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ORIGINAL ARTICLE

Occurrence, Distribution, and Abundance of Microplastics in the Rohtak Municipal Solid Waste Landfill

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Abstract

Objectives: To investigate the occurrence, distribution, morphological characteristics, and polymer composition of microplastics (MPs) in Rohtak municipal solid waste landfill underburdened soil samples. MPs were categorized based on size, shape, colour, and polymer type using microscopic examination and Fourier Transform Infrared Spectroscopy (FTIR). **Method:** Underburdened soil samples were collected from within 0-20 cm depth of the landfill site. Soil samples were filtered through a series of stainless-steel sieves of decreasing mesh size as followed 3000 μm, 2800 μm, 700 μm and 600 μm. MPs in the samples were visually examined, separated, and counted in 500g of total dry weight of underburdened soil. Further categorization was performed based on size, colour, and morphology under microscopic examination. **Findings:** The results revealed that smaller-sized MPs (750–600 μm) were more abundant than larger fractions, indicating progressive fragmentation of plastic debris into secondary MPs. Shape analysis showed the dominance of film-type particles, followed by fibres and fragments. Transparent particles were the most dominant colour category, indicating prolonged environmental weathering and degradation processes. FTIR analysis confirmed the presence of major polymers including polyethylene (HDPE and LDPE), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS). The predominance of polyethylene and polypropylene reflected the extensive use of packaging and household plastic materials in municipal solid waste. **Novelty:** This study provides one of the limited investigations on microplastics contamination in landfill under burdened soil from India, particularly from the Rohtak Municipal Solid Waste Landfill. Unlike conventional landfill assessments that mainly focus on heavy metals and organic pollutants, the present work highlights the overlooked issue of MPs contamination in recovered landfill residues, thereby contributing valuable baseline data for sustainable landfill mining and waste management strategies.

Keywords: Microplastics; Landfill soil; Plastic pollution; FTIR

1 Introduction

Plastics are organic synthetic polymer compounds or materials produced from crude oil derivatives [1]. Because of their excellent properties, including durability, flexibility, and low cost, they have become indispensable in modern society. Global plastic production has increased rapidly since the 1950s, reaching 390.7 million tonnes in 2021, with approximately half of all plastics used for single-use disposable products such as food containers, straws, and cups [2]. The fragmentation and disintegration of larger plastic items are driven by complex physical, chemical, and biological processes, including weathering, ultraviolet (UV) radiation, mechanical abrasion, and microbial decomposition which leads to formation of MPs. MPs are groups of synthetic polymer particles measuring less than 5 mm in diameter or length [3]. Tiny plastic particles intentionally manufactured in micro-sizes for commercial or industrial use such as microbeads used in cosmetics and personal care products, glitter, and industrial resin pellets are called primary MPs, while naturally degraded plastic particles are called secondary MPs [4]. MPs have become a global concern and a persistent environmental threat because they are non-biodegradable and can persist in the environment for decades or even centuries [5]. They have been detected in almost every ecosystem on Earth, including marine environments, freshwater, soil, the atmosphere, and even remote regions like Antarctica [6]. MPs have the ability to act as vectors and carriers for hazardous pollutants, such as heavy metals, persistent organic pollutants (POPs), antibiotics, and pathogens, which can then be transported into the food chain [1]. Recent studies have highlighted the direct threat to human health, as MPs have been found in human blood, lungs, breastmilk, and stool samples [7],[8]. Soil is recognized as a major environmental sink and reservoir for MPs, with studies estimating that the total MPs load in soil systems may be 4 to 23 times higher than in marine ecosystems. Once deposited, these particles persist due to their high stability and low natural degradation rates, potentially altering soil properties, affecting microbiota, and entering the food chain [9],[10]. Currently, plastic films (predominantly PE and polyvinyl chloride) account for about 50% of total agricultural plastics. Irrigation with contaminated surface water or groundwater acts as a pathway for MPs entry [10],[11]. Landfills store an estimated 21–42% of global plastic waste, which undergoes fragmentation over decades due to physical stress and biochemical reactions. As water percolates through buried waste, it generates leachate containing high concentrations of MPs, which can leak into the underlying soil and groundwater, especially in un-engineered or unsanitary dumpsites [4]. Improperly managed landfills without adequate cover allow MPs to be dispersed into the surrounding environment via prevailing winds and surface runoff [9]. Despite growing concerns regarding MPs pollution, research has predominantly focused on aquatic ecosystems, agricultural soils, sediments, and wastewater treatment systems. Studies investigating MPs contamination within landfill environments, particularly in under-burdened soils and landfill-derived residues, remain scarce. The present study aimed to assess the abundance, morphological characteristics, and polymer composition of MPs in landfill under burdened soil samples collected from Rohtak MSW landfill, located in Haryana, India, a major municipal waste disposal site receiving mixed urban solid waste. Underburdened soil is mixture of soil and degraded legacy municipal waste. It is not "true" natural soil, the residues resemble soil in appearance and texture but are composed of decomposed organic matter, mineral components, and anthropogenic waste [12]. Traditional assessments of landfill-mined residues or "soil-like materials" (SLM) typically focus on heavy metals, salts, and organic contaminants to determine their feasibility for reuse as compost or fill material. The risk of MPs pollution in these materials has often been overlooked [8]. Therefore, this study expands current understanding of landfill soils as potential reservoirs of MPs and generates baseline data essential for future risk assessment, landfill mining, and sustainable waste management practices.

