Proceedings of the 9th World Congress on Civil, Structural, and Environmental Engineering (CSEE'23)
London, United Kingdom - April, 2024
Paper No. ICEPTP 111
DOI: 10.11159/iceptp24.111

Microplastics in Sharjah's Groundwater: Enumeration, Characterization and Spatial Distribution

Bushra Tatan[1], Md Maruf Mortula[1], Tarig Ali [1]
[1]American University of Sharjah
American University of Sharjah, Sharjah 26666, UAE
g00069371@alumni.aus.edu; mmortula@aus.edu
atarig@aus.edu

Abstract **-** The global production of plastics is projected to continue rising with increasing consumption. Plastics break down in the environment, leading to the formation of microplastics. Despite the growing concern over microplastic pollution, there have been limited studies assessing its contamination in groundwater. This may be attributed to the lack of monitoring efforts specifically focused on microplastics in groundwater. In the UAE, groundwater accounts for more than half of the water supply. Therefore, the main objective of this study was to investigate the presence of microplastics in groundwater in the UAE. The study identified 30 groundwater boreholes in the Rahmaniya, Bedee, and Falah regions of Sharjah, UAE, from which samples were collected. To prepare the samples, a series of pretreatment procedures involving 30% hydrogen peroxide, density separation, and extraction filters were employed. Microplastics were subsequently detected using a microscope with 40x magnification, revealing the presence of microplastics in the water of 11 boreholes in Rahmaniya, ranging from 12 to 235 n/L, respectively. In the Falah area, contamination was observed in two boreholes, with 56 and 41 n/L, respectively, while no contamination was found in the Bedee area. Characterization of microplastics was conducted using ATR-FTIR analysis, which has successfully matched the obtained spectra with polyethylene terephthalate, polyethylene, and polypropylene for 10 samples. GIS analysis, using IDW interpolation, highlighted significant microplastics contamination in Rahmaniya. The study also identified potential sources of contamination, including industrial areas, the Sajaa landfill, Bedee Farmland, and the water dump lagoon.

***Keywords*:** Microplastics, Groundwater, Geographic Information System, Fourier-transform Infrared Microscopy

1. Introduction

Currently, plastics are extensively used worldwide in various applications such as pipes, phones, food packaging, textiles, and more. Global plastic production has surged from 1.5 million tons in 1950 to 320 million tons in 2017 [1]-[2], and it is estimated to reach 800 million tons by 2050. Plastics are extensively used worldwide due to their attractive characteristics such as low cost, corrosion resistance, and high ten-sile strength. Common methods of plastic disposal include landfill, incineration, and recycling. In 2015, the production of plastic waste amounted to approximately 6.3 billion tons. Out of this total, only 9% was recycled, 12% was incinerated, and a staggering 79% was either disposed of in landfills or released into the natural environment [3]. Plastics can degrade to microplastics through photodegradation, thermos-oxidative degradation, hydrolysis, and microbial biodegradation [4]. Microplastics are plastic particles that have a diameter smaller than 5 mm, with a minimum size of 1 μm.

Microplastics have been detected in human feces, colectomy specimens [5], and even more recently, in human blood [6]. This is not unexpected considering that micro-plastics have been found in various food sources, including seafood, sugar, salt, honey, and even drinking water, posing a significant risk to human health [5]. Micro-plastics can either be excreted or accumulated within the body, potentially causing localized toxicity and impacting the immune response [7]. Additionally, due to their hydrophobic nature, microplastics can absorb toxic contaminants like polybrominated diphenyl ethers and per-/poly-fluoroalkyl substances (PFAS). These particles may release additives or adsorbed pollutants that can result in certain types of cancers or developmental toxicity [7]-[8].

Groundwater is a crucial source of freshwater, utilized by over 2 billion people worldwide for various purposes [9]. It replenishes surface water sources and supplies in regions with scarce surface water. Microplastics have various pathways to reach groundwater, including sources such as wastewater treatment plants (WWTPs) [10], saltwater intrusion [11], aquifer recharge [12], agricultural practices like plastic mulching [13], and landfill leachate [14]. Nevertheless, few studies investigated microplastics contamination in groundwater [15]-[19]. The studies have identified PE and Polyethylene terephthalate (PET) are the most detected microplastic types. In terms of shapes, fragments and fibres are the most frequently observed forms of microplastics in the studies mentioned.

