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Microplastic Contamination in Groundwater Around Landfills: A Systematic Literature Review

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Abstract

Microplastic contamination in groundwater has become an emerging environmental concern, particularly in areas surrounding landfill sites. This study aims to systematically review the occurrence, distribution, characteristics, and influencing factors of microplastics in groundwater near landfills. A systematic literature review was conducted using the PRISMA 2020 framework, selecting articles published between 2021 and 2025 from Scopus and Google Scholar based on defined criteria. A total of 18 relevant studies were analyzed. The results show that microplastic abundance in groundwater varies widely, ranging from less than 1 particle/L to more than 1000 particles/L. Most microplastics are smaller than 500 µm, with polyethylene (PE) and polypropylene (PP) as the dominant polymers. Fragments and fibers are the most common forms, while color variation reflects differences in waste composition and environmental conditions. Microplastic distribution is influenced by distance from landfills, well type, depth, and age. Wells located within 1 km of landfills and shallow dug wells are more vulnerable to contamination. Landfill leachate plays a key role in transporting microplastics into groundwater systems. Therefore, integrated management strategies based on the Source–Pathway–Receptor approach are essential to mitigate contamination and protect groundwater quality.

Keywords: *microplastic pollution, groundwater contamination, landfill leachate, source–pathway–receptor*

Abstrak

Pencemaran mikroplastik dalam air tanah telah menjadi isu lingkungan yang semakin berkembang, khususnya di sekitar lokasi tempat pembuangan akhir (TPA). Penelitian ini bertujuan untuk mengkaji secara sistematis keberadaan, distribusi, karakteristik, serta faktor-faktor yang memengaruhi mikroplastik dalam air tanah di sekitar TPA. Kajian dilakukan menggunakan metode systematic literature review dengan kerangka PRISMA 2020, dengan memilih artikel yang dipublikasikan pada tahun 2021–2025 dari basis data Scopus dan Google Scholar berdasarkan kriteria yang telah ditentukan. Sebanyak 18 artikel relevan dianalisis. Hasil penelitian menunjukkan bahwa kelimpahan mikroplastik dalam air tanah bervariasi luas, yaitu kurang dari 1 partikel/L hingga lebih dari 1000 partikel/L. Mikroplastik umumnya berukuran <500 µm, dengan polietilena (PE) dan polipropilena (PP) sebagai polimer dominan. Fragmen dan fiber merupakan bentuk yang paling umum ditemukan, sementara variasi warna mencerminkan perbedaan komposisi sampah dan kondisi lingkungan. Distribusi mikroplastik dipengaruhi oleh jarak dari TPA, jenis sumur, kedalaman, dan umur sumur. Sumur dalam radius <1 km serta sumur dangkal lebih rentan terhadap kontaminasi. Lindi TPA berperan penting dalam transport mikroplastik ke dalam sistem air tanah. Oleh karena itu, strategi pengelolaan terpadu berbasis konsep *Source–Pathway–Receptor* diperlukan untuk mengendalikan pencemaran dan melindungi kualitas air tanah.

Kata Kunci: *pencemaran mikroplastik, kontaminasi air tanah, lindi TPA, transport bawah permukaan, source–pathway–receptor*

1. Introduction

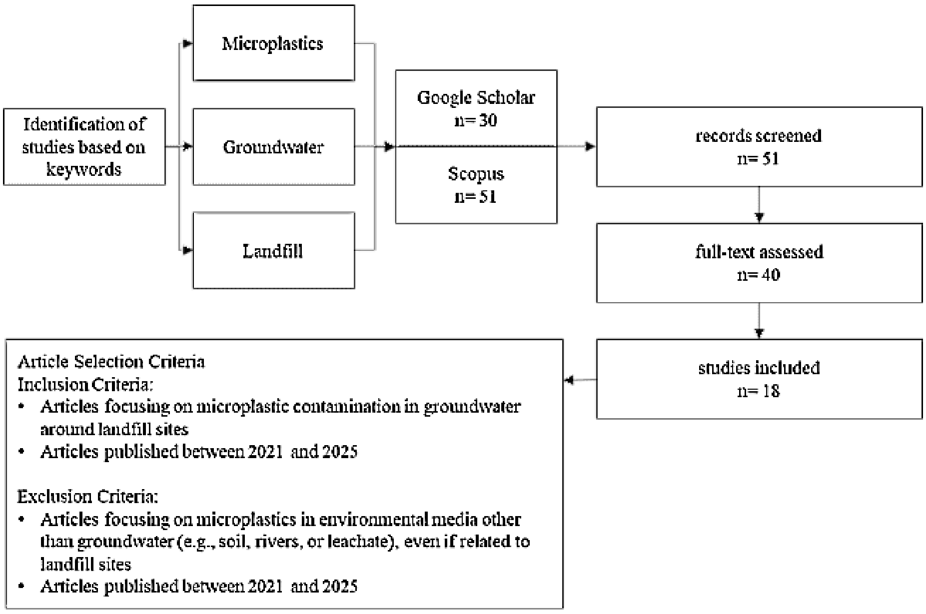
Plastic is one of the most widely used synthetic materials due to its lightweight, durability, and resistance to degradation; however, these properties also cause environmental problems because plastics degrade very slowly in natural environments [1], [2]. Over time, plastics break down into smaller particles known as microplastics (<5 mm), which are classified as emerging pollutants due to their persistence, mobility, and ability to transport hazardous substances [3][4]. Groundwater, as a crucial source for domestic, agricultural, and industrial use, has recently gained attention as a medium affected by microplastic contamination [5][6]. Landfill sites are identified as major sources, where plastic waste degrades and produces leachate containing microplastics that can migrate into soil and aquifers, especially when liner systems are ineffective [7][8][9] [10][11] [12] [13] [14].