2 Methodology

2.1 Sample collection and isolation of microplastics

This study was conducted to investigate level of MPs pollution in under burdened soil of landfill site of Rohtak city. The city lies 70 km north-west of New Delhi, area of the city is 1745 km^2 with a population 10, 58,683. It is located at 28.8909°N latitude and 76.5796°E longitude, the general location of the sampled landfills is presented in Figure 1.

The Rohtak Municipal Solid Waste Landfill was selected as the study site due to its substantial plastic waste burden, which is among the highest reported for landfills in Haryana [13]. Sampling was carried out in areas where legacy waste had historically accumulated but had been excavated and removed before sample collection. This approach enabled the evaluation of residual MPs contamination in the underburdened landfill soil and provided insights into the long-term persistence of plastic-derived pollutants following legacy waste remediation. A random sampling approach was used to ensure representative coverage of the landfill area. Samples typically weighing around 2kg were collected from 0-20cm depth with stainless steel shovels [9]. Before further analysis, large non-plastic debris such as stones, wood chips, metals, and glass were removed manually. In the lab samples were air dried at room temperature and then oven dried at 40°C to 60°C to reach a constant mass without causing thermal damage to potential MPs contaminants. Underburdened soil samples were filtered through a series of stainless-steel sieves



Fig 1. Google Earth image showing the location of the sampling sites selected for the present study

of decreasing mesh size as followed 3000 μm, 2800 μm, 700 μm, and 600 μm. MPs in the samples were visually examined, separated and counted in 500g of total dry weight of under burdened soil. Quality assurance and quality control (QA/QC) measures were implemented throughout the study to minimize contamination and ensure reliability of results. All glassware and metallic equipment were thoroughly rinsed with distilled water before use. Plastic materials were avoided during sample processing wherever possible. Samples were processed under clean laboratory conditions and covered with aluminium foil to prevent airborne contamination. Laboratory personnel wore cotton lab coats. All experiments were conducted in triplicate, and results were expressed as mean $\pm$ standard deviation to ensure reproducibility and consistency of the analytical procedure.

2.2 Characterization of microplastics

MPs were identified with naked eyes and a trinocular microscope classified based on the sizes S1 (5000–3000 μm), S2 (3000–2800 μm), S3 (2800–750 μm), and (S4: 750–600 μm) shapes film, fragments, fibres, pellet, foam and other and colours were red, black, green, white, transparent and other. MPs were randomly selected and characterized by micro-Fourier transform infrared spectroscopy (FTIR) operating in attenuated total reflectance (ATR) mode. The acquired spectra were then compared with standard spectra in open-access database. The chemical compositions of MPs were identified based on the presence of characteristic peaks in the samples' spectra and their similarities with standard spectra (a match score $\geq$80% was regarded as indicating a positive match). Subsequently, the MPs were categorised based on their chemical compositions.