Geographic Information System (GIS) is a system that encompasses the creation, management, and analysis of diverse types of data [20]. It is a valuable tool that enables the representation and analysis of georeferenced data on map layers. For instance, GIS has been utilized to assess the spatial and temporal variations in water quality within a water distribution system [21]. Furthermore, GIS allows users with limited technical expertise to integrate data from multiple sources and apply various analytical techniques to understand environmental processes.

Groundwater plays a significant role in meeting 70% of the total water demand in the United Arab Emirates (UAE) [22]. Sharjah, one of the Emirates in the UAE, experiences a climate that is described as hot, dry, and humid, with the rainy season occurring between November and March [11]. The groundwater wells in Sharjah have a combined capacity of approximately 21.50 million gallons per day, and the average daily water production from these wells is approximately 15.46 million gallons [23]. It is essential to assess the level of plastic pollution in groundwater because contamination can lead to the pollution of soil and crops. This cycle needs to be halted to pre-vent severe impacts and potential costs. Waiting for visible damage to occur can be detrimental, making it necessary to take proactive measures to prevent further pollution. Therefore, this study aims to investigate the abundance of microplastics in the ground- water of Sharjah and identify the spatial distribution of microplastics using GIS.

2. Methodology

2.1. Study Site

The study was conducted on some selected groundwater boreholes in the Emirate of Sharjah, UAE. Due to restrictions and regulations, the areas that were granted access to by Sharjah Electricity and Water Authority (SEWA) are Rahmaniya, Bedee and Falah. The study areas stretch from longitude 55°36'18.6"E to 55°31'55.8"E and latitude 25°21'46.9"N to 25°15'06.0"N. The aquifer in these areas is unconfined.

2.2. Sample Collection

A total of 90 groundwater samples were collected from 30 boreholes in the study area, with 45 samples obtained from 15 boreholes in Rahmaniya, 21 from 7 boreholes in Bedee, and 24 from 8 boreholes in Falah. The selection of the boreholes aimed to ensure a representative sample, considering factors such as the area size, proximity to different land uses, and availability of boreholes. For the Rahmaniya area, which has the largest area and the highest number of boreholes, 15 boreholes were chosen for sampling.

Each borehole was carefully sampled by collecting 1 Liter of water in amber glass bottles. The water was retrieved through the dedicated pipes and pump system in-stalled in the boreholes, which are made from galvanized iron. After collection, the samples were stored at a temperature of 6°C until they were prepared for analysis.

2.3. Analytical Methods

Pretreatment is necessary to remove any contaminants that could interfere with the analysis. Environmental samples often contain organic matter that cannot be eliminated through filtration or density separation alone. Hence, the removal of organic matter is essential to avoid the possibility of any interference for the microplastics enumeration. However, it has been noted [24] that over 90% of the organic matter in groundwater is dissolved. Dissolved organic matter can pass through a filter with a pore size of 0.45 μm, which is smaller than the size of microplastics. As a result, oxidation is not required unless visual indications suggest the need for it. To eliminate organic matter, a suggested method is to add 40 mL of 30% hydrogen peroxide to the samples and incubate them at 60°C for 12-24 hours. The duration of oxidation depends on the organic content present in the samples.

Density separation was implemented to successfully separate microplastics from inorganic materials like aggregates, which typically exhibit a density range of 2.4-2.9 gcm^{-3}. Density separation was conducted by elevating the density of water to 1.45 gcm^{-3} using zinc chloride. In a previous study [25], a novel isolation unit was used for density separation. The unit can achieve an impressive average recovery performance of 95.8%. This unit was employed for a duration of 24 hours and demonstrated efficient extraction of microplastics in a single step. After the density separation process, each sample underwent vacuum filtration using a 0.8 μm Whatman cellulose nitrate filter paper. Subsequently, the the filter paper was carefully transferred to a glass petri dish and left to air-dry for 24 hours in a desiccator.