Studies report that microplastic concentrations in groundwater range from <1 to >1000 particles/L, with diverse characteristics in size, shape, color, and polymer type. Polyethylene (PE) and polypropylene (PP) are the dominant polymers, while fragments and fibers are the most common forms. These variations reflect differences in waste composition, degradation processes, and environmental conditions. Contamination levels are influenced by hydrogeological factors such as distance from landfills, well type, and depth, with shallow wells (2–30 m) and those within 1 km of landfill sites being more vulnerable. Although deeper wells are relatively protected, they remain at risk due to possible hydraulic connectivity between aquifer layers.

The presence of microplastics in groundwater poses significant risks to environmental and human health, as they can act as carriers of toxic chemicals and potentially cause oxidative stress, inflammation, metabolic disorders, and other health issues [15][16] [17][18]. Therefore, effective control measures are required, including both source management and technological interventions in water treatment. This study aims to systematically review the occurrence, distribution, characteristics, influencing factors, and mitigation strategies of microplastics in groundwater around landfill sites, providing a comprehensive framework to support sustainable environmental management and safe water supply.

2. Materials and Methods

This study employs a systematic literature review based on the PRISMA 2020 framework to ensure a structured process of identifying, screening, and evaluating relevant studies. The review includes articles published between 2021 and 2025 from Scopus and Google Scholar, selected based on defined inclusion and exclusion criteria. Only full-text studies focusing on microplastic contamination in groundwater around landfill sites were included, while studies on other environmental media were excluded. The analysis compiles key data such as landfill location, microplastic abundance, size, polymer type, shape, color, and analytical methods. It also considers factors influencing microplastic distribution, including well type, depth, and distance from landfill sites. The article selection process is illustrated in **Figure 1**.



Article Selection Criteria
Inclusion Criteria:
- Articles focusing on microplastic contamination in groundwater around landfill sites
- Articles published between 2021 and 2025

Exclusion Criteria:
- Articles focusing on microplastics in environmental media other than groundwater (e.g., soil, rivers, or leachate), even if related to landfill sites
- Articles published between 2021 and 2025

Fig. 1: Flow Diagram of Article Review Based on PRISMA 2020
Source: Author's elaboration based on PRISMA 2020

3. Results and Discussion

Processes and Factors Influencing Microplastic Distribution in Groundwater Around Landfills

The distribution of microplastics in groundwater around landfill sites is a complex process influenced by various environmental, technical, and hydrogeological factors [4]. Landfills, as accumulation sites for waste—particularly plastic waste—serve as major sources of microplastics that can potentially contaminate the environment [10]. During rainfall events, water infiltrates the waste mass and generates leachate containing various contaminants, including microplastic particles derived from the incomplete degradation of plastics (**Figure 2**). This leachate subsequently percolates into the soil, especially when the landfill liner system is damaged or not functioning properly [12]. Microplastics transported by leachate can migrate vertically through soil pores and eventually reach shallow aquifers that store groundwater [13][14]. Once reaching the aquifer, microplastics may disperse horizontally following groundwater flow, leading to the spread of contamination to surrounding areas [20]. This indicates a potential risk of chronic exposure to microplastics through groundwater consumption, which may pose long-term health risks as microplastics can act as vectors for toxic compounds and other contaminants.