3 Results and Discussion

3.1 Size-wise distribution of microplastics (S1–S4)

The abundance of MPs across all sampling sites (A1–A10) exhibited a clear size-dependent trend. In all samples, the smallest size fraction (S4: 750–600 μm) showed the highest MP abundance, followed by S3 (2800–750 μm), S2 (3000–2800 μm), and S1 (5000–3000 μm), which consistently recorded the lowest values. MPs abundance in landfill soil from various studies across the world has been shown in Table 1. For instance, in sample A3, MPs abundance increased from 89.6 $\pm$ 16.7 (S1) to 280.3 $\pm$ 15.6 (S4), while a similar pattern was observed across all locations. Overall, S4 values ranged between 243.6 $\pm$ 3 to 280.3 $\pm$

15.6, indicating the dominance of smaller-sized particles shown in Figure 2. Similar dominance of smaller-sized MPs has been reported in landfill-associated environments and urban solid waste residues by [14], [15], [16] where finer MP fractions were linked with prolonged environmental weathering and fragmentation processes.

This trend suggests that secondary MPs formed through fragmentation processes, dominate landfill soils in contrast to aquatic environments where hydrodynamic sorting strongly influences MPs size distribution. Plastic waste in landfill environments undergoes physical abrasion, microbial degradation, and chemical weathering, leading to breakdown into smaller particles [17]. The progressive increase in MPs abundance with decreasing particle size reflects ongoing degradation processes, where macro-plastics gradually transform into MPs under landfill conditions. Such findings are consistent with previous studies, where smaller MPs were reported to be more abundant due to fragmentation and prolonged environmental exposure [2]. Additionally, landfill systems act as reservoirs of plastic waste, continuously generating MPs through long-term degradation mechanisms [5].

Table 1. Studies from various location showing different concentration and size ranges of MPs

Location of Study	Size Range	Concentration	Reference
Tabriz, Iran	0.3–4.75 mm	7860 item/kg (dry weight)	[9]
Tehran, Iran	0.1–0.5 mm	863 ± 681 particles/kg	[18]
Delhi, India	75 μm to 4.75 mm	3750 items/kg to 7050 items/kg	[8]
Jinyeong & Cheonseon, Republic of Korea	< 1 mm to 5 mm	inyeong: 49–90 ea/kg; Cheonseon: 81–113 ea/kg	[1]
Depok City, Indonesia	Not mentioned	60,111.67 particles/kg	[19]
Akmola Region, North Kazakhstan	< 5 mm to 50 mm	810 particles/kg	[5]
Kaunas County, Lithuania	< 0.1 mm to 5 mm	Up to 55 particles/g	[20]
Rayong Province, Thailand	< 0.5 mm to 4.80 mm	240–26,100 pieces/kg	[2]
Howrah, India	1mm – 2mm	34,500± 7778.2 particles/kg	[21]
Madhyamgram, India	1mm – 2mm	21,500 ± 2121.3 particles/kg	[21]
Baruipur, India	1mm – 2mm	13,000 ± 4242.6 particles/kg	[21]
Dhapa, India	1mm – 2mm	12,500 ± 5066.2 particles/kg	[21]
Chandannagar, India	1mm – 2mm	11,500 ± 707.1	[21]
Amin Bazar & Kodda, Bangladesh	<0.5mm to 5mm	66-1510 particles/kg	[22]