After the separation and extraction process, the filter paper was divided into quarters. One quarter was selected for counting and quantifying microplastic particles using a stereoscopic microscope set to a magnification of 40x. Microplastics were identified based on specific criteria, including the absence of cellular or organic matter, distinct edges, consistent fibre thickness, clear and uniform colour, and non-straight fibres indicating a biological origin [26]. Colours facilitated their identification, but caution was needed to avoid underestimating microplastic numbers, especially for those with muted colours. In addition, microplastics are generally flexible and do not easily break when prodded. Therefore, a careful examination with tweezers or a probe was conducted to identify microplastic particles. Any particles that broke upon touching were not considered as microplastics. Fibers and fragments were categorized based on shape, and the abundance of microplastics on the entire filter paper was expressed as particles per Liter (n/L).

Attenuated Total Reflection Fourier Transform Infrared spectroscopy (ATR-FTIR) was used for the characterization of micro- plastics. This instrument was configured with a resolution of 4 cm^{-1} and 32 scans, which were automatically averaged to generate a single spectrum. First, the background spectrum was acquired and automatically subtracted from subsequent sample spectra to eliminate any background noise. Next, the spectrum of the filter paper and zinc chloride was obtained, enabling their subtraction from the sample spectrum. This process aimed to obtain a clean spectrum that closely resembled the microplastic being analysed, free from impurities. Finally, using a tweezer, the microplastic pieces were carefully picked up and placed on the ATR crystal to obtain their respective spectra. These spectra were then compared to the commercially available ATR-FTIR library or literature.

To ensure caution, method blanks using deionized water were conducted to detect potential external contamination during the research process. Equipment was rinsed with deionized water, glassware was preferred to minimize plastic contamination, and protective measures such as cotton lab coats and nitrile gloves were used. Work-station surfaces were regularly wiped to prevent plastic contamination. The number of microplastics identified in the blanks was subtracted from corresponding samples.

Finally, in GIS, spatial interpolation techniques can be employed to estimate values of a specific parameter at unsampled locations. One commonly used spatial interpolation method is Inverse Distance Weighting (IDW), which relies on the inverse of the distance between the sampled and unsampled locations of interest as a weighting factor. Given the locations of the boreholes, a raster layer was created in GIS for the micro-plastics abundance obtained in the samples using IDW interpolation. The layer was analysed to understand the spatial variability, contamination sources, considering land use and locations.

3. Results and Discussion

3.1. Enumeration of Microplastics in Groundwater

This study specifically focuses on microplastic particles with a diameter larger than 20μm due to limitations of the FTIR technique. A quarter of each blank and sample filter paper was analysed to determine the microplastics concentration on the entire filter paper. The counts obtained from the blank samples were subtracted from the final sample counts, with any negative values reported as zero. All triplicates went through the same procedures and an average was calculated. The concentrations of microplastics varied across the boreholes. Table 1 shows that Rahmaniya exhibited contamination in 11 boreholes, with the highest and lowest microplastics counts at 235 n/L and 12 n/L, respectively. In contrast, Falah had contamination in only two boreholes, while Bedee showed no contamination.

There can be several reasons for the variations of microplastics abundance. An-other reason could be attributed to the density of soil. Soil layers range from loose to medium dense and dense in Falah and Rahmaniya, while in Bedee they range from medium dense to very dense. Loosely packed sand with larger void spaces facilitates easier transport of microplastics compared to dense and very dense soil layers. In Rahmaniya, the primary form of microplastics discovered was fragments, which accounted for 82.94% of the microplastics observed. Conversely, in Falah, fibres were the most common type, making up 56.12% of the microplastics. It is important to note that different studies have yielded varying results regarding the prevalence of different microplastic shapes. In the case of Falah, the high occurrence of fibres can be attributed to the water pumping level, which enables fragments to settle in deeper layers of soil, while fibres tend to interlace with soil particles and form clumps [27].

Table 1: Microplastics contamination in groundwater.