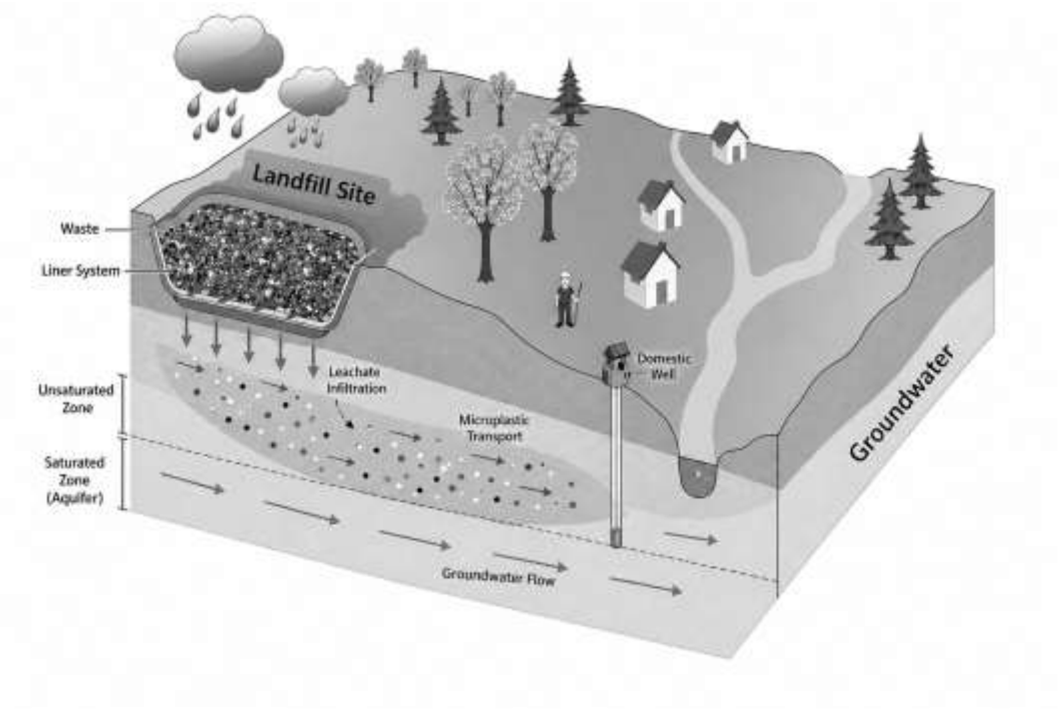


Fig. 2: Conceptual Model of Microplastic Transport from Landfill to Groundwater
Source: Modified from Siddiqua et al., 2022

One of the primary factors influencing the level of microplastic contamination is the distance of wells from landfill sites [22]. As shown in Table 1, several studies indicate that wells located within a radius of less than 1 km from landfills tend to exhibit higher microplastic concentrations compared to those located farther away. This is attributed to the increased potential for infiltration of leachate containing microplastics from waste deposits into the soil and subsequently into groundwater, particularly in areas with inadequate leachate management systems [23] [24]. Leachate generated from the degradation of organic and plastic waste can transport microplastic particles through vertical percolation and lateral flow into shallow aquifers that serve as water sources for nearby wells [13] [14].

In addition to distance, well type also plays a significant role in determining vulnerability to microplastic contamination [6]. Dug wells, which are typically shallow and have more open structures, are more susceptible to contamination from surface sources, including runoff carrying leachate containing microplastic particles [25] [26]. In contrast, bore wells, which are constructed with more enclosed systems and extend to greater depths, generally offer better protection against surface contamination [27]. However, bore wells are not entirely free from risk, particularly when hydraulic connectivity exists between shallow and deep groundwater layers, or when structural failures occur in the casing or sealing system [28] [29].

Another important factor is well age, which indirectly affects the structural integrity of wells and their ability to prevent contaminant infiltration [30]. Older wells tend to experience degradation in protective linings, pipe joints, or filtration systems, allowing microplastic particles to enter through cracks or structural weaknesses [31]. The longer a well is used without proper maintenance, the greater the risk of contamination from surrounding environments, particularly if the well is located near an active landfill or lacks an adequate buffer zone [32] [33].

Finally, well depth is a crucial factor influencing vulnerability to microplastic contamination [34]. Shallow wells are more susceptible to contamination from surface sources such as leachate, as the protective soil layer is relatively thin and the travel time of pollutant particles to the aquifer is shorter [35]. This indicates that shallow soil layers have limited filtration capacity for small-sized microplastic particles, allowing them to more easily reach aquifers. Microplastics can migrate to various depths through soil pores or rock fractures, particularly in soils with high porosity or under hydraulic pressure that promotes vertical movement [22][36]. Although deep wells are generally better protected, they may still be exposed if there is connectivity between shallow and deep groundwater systems or if groundwater flow carries microplastics into deeper aquifer layers [6].