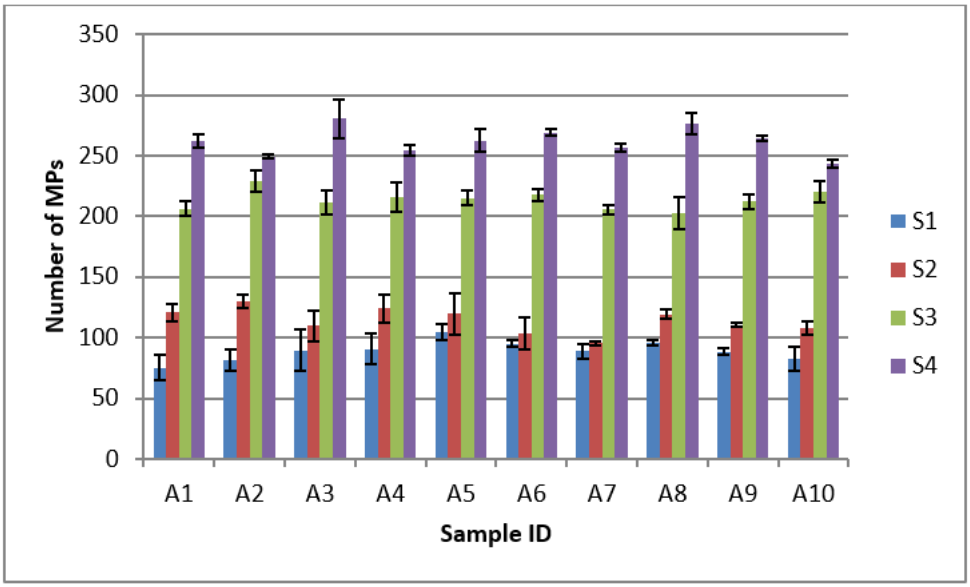


Fig 2. Distribution of MPs based on different size ranges (S1 5000–3000 μm, S2 3000–2800 μm, S3 2800–750 μm, and S4 750–600 μm) detected in landfill soil samples

3.2 Spatial Variation of microplastics (A1–A10)

Although the size-based trend remained consistent, variations were observed among sampling sites. Higher MP abundance was recorded in sites such as A3 having 690.8 particles, A8 having 694.5 particles, and A6 having 684.9 particles particularly in finer fractions (2800–750 μm and 750–600 μm), whereas relatively lower values were observed in A2 having 689.5 particles and A10 having 654.6 particles. Spatial variation in MPs abundance observed among sampling sites may also reflect differences in waste age, localized disposal practices, and heterogeneity of landfill composition. Similar site-to-site variations were reported by [23] and [24], where older waste deposition zones exhibited significantly higher MPs accumulation compared to recently deposited areas. These spatial differences can be attributed to variations in waste composition, age of landfill deposits and degree of exposure to environmental conditions. Older landfill zones typically exhibit higher MPs abundance due to prolonged degradation and weathering processes [17]. Furthermore, heterogeneity in waste disposal practices can influence the distribution and fragmentation rate of plastics across different sites.

3.3 Shape-wise distribution of microplastics

Among different shapes, film-type MPs dominated across all sampling sites, followed by fibers and fragments, while pellets and foam were present in minimal quantities shown in Figure 4. Film types of MPs were recorded 464 to 504.3, fragments were 72.3 to 104 and pellets were 0.66 to 12 and foams were 1-12 least among all shown in Figure 3. The predominance of film-type MPs observed in the present study is consistent with findings reported from landfill and municipal solid waste environments, where films constituted the major morphological category [14], [15], [23]. The dominance of films suggests that plastic bags, packaging materials, and agricultural films are the primary sources of MPs in landfill soils. Film-type plastics are highly susceptible to fragmentation due to their thin structure, making them a major contributor to secondary MPs. Similar findings have been reported where landfill-derived MPs were dominated by films and fragments due to degradation of packaging materials [25]. Additionally, environmental transport processes such as wind action, surface runoff, leachate movement, landfill settlement, and repeated waste handling can further break down and redistribute film plastics, increasing the proportion of smaller-sized particles in the landfill soil [21]. Fibres presence indicates contributions from textiles and synthetic materials, which enter landfill systems through municipal waste. The very low abundance of pellets suggests limited contribution from primary MPs, indicating that secondary MPs dominate the study area.