Rahmaniya		Falah	
Borehole Number	Average Microplastics Count (n/L)	Borehole Number	Average Microplastics Count (n/L)
1.00	12	14	41
41.00	111	19	56
51.00	25		
74.00	95		
77.00	72		
104.00	163		

3.2. Characterization of Microplastics

Microplastics colours found in the samples were red, green, blue, transparent, and black. Figure 1 shows a blue fibre. ATR-FTIR analysis was used to identify the type of microplastics in the samples. Out of the 13 samples analysed for microplastics, three yielded inconclusive results, while the remaining samples showed matches for plastics like PET, PE, and PA. Figure 2 shows the spectrum of one of the microplastics. The spectrum does not exhibit the highest match to any specific plastic, but PE was identified as the seventh closest match (35.15%) in the library. The sample's spectrum was compared to existing literature, revealing small peaks between 2800 and 2900 cm^{-1}, around 1500 cm^{-1}, and 1700 cm^{-1}, which are indicative of PE [28].

Fig. 1: Blue fibre.

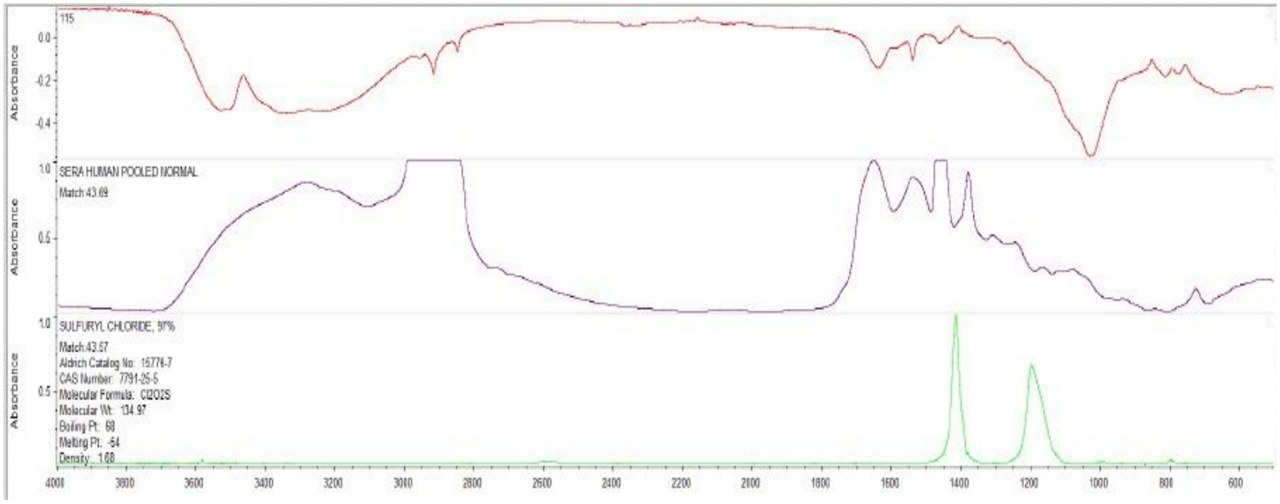

Fig. 2: Sample 115 spectrum.

3.3. Spatial Analysis

Figure 3 depicts the spatial distribution of microplastics using the IDW interpolation method for the Rahmaniya, Bedee, and Falah areas. This distribution pattern aligns with expectations, as Rahmaniya shows the highest level of microplastics contamination. Land uses around the areas were studied. It was found that Rahmaniya is sur-rounded by various sources that have the potential to contribute to microplastics contamination. The industrial area, located approximately 2.3 km away, includes many plastic factories. A research study indicates that boreholes near industrial areas exhibit the highest microplastics contamination in groundwater [19]. Additionally, the BEEAH Waste Complex and Al Sajaa Landfill, situated around 6 km from Rahmaniya, are potential sources of groundwater contamination as waste complexes and landfills are known contributors to contamination. Furthermore, the Al Bedee Farmland, which is closer to Rahmaniya than Bedee itself, raises concerns about the potential for microplastics contamination from agricultural activities. Lastly, there is a water dump area with the reject water lagoon located approximately 1.7 km away from Rahmaniya.