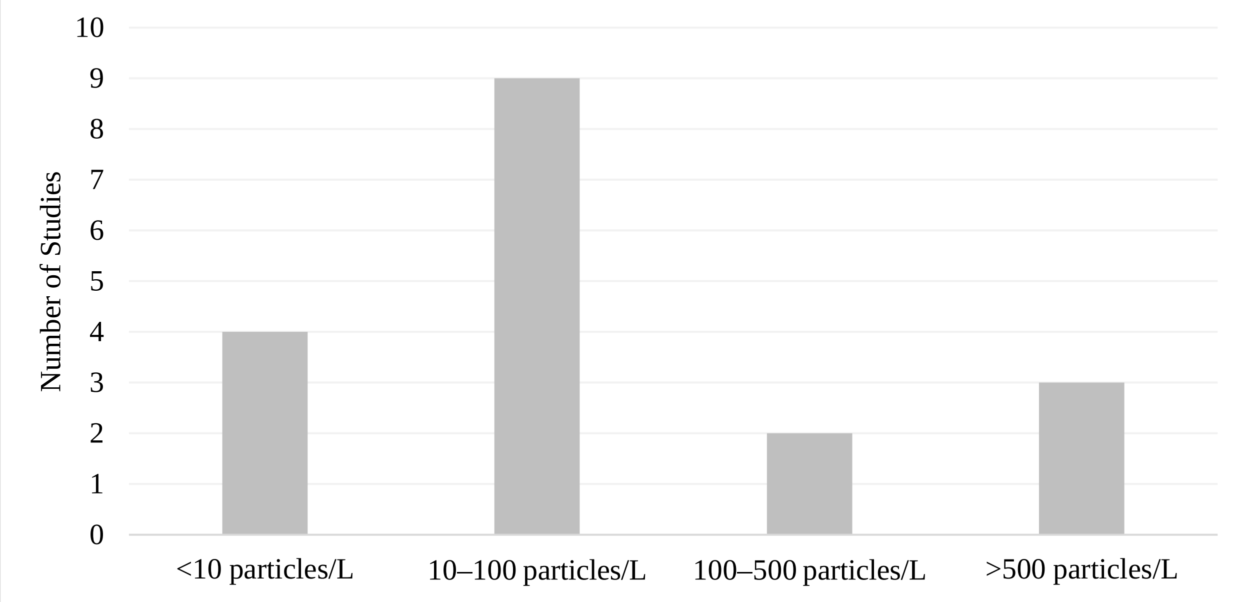


Fig. 3: Distribution of Microplastic Abundance in Groundwater Based on 18 Reviewed Studies

Characteristics and Abundance of Microplastics in Groundwater Around Landfills

The synthesis of 18 reviewed articles on the occurrence and distribution of microplastics in groundwater around landfill sites across various countries is systematically summarized presented in **Table 1**. The table summarizes key findings related to microplastic abundance, size, polymer type, morphology, color and analytical methods used in each study. In addition, supplementary notes are included regarding specific factors influencing microplastic distribution patterns, such as well type, depth, and distance from landfill sites.

Based on the synthesis of these studies, it can be concluded that microplastic abundance varies substantially, ranging from <1 to >1000 particles/L across the reviewed studies. The units used to report microplastic abundance also vary among studies, reflecting the lack of a standardized international framework for reporting microplastic concentrations [37]. A more detailed distribution of microplastic abundance is presented in **Figure 3**. The figure shows that most reviewed studies report microplastic abundance within the range of 10–100 particles/L. This indicates that concentrations within this range are the most frequently observed in groundwater around landfill sites. Although higher and lower values have been reported, these findings suggest that groundwater near landfills is commonly characterized by microplastic concentrations between 10 and 100 particles/L.

The size of microplastics identified ranges from less than 1 µm to 5000 µm (5 mm), with a predominance of particles smaller than 500 µm. This indicates that smaller particles are more easily transported through soil pores and have a higher potential to reach aquifer layers. A more detailed distribution of microplastic size is presented in **Figure 4**. The figure shows that particles within the size range of 100–500 µm are the most frequently reported among the reviewed studies, followed by particles smaller than 100 µm and those larger than 500 µm, while a smaller number of studies did not report size data. The dominance of microplastics in the 100–500 µm range suggests that particles of intermediate size have a higher likelihood of being detected due to both their mobility in porous media and the limitations of analytical methods. Smaller particles (<100 µm), although potentially more mobile, may be underrepresented due to detection constraints, whereas larger particles (>500 µm) are more likely to be retained within soil matrices, limiting their transport into groundwater systems.