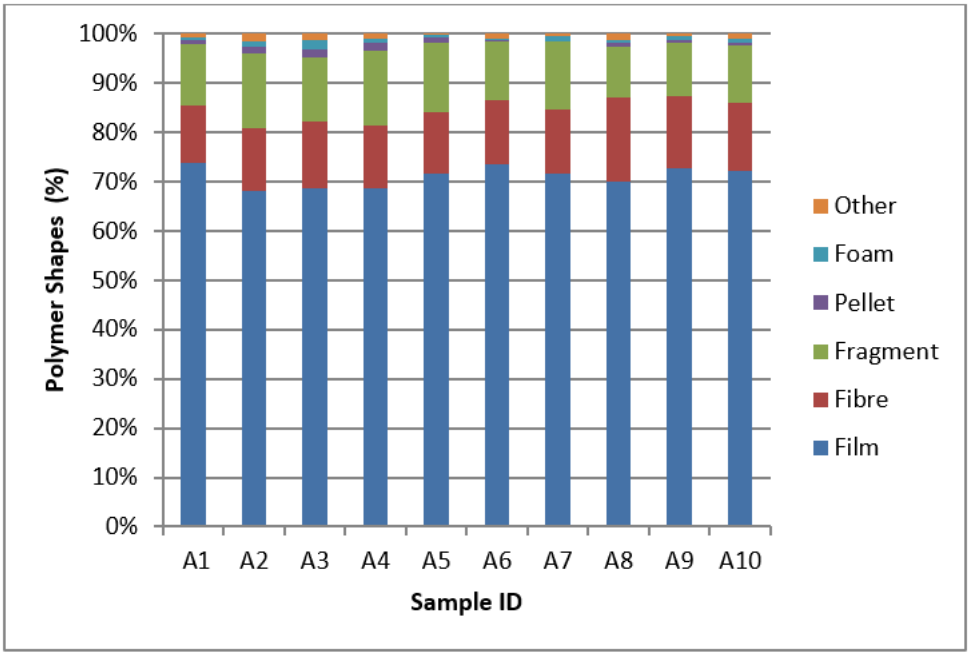


Fig 3. Distribution of MPs according to shape categories identified in the analysed samples

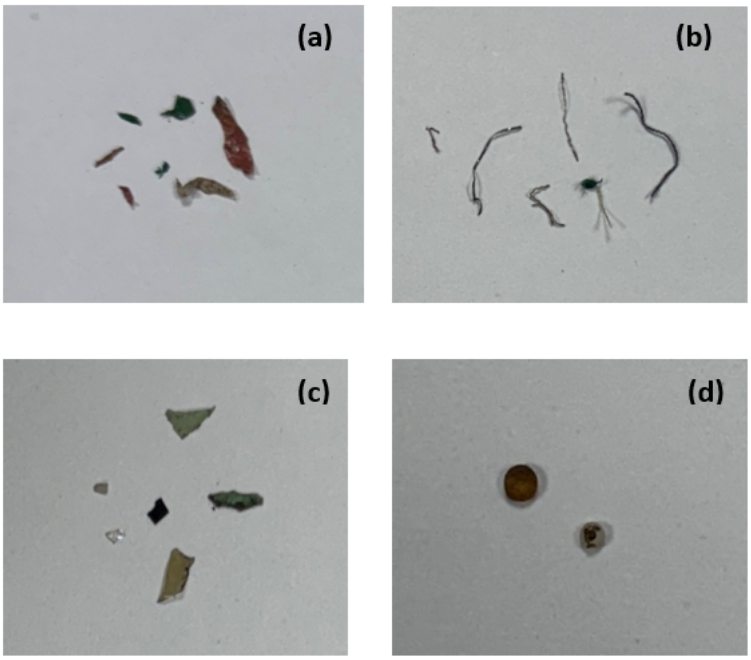


Fig 4. Various shapes of MPs observed in landfill soil samples (a) Film (b) Fibre (c) Fragment (d) Pellet

3.4 Colour-wise distribution of microplastics

Colour analysis revealed that transparent MPs were the dominant across all samples, followed by other colours such as red, white, green, and black. Transparent particles were 958 to 1084 and red particles were 150 to 226, white particles were 173 to 228, green were 127 to 186 and black were 94 to 152 shown in Figure 5. The dominance of transparent MPs indicates that degraded plastic materials lose pigmentation over time, becoming colourless due to weathering and chemical changes. Similar dominance of transparent and light-coloured MPs has been documented in landfill soils and urban waste environments by [16] and [26]. Previous studies also reported transparent or light-coloured MPs as dominant in landfill environments [6]. Additionally, high transparent MP abundance suggests advanced degradation stages, longer residence time in landfill and exposure to UV and chemical processes. In contrast, studies conducted in freshwater and coastal ecosystems often report blue and black MPs as dominant due to fishing activities, textile fibres, and industrial discharge. The variation in colour profiles between landfill and aquatic systems highlights differences in pollution sources and degradation pathways.