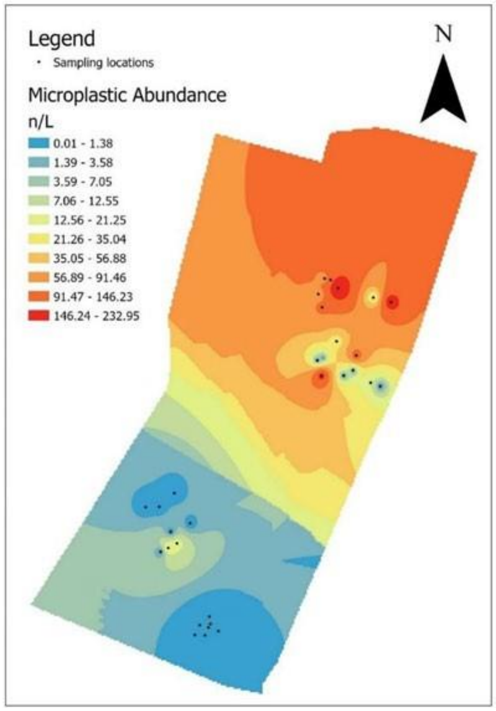

Fig. 3: IDW map.

4. Conclusion and Recommendations

In conclusion, this study investigated the presence of microplastics in groundwater in a specific area of Sharjah, UAE. The sampling of 30 boreholes, along with pretreatments and microscopic analysis, revealed varying abundances of microplastics across the sampled locations. Rahmaniya exhibited the highest contamination, while Falah had a lower abundance, and Bedee showed no contamination. The ATR-FTIR analysis confirmed the presence of plastics such as PET, PE, and PA in the samples. GIS analysis, using IDW interpolation, highlighted significant microplastics contamination in Rahmaniya. The study also identified potential sources of contamination, including industrial areas, the Sajaa landfill, Bedee Farmland, and the water dump lagoon.

The findings of this study serve as a baseline for future research. Groundwater modelling could provide insights into contamination spread and assist in implementing effective control measures. Increasing the number of sampled boreholes and con-ducting experiments in controlled environments would enhance the reliability of results. Additionally, combining FTIR with other characterization methods like SEM-EDX would improve the analysis, especially for smaller microplastics found in groundwater samples.

Acknowledgements

The authors would like to acknowledge the support for Microplastic Research Group provided by the American University of Sharjah and Sharjah Electricity, Water, and Gas Authority (SEWA).

References

[1] O. S. Alimi, J. Farner Budarz, L. M. Hernandez and N. Tufenkji , "Microplastics and Nanoplastics in Aquatic Environments: Aggregation, Deposition, and Enhanced Contaminant Transport," *Environ. Sci. Technol.*, vol. 52, no. 4, pp. 1704-1724, 2018.

[2] P. Wanner , "Plastic in agricultural soils–a global risk for groundwater systems and drinking water supplies?–a review," *Chemosphere*, vol. 264, p. 128453, 2021.

[3] R. Geyer, J. R. Jambeck and K. L. Law, "Production, use, and fate of all plastics ever made," *Sci. Adv.*, vol. 3, no. 7, p. e1700782, 2017.

[4] H. K. Webb , J. Arnott, R. J. Crawford and E. P. Ivanova, "Plastic Degradation and Its Environmental Implications with Special Reference to Poly(ethylene terephthalate)," *Polym.*, vol. 5, no. 1, p. 18, 2013.

[5] C. J. Rhodes, "Plastic pollution and potential solutions," *Sci. Prog.*, vol. 101, no. 3, pp. 207-260, 2018.

[6] H. A. Leslie, M. J. Van Velzen, S. H. Brandsma, A. D. Vethaak, . J. J. Garcia-Vallejo and M. H. Lamoree, "Discovery and quantification of plastic particle pollution in human blood," *Environ. Int.*, vol. 163, p. 107199, 2022.

[7] S. L. Wright and F. J. Kelly, "Plastic and Human Health: A Micro Issue?," *Environ. Sci. Technol.*, vol. 51, no. 12, pp. 6634-6647, 2017.

[8] Z. Yuan, R. Nag and E. Cummins, "Human health concerns regarding microplastics in the aquatic environment - From marine to food systems," *Sci. Total Environ.*, vol. 823, p. 153730, 2022.

[9] N. A. Khant and H. Kim, "Review of Current Issues and Management Strategies of Microplastics in Groundwater Environments," *Water.*, vol. 14, no. 7, 2022.