The identified polymer types show relatively consistent patterns, with polyethylene (PE) and polypropylene (PP) as the dominant polymers, followed by others such as polyethylene terephthalate (PET), polystyrene (PS), polyvinyl chloride (PVC), and polyamide (PA/nylon). Several studies also reported the presence of other polymers, including polyester (PES) and polyurethane (PU), although at lower frequencies. In terms of morphology, fragments and fibres are the most observed forms, while other shapes such as foams, pellets, films, sheets, rods, and particles are identified in smaller proportions. The variation in microplastic morphology reflects complex plastic degradation processes influenced by environmental conditions surrounding landfill sites.

Microplastic colors are also highly diverse, with dominant colors including black, red, transparent, blue, yellow, and green. Other colors such as white, orange, purple, gray, pink and brown are also reported, albeit less frequently. As shown in **Figure 5**, this variation in color may indicate differences in plastic material sources as well as the degree of degradation occurring within landfill environments. Overall, the diversity in microplastic abundance, size, polymer type, morphology, and color indicates that groundwater contamination by microplastics is highly complex and strongly influenced by waste composition in landfills, plastic degradation processes, and local hydrogeological characteristics.

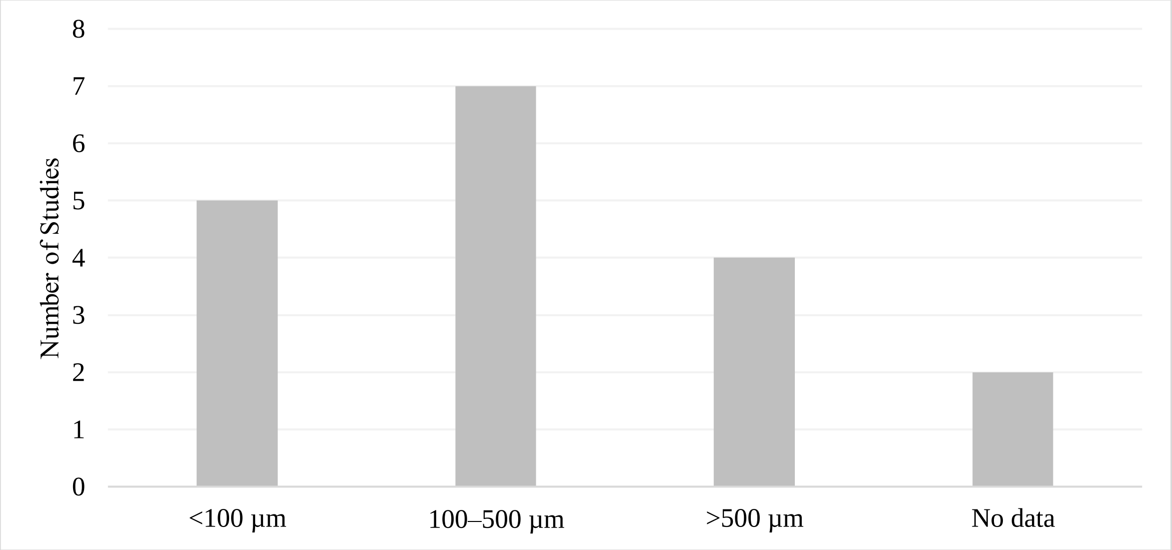


Fig. 4: Distribution of Microplastic Size in Groundwater Based on 18 Reviewed Studies

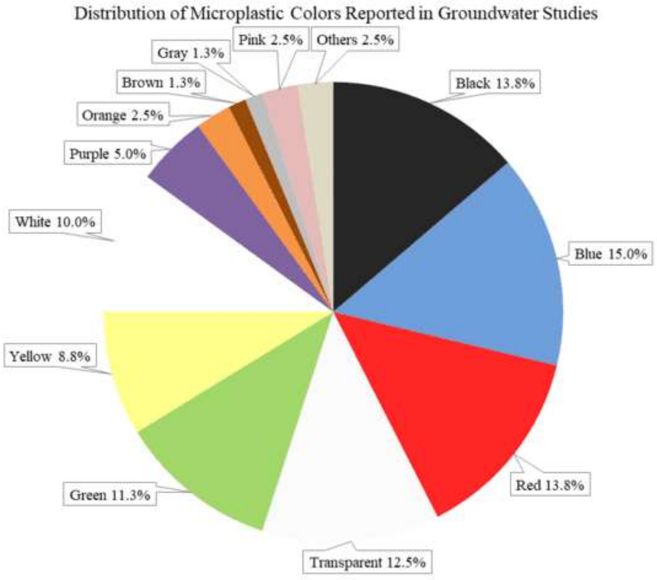


Fig. 5: Distribution of Microplastic Colors in Groundwater Based on 18 Reviewed Studies

Strategies for Landfill Management in Controlling Microplastic Pollution

Microplastic pollution in groundwater near landfill sites is strongly influenced by how the landfill itself is managed. Landfills are widely recognized as major sources of microplastics, as plastic waste gradually degrades into smaller particles that can be transported by leachate and eventually reach the aquifer [10] [12] [14]. For this reason, controlling microplastic pollution requires effective management strategies, particularly at the source.