3.5 Polymer composition of MPs

Fourier Transform Infrared Spectroscopy (FTIR) was employed to identify the polymeric composition of the isolated MPs from landfill soil samples. FTIR is considered a rapid and reliable analytical technique for polymer identification because each plastic polymer exhibits a characteristic infrared absorption fingerprint associated with specific molecular vibrations and functional groups. The obtained spectra were compared with standard reference bands reported in literature for confirmation of polymer types. The FTIR spectra confirmed the presence of major synthetic polymers including polystyrene (PS), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyethylene terephthalate (PET), and polypropylene (PP) in the analysed landfill soil samples. The dominance of these polymers indicates the extensive contribution of packaging materials, disposable consumer products, textile residues, and plastic waste dumping activities within the landfill environment. Polystyrene was identified through characteristic absorption bands observed at 1650, 1048, and 689 cm^{-1} shown in Figure 6(a) [27].

HDPE and LDPE polymers were identified by prominent peaks within the aliphatic C–H stretching region. HDPE showed absorption bands at 2809 and 2867 cm^{-1} shown in Figure 6 (b), whereas LDPE exhibited peaks at 2893 and 2815 cm^{-1} shown in Figure 6(c) [27]. PET was confirmed by characteristic absorption peaks at 713, 1052, 1264, and 1743 cm^{-1} shown in Figure 6(d). The strong peak at 1743 cm^{-1} corresponds to ester carbonyl (C=O) stretching vibrations, while peaks around 1264 and 1052

