are lacking except where microplastics were detected in the soils of Maharashtra and Karnataka regions [57]. This study collected 30 soil samples which included mulched, un-mulched, and dumpsites. Among the mulched soil category, the highest amount of microplastics was reported to be 40.46 pieces/kg (in Maharashtra), while the lowest as 8.45 pieces/kg (in Karnataka). For un-mulched soil category as well, the highest amount was reported in Maharashtra (viz. 20.54 pieces/kg) and lowest in Karnataka (viz. 2.83 pieces/kg). Majority of the microplastic particles reported in these soils were found to be varying across the size range of 0.3–1 mm. Chemical composition analysis revealed the presence of polyacrylamide (69.8%), polyethylene (11.63%), polypropylene (7.7%), cellulose (3.87%), and polyethylene terephthalate (3.87%) [57]. High occurrence of polyethylene and polypropylene in the present study, therefore, matches with this Indian study.

Ecological risk assessment

Assessment of risk in the present study was done by utilizing the percentage of microplastic polymer type collected at the individual sampling site and hazard score of respective plastic polymer. The hazard scores of the studied plastic polymers are shown in Table 2 [53]. It can be seen that there is wide variation in the hazard scores of polymers. The high hazard score of polymers (*e.g.* PVC) is inevitable to enhance the risk posed considerably, even if the number of plastic particles is low, as seen in Fig. 6 of the present study. In case of other polymer types, though the microplastics' amount is high (Fig. 5), but risk imposed is comparatively less (Fig. 6) owing to low hazard scores (Table 2).

Quantification of risk index (H) in the studied soil samples (Fig. 6) infers that there is considerable ecological risk due to microplastic contamination in the region. As per Du et al., the risk index may be categorized under different hazard levels as shown in Table 3 [52]. Following this scenario, the mean/median risk index calculated in the present study may be categorized under the hazard level I (*i.e.* very low hazard) and hazard level II (*i.e.* low hazard) for Bhauri (H_{mean}—458.7) and Kokta (H_{median}—1044.4) agricultural areas, respectively. However, here it is noteworthy that other methods with varied categorization of hazard levels are also available [63, 64].

Table 3 Ecological risk assessment of microplastic pollution

Hazard level	Assessment statement	Microplastics' induced risk index (H) (Du et al. 2020)
I	Very low hazard	<1000
II	Low hazard	1000–1500
III	Medium hazard	1500–2000
IV	High hazard	2000–2500
V	Very high hazard	>2500

Nevertheless, risk due to the microplastics is evident; and in the long term, even the low hazard level of microplastics is anticipated to affect soil characteristics in a considerable manner. Studies have reported that microplastics alter soil pH, soil respiration, and enzymatic activities [65]. Moreover, the features (such as size, shape, chemical composition etc.) of microplastic particles also influence various soil characteristics. Apart from altering the soil's physico-chemical properties, microplastics may also affect the microbial composition of soil [5, 66]. It has been shown that microbes colonize the microplastic particles present in soil. Composition of these microbes is different from the microbes of the bulk soil. Thus, excess amount of microplastics would lead to more colonization and thereby affect the community composition of soil microbiota to an important extent [67]. Longer retention of microplastics in soil will further result in the generation of nanoplastics which may migrate through soil, thus, contaminating the underlying groundwater resources [23]. Further, since microplastics are efficient carriers of various contaminants [9, 37]; percolation of agro-chemicals (fertilizers, pesticides etc.) into underground aquifers through these particles is also anticipated [7]. Therefore, repercussions of microplastics' occurrence in the soil are varied and hold the possibility of affecting not only the soil quality; rather, crop growth, crop nutrition, groundwater, and human health as well. In order to minimize these repercussions, improved plastic waste management leading towards the approach of circular economy needs to be strengthened [68, 69].

Conclusion

This study reported the presence of microplastics in agricultural soil of Bhopal, Central India, which is the pioneering study in this region. Agricultural soil from two different areas, viz. Bhauri and Kokta, were sampled and analyzed. Except one, all the sampled sites (10 in each area) were found to be contaminated with microplastics having a total of 307.5 ± 9.19 particles and 69.5 ± 4.95 particles in Bhauri and Kokta, respectively. Polyethylene and polypropylene were the two major types of microplastic particles reported in the studied region. These polymers are generally used in packaging of fertilizers, pesticides, and other agricultural commodities. Risk assessment analysis indicated that the studied areas are having low hazard level of contamination from microplastics; however, preventive actions are required to be adopted in order to minimize further contamination.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10163-023-01805-6.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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