One important approach is shifting from open dumping to sanitary landfill systems. In open dumping conditions, waste is directly exposed to environmental factors such as UV radiation, temperature changes, and physical disturbances, all of which accelerate plastic fragmentation [38] [39]. By contrast, sanitary landfills are designed with daily cover layers and environmental controls that help reduce degradation processes and limit microplastic generation. They also allow better control of leachate, reducing its potential to infiltrate into the surrounding soil [13].

The performance of the liner system is another critical aspect. As the main barrier between waste and the subsurface environment, a damaged or poorly functioning liner can increase the risk of leachate leakage containing microplastics. Using multi-layer liners, such as geomembrane combined with clay, along with proper maintenance, can help minimize this risk [13] [14].

Leachate management also plays a key role, since it acts as the primary pathway for microplastic transport. Treatment systems should not only focus on conventional parameters (e.g., BOD, COD, ammonia), but also consider microplastic removal. Combining physical, chemical, and advanced treatment processes can reduce the amount of microplastics released into the environment [40], [41]. In addition, an efficient drainage system is needed to prevent leachate accumulation and reduce downward percolation into the soil [42].

Efforts at the source should also include reducing plastic waste generation. The composition of landfill waste directly affects the type and quantity of microplastics produced. Therefore, implementing 3R (reduce, reuse, recycle) programs and limiting single-use plastics can help decrease the overall microplastic load [43][44].

Finally, regular monitoring and evaluation are essential. This includes reactivating monitoring wells and routinely assessing leachate and groundwater quality, with microplastics included as an emerging parameter. Such monitoring supports early detection of contamination and helps evaluate the effectiveness of management strategies [25] [45].

Overall, controlling microplastics in landfill environments requires an integrated approach that combines technical improvements, operational practices, and source reduction (**Figure 6**). This is consistent with the Source–Pathway–Receptor (SPR) framework, which emphasizes controlling pollutants from their origin, along transport pathways, and at the point of exposure, in order to protect groundwater and the surrounding environment.