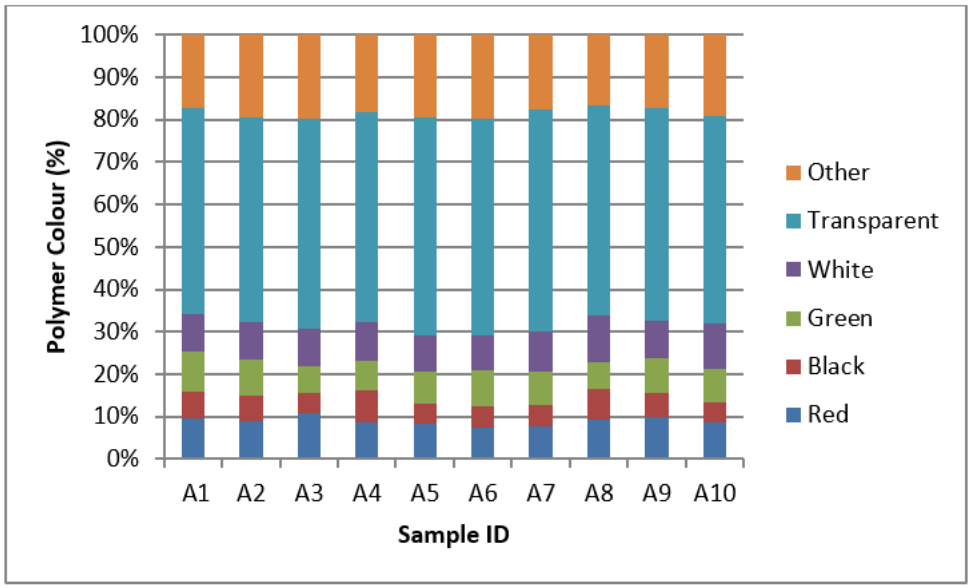


Fig 5. Colour-wise distribution of MPs observed in landfill soil samples

cm^{-1} represent C–O stretching vibrations of ester groups. The peak near 713 cm^{-1} indicates aromatic C–H out-of-plane bending. Polypropylene was identified through characteristic bands at 2872, 1326, 1464, and 1061 cm^{-1} shown in Figure 6(e). These peaks correspond to methyl (CH_3) bending, CH_2 bending and C–C stretching vibrations typical of PP polymers. Several researchers have reported polyethylene and polypropylene as the most abundant MPs polymers due to their low production cost, high consumption rate, and resistance to environmental degradation. The predominance of these polymers in the present study therefore reflects continuous accumulation and fragmentation of municipal plastic waste within landfill ecosystems [2]. Overall, the FTIR analysis shown in Figure 6 confirmed that the landfill soil samples contain a diverse mixture of secondary MPs dominated by PE, PP, PET, and PS polymers. Studies by [28], [29], and [26] similarly identified PE and PP as dominant polymers. Likewise, PP/PS as the dominant polymer group in soil and environmental samples, followed by PE and PET, emphasizing the widespread contribution of consumer plastics to terrestrial contamination [30]. It is also observed that PP, PE, PS, and PET were the major polymers detected in landfill soils, sediments, leachate, and groundwater surrounding municipal solid waste disposal sites, demonstrating the ability of these polymers to persist and migrate across multiple environmental compartments [22]. The identified polymer types strongly suggest that municipal solid waste disposal, packaging materials, household plastic products, and anthropogenic littering are major contributors to MPs contamination in the studied landfill environment. Compared with studies conducted in aquatic ecosystems where PET and nylon fibres are frequently dominant due to textile contamination, the polymer profile observed in the present study reflects direct input from municipal solid waste disposal activities.

3.6 Environmental Implication

The observed dominance of smaller-sized MPs (2800-750 μm and 750-600 μm), film-type shapes, and transparent particles indicates that landfill soils act as active sources and sinks of MPs. MPs in landfill environments can migrate into soil and groundwater through leachate and act as carriers of pollutants such as heavy metals and organic contaminants and may enter the food chain via soil-plant interactions [20]. MPs transport in landfill environments is strongly influenced by particle size, density, polymer type, soil characteristics, and hydrological conditions, with smaller particles exhibiting greater mobility and infiltration potential [31]. Recent investigation reported the occurrence of MPs not only in landfill soils but also in sediments, leachate, surface water, and groundwater surrounding municipal waste disposal sites, confirming the ability of landfill-derived MPs to migrate beyond their source area [22]. Similarly, it is highlighted that soil permeability, groundwater recharge, preferential flow paths, and hydrogeological conditions can significantly influence the movement of MPs into subsurface water resources [32]. As groundwater constitutes an important source of drinking and irrigation water, the infiltration of landfill-derived MPs may pose long-term environmental and public health concerns. Furthermore, landfill-derived MPs can be transported through