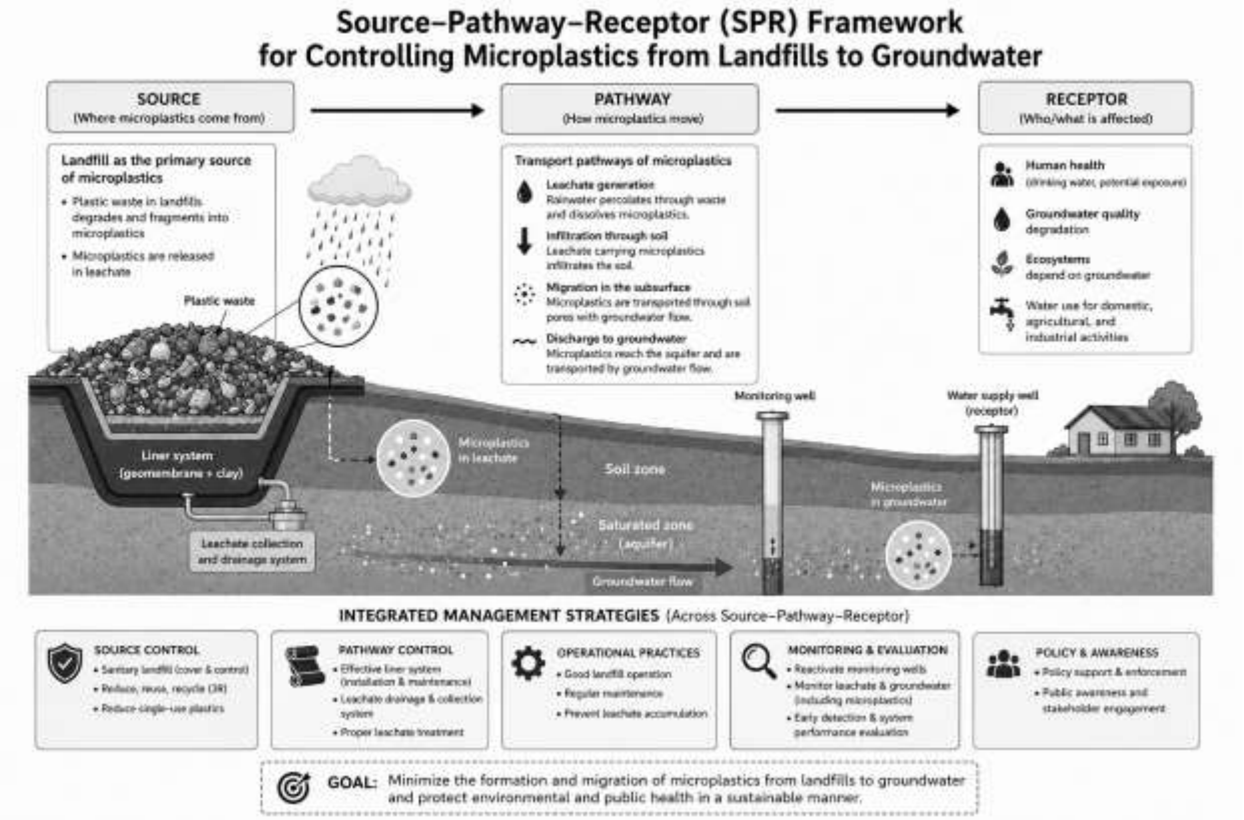


Fig.6: Conceptual Source–Pathway–Receptor (SPR) framework illustrating microplastic sources from landfill, transport pathways through leachate and soil into the aquifer, and affected receptors, along with integrated management strategies for pollution control.

Source: Author’s elaboration (visualized using AI tools)

Table 1. Abundance and Characteristics of Microplastics in Groundwater Near Landfills Across Different Countries

No.	Country	Abundance	Size	Polymer Type	Shape	Color	Analytical Method	Notes	References
1	India (Kodungaiyur and Perungudi Landfills)	2-80 items/L	500 µm - 5 mm	PP, PE, PET, PS, PVC	Fragments, fibers, film, pellets, foam	Transparent, white, blue, black, red	Stereo zoom microscope (LABOMED CZH4, 40×), SEM-EDX, ATR-FTIR, ArcGIS 10.7.1, GeoDa, Origin 2018b, Microsoft Excel 2016	Samples were collected from 20 bore wells (3–30.48 m depth); highest abundance observed within 1 km.	[46]
2	India (Bhalswa dumpsite)	26 items/L- 171 items/L	0.45 - 100 µm	PE, PP, PES, PA, PET, PVC, PS	Fragments, fibers, film, sphere	White, transparent, black, red, blue	Stereo microscope, Raman spectroscopy	Samples from 13 bore wells (5.3–17 m) depth; highest abundance at 200 m from the dumpsite.	[47]
3	India (8 dumping site from Kollam Corporation)	5.8 items/L – 24.6 items/L	Not specified	Not specified	Fibers, flakes, fragments, and other	Black, red, green, blue, yellow, white, pink, transparent, brown, orange, and others	NOAA method, stereomicroscope, ArcGIS	Eight dumping sites; 4 samples/site (500 m); highest at Kureepuz landfill; well depth not reported.	[22]
4	United Arab Emirates (Sajaa Landfill)	Rahmaniya: 12-235 n/L Falah: 41 & 56 n/L	30.99 µm-2 mm	PET, PA, PVC	Fragments, fibers	Red, green, blue, transparent, and black	Stereo microscope (LABOMED CZH4, 40×), SEM-EDX, ATR-FTIR, ArcGIS 10.7.1	30 bore wells; depth and distance not reported.	[28]
5	France (Prairie de Mauves Landfill)	0.71 – 106.7 MP/L	32 - 2758 µm	PE, PP, PET, PA, PS, PVC, ABS, PVAc, PU, acrylic, vinyl copolymer, and alkyd	Not specified	Not specified	Microscopy, ATR-FTIR	Samples from 6 monitoring wells (2–5 m); highest at <50 m from landfill.	[48]
6	China (Informal Landfill in Guangdong Province)	11-17 items/L	20–150 µm	PU, PET, PA, PVC, PP, PE, PS, PET	Not specified	Not specified	SEM, FTIR, Microsoft Excel 2019, SPSS version 22.0	Samples from 3 wells (upstream–downstream; 2.3–3.7 m); distance not reported.	[49]

No.	Country	Abundance	Size	Polymer Type	Shape	Color	Analytical Method	Notes	References
7	China (Landfill in Jizhou District)	27.0 ± 5.72 n/L	10–5000 µm	Not specified	Fibers, fragments, films, and pellets	Transparent, white, blue, green, black, and red	Stereo microscope (40× magnification) and ATR-FTIR	Samples were collected from one deep well in front of the landfill (12 m depth, 10 m distance).	[50]
8	China (Landfill in Hainan Province)	3 – 23.5 items/L	50–1000 µm	PE, PET, PVC, PA	Fragments, fibers, particles	Blue, black, transparent, and red	Stereo microscope, FTIR	Samples were collected from 14 monitoring wells upstream and downstream of the landfill, while the sampling radius and well depth were not reported.	[51]
9	Bangladesh (Amin Bazar Landfill)	320-1170 MP/L	0.1–0.5 mm	LDPE, HDPE, PP, PETE, nylon, nitrile	Fragments, fibers, films, pellets, foams	Black, blue, white, red, green, purple, and yellow	Stereo microscope (Leica, 8×–40×), FTIR, and SEM	Samples were collected from eight deep bore wells (100–120 m), all within 1 km of the landfill, with the highest microplastic abundance observed at GW-1 as the closest point.	[29]
10	Bangladesh (Anandabazar dumping site area, Halishahar)	Not specified	Not specified	LDPE, HDPE, Polyamides, Polyureas, Fluoro-Polymers, Resins	Not specified	Not specified	FTIR	Samples were collected from five shallow bore wells (3–20 m) located within 500 m of the site.	[52]
11	Bangladesh (Matuail Landfill)	323 ± 35 1170 ± 50 - MPs/L	<0.1 – 5 mm	LDPE, HDPE, PP, PS, Nylon, EVA, PU, PMMA, and PAN	Pellet, fragment, foam, film, fiber	Purple, black, blue, yellow, red, white, and transparent	Microscopy, FTIR, and SEM	Samples were collected from 10 bore wells (100–120 m) located 500 m from the landfill, with the highest microplastic abundance observed at GW01 as the closest point.	[53]

No.	Country	Abundance	Size	Polymer Type	Shape	Color	Analytical Method	Notes	References
12	Vietnam (Khanh Son Landfill)	2 - 21 particles/L	117.7 ± 148,8 µm	PET, POM, EVOH, PA, PO, PAM, PTFE, PES, PEI	Fragments, fibers	Not specified	Stereo microscope and FTIR	Samples were collected from one bore well and four dug wells (15–38 m) located 100–1000 m from the landfill, with the highest microplastic abundance observed at NN1 (38 m depth, 100 m distance).	[2]
13	Thailand (Muangpak Landfill)	Groundwater point 1 : 21.25±14.01 items/L Groundwater point 2 : 13.75±6.17 items/L Groundwater point 3 : 22.92±5.94 items/L	Not specified	PP and LDPE	Not specified	Not specified	Stereo microscope and FTIR	Samples were collected from three monitoring wells within the Muangpak landfill area, while well depth and distance were not reported.	[54]
14	Thailand (Landfill in Rayong Province)	18-94 pieces/L	<0.5 mm – >1 mm	PP, PE, Rayon	Fiber, fragment, sheet	Green, blue, orange, and black	Stereo microscope and µ-FTIR (LUMOS II, Bruker)	Samples were collected from seven wells (7–16 m), with the highest microplastic abundance observed within 20 m of the landfill.	[34]
15	Poland (Closed landfill site since 2001)	2 particles	Not specified	PE and PET	Not specified	Not specified	µ-FTIR	Samples were collected from three monitoring wells, with the highest microplastic abundance at P-1 (570 m from the landfill; groundwater depth 1.95–2.42 m).	[55]
16	Indonesia (Tamangapa Landfill)	0.25-0.95 items/L	0.069–4.450 µm	Not specified	Fragments and fibers	Blue, red, transparent, green, and purple	Microscopy	Samples were collected from eight dug wells around the landfill, with the highest microplastic abundance observed	[56]

No.	Country	Abundance	Size	Polymer Type	Shape	Color	Analytical Method	Notes	References
								at locations >500 m from the landfill.	
17	Indonesia (Piyungan Landfill)	77-149 partikel/L	10.55–97.41 µm	PS and PVC	Not specified	Not specified	Microscopy and FTIR	Samples were collected from three dug wells (10–25 m), with the highest microplastic abundance observed within 1 km of the landfill.	[57]
18	Indonesia (Gampong Jawa Landfill)	808 - 979 items/L	<100–>1000 µm	Not specified	Fragment, fiber, film, pellet, rod	Black, yellow, pink, red, blue, green, white, gray, purple, and others	Optical microscopy, FTIR, Raman spectroscopy, and SEM-EDX	Samples were collected from two wells (300 and 600 m), with the highest microplastic abundance observed at ST-7 as the closest point to the landfill.	[58]

4. Conclusion

This study shows that microplastic contamination in groundwater around landfill sites is widespread and complex, with abundances ranging from <1 to >1000 particles/L. Microplastics are mostly <500 µm, dominated by PE and PP, and commonly found as fragments and fibers. Their distribution is influenced by distance from landfills, as well as well type, depth, and age, with shallow wells within 1 km being more vulnerable. Landfill leachate plays a key role in transporting microplastics into groundwater. Therefore, integrated management strategies based on the Source–Pathway–Receptor approach are needed, along with improved analytical methods and further research on long-term impacts.

5. Acknowledgment

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