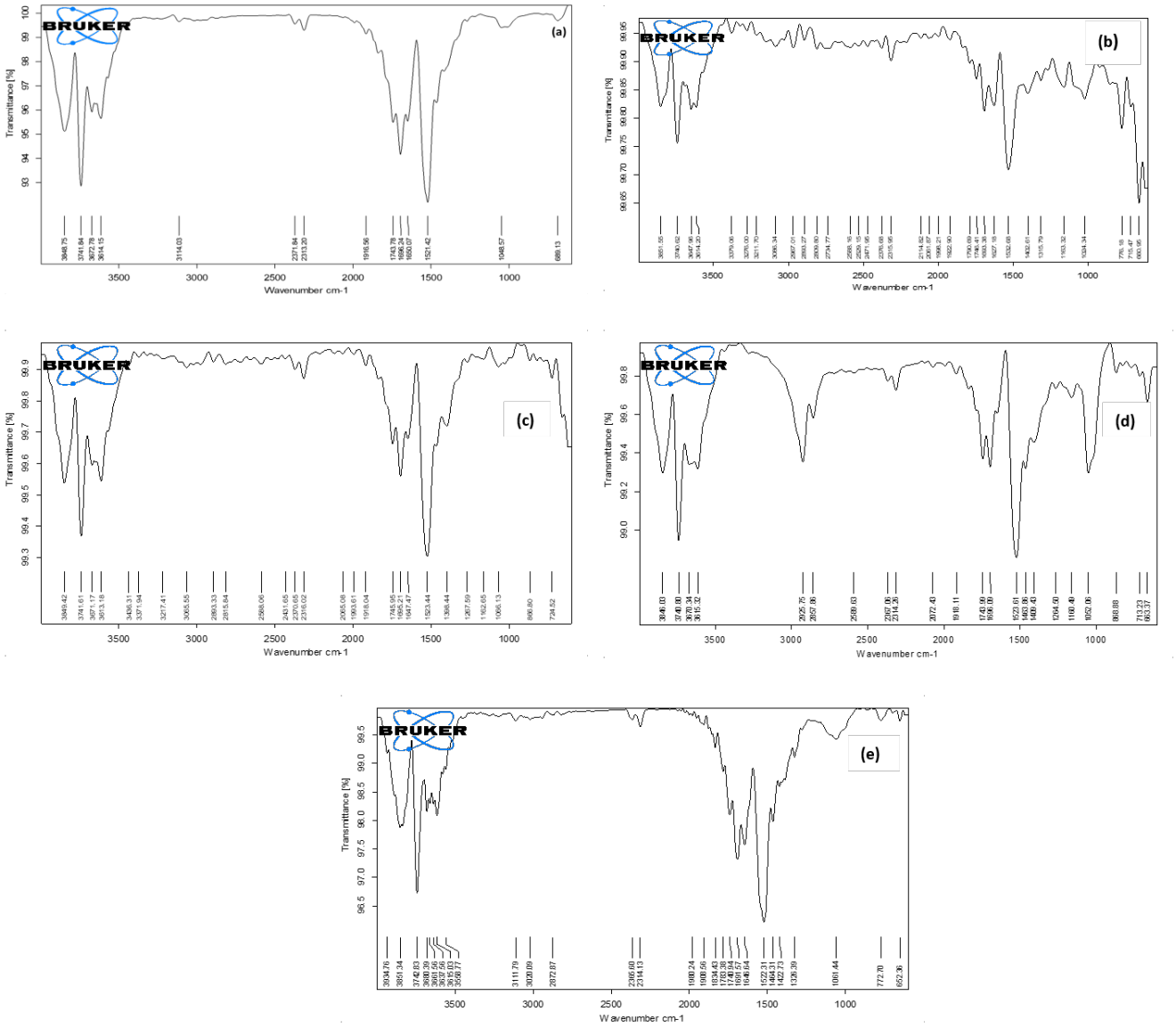


Fig 6. FTIR spectra showing characteristic absorption bands of identified MPs polymers (a) Polystyrene (b) HDPE (c) LDPE (d) PET (e) PP

wind and runoff, once released, these particles may accumulate in soils, interact with microorganisms, alter soil properties, and potentially enter food chains through plant uptake and trophic transfer contributing to wider environmental contamination [5].

4 Conclusion

The present study revealed the widespread occurrence of MPs in landfill soil samples, highlighting landfill environments as significant reservoirs of plastic contamination. Size-wise analysis demonstrated that smaller MPs fractions (750–600 μm) with abundance ranging from 243.6 $\pm$ 3 to 280.3 $\pm$ 15.6 particles, whereas larger fractions (5000–3000 μm) showed comparatively lower abundance. This trend indicates extensive fragmentation and weathering of plastic debris within the landfill ecosystem. The progressive increase in MPs abundance with decreasing particle size suggests continuous degradation of macro-plastics into secondary MPs through physical, chemical, and biological processes. Shape analysis showed the dominance of film-type MPs (464–504.3 particles), followed by fibres and fragments, while pellets and foams were comparatively less abundant. The predominance of films suggests that packaging materials, carry bags, and thin plastic sheets are the major contributors to

landfill-derived MPs. Colour distribution analysis revealed transparent particles as the dominant category (958–1084 particles), indicating prolonged environmental exposure and pigment loss during weathering processes. FTIR characterization confirmed the presence of major synthetic polymers including polyethylene (HDPE and LDPE), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS). The dominance of polyethylene and polypropylene reflects their extensive use in packaging materials and household products, whereas PET and PS likely originated from beverage containers, synthetic fibres, and disposable consumer items. The results emphasize the need for improved source segregation, reduction of single-use plastics, enhanced recycling infrastructure, scientific landfill engineering, and effective leachate collection and treatment systems to minimize the generation and environmental release of secondary MPs. Compared to previous studies primarily focused on aquatic environments, the present investigation provides important baseline information on landfill soil MPs contamination in north India. The study therefore highlights the role of unmanaged municipal landfills as continuous sources of secondary MPs capable of contaminating surrounding terrestrial ecosystems. Policies must mandate upgrading open dumps to engineered landfills with liners and integrated treatment to prevent MPs leakage. Regulatory frameworks should establish thresholds for MPs and future studies should focus on seasonal variation, transport pathways, ecological risk assessment, and interaction of landfill-derived MPs with heavy metals and organic pollutants.

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