[10] F. Murphy, C. Ewins, F. Carbonnier and B. Quinn, "Wastewater Treatment Works (WwTW) as a Source of Microplastics in the Aquatic Environment," *Environ. Sci. Technol.*, vol. 50, no. 11, pp. 5800-5808, 2016.

[11] M. Sherif, A. Sefelnasr, A. A. Ebraheem, M. Al Mulla, M. Alzaabi and K. Alghafli, "Spatial and Temporal Changes of Groundwater Storage in the Quaternary Aquifer, UAE," *Water.*, vol. 13, no. 6, p. 864, 2021.

[12] E. Severini, L. Ducci, A. Sutti, S. Robottom, S. Sutti and F. Celico, "River–Groundwater Interaction and Recharge Effects on Microplastics Contamination of Groundwater in Confined Alluvial Aquifers," *Water.*, vol. 14, no. 12, 2022.

[13] B. Long, F. Li, K. Wang, Y. Huang, Y. Yang and D. Xie, "Impact of plastic film mulching on microplastic in farmland soils in Guangdong province, China," *Heliyon.*, vol. 9, no. 6, p. e16587, 2023.

[14] M. M. Mortula, S. Atabay, K. P. Fattah and A. Madbuly, "Leachability of microplastic from different plastic materials," *J. Environ. Manag.*, vol. 294, p. 112995, 2021.

[15] A. Esfandiari, S. Abbasi, A. B. Peely, D. Mowla, M. A. Ghanbarian, P. Oleszczuk and A. Turner, "Distribution and transport of microplastics in groundwater (Shiraz aquifer, southwest Iran)," *Water Res.*, vol. 220, p. 118622, 2022.

[16] Y.-I. Kim, E. Jeong, J.-Y. Lee, R. W. Chia and M. Raza, "Microplastic contamination in groundwater on a volcanic Jeju Island of Korea," *Environ. Res.*, vol. 226, p. 115682, 2023.

[17] S. Selvam, K. Jesuraja, S. Venkatramanan, P. D. Roy and V. Jeyanthi Kumari, "Hazardous microplastic characteristics and its role as a vector of heavy metal in groundwater and surface water of coastal south India," *J. Hazard. Mater.*, vol. 402, p. 123786, 2021.

[18] S. Samandra, J. M. Johnston, J. E. Jaeger, B. Symons, S. Xie, M. Currell, A. V. Ellis and B. O. Clarke, "Microplastic contamination of an unconfined groundwater aquifer in Victoria, Australia," *Sci. Total Environ.*, vol. 802, p. 149727, 2022.

[19] H. Mu, Y. Wang, H. Zhang, F. Guo, A. Li, S. Zhang, S. Liu and T. Liu, "High abundance of microplastics in groundwater in Jiaodong Peninsula, China," *Sci. Total Environ.*, vol. 839, p. 156318, 2022.

[20] Esri, "What is GIS?," [Online]. Available: https://www.esri.com/en-us/what-is-gis/overview.

[21] M. M. Mortula, T. A. Ali, R. Sadiq, A. Idris and A. Al Mulla, "Impacts of Water Quality on the Spatiotemporal Susceptibility of Water Distribution Systems," *Clean (Weinh).*, vol. 47, no. 5, p. 1800247, 2019.

[22] Y. Abdullah , S. Am , A.-R. Rami and K. Naseraldin , "Spatio-Temporal Trend Analysis of Groundwater Levels in Sharjah, UAE," *Int. J. Environ. Sci. Dev.*, vol. 11, no. 1, pp. 9-14, 2020.

[23] A.-D. R. H. , "Water resources management in Sharjah, UAE," *ISESCO J. Sci. Technol,*, vol. 12, pp. 38-53, 2016.

[24] S. Regan, P. Hynds and R. Flynn, "An overview of dissolved organic carbon in groundwater and implications for drinking water safety," *Hydrogeol. J.*, vol. 25, no. 4, pp. 959-967, 2017.

[25] R. L. Coppock, M. Cole, P. K. Lindeque, A. M. Queirós and T. S. Galloway, "A small-scale, portable method for extracting microplastics from marine sediments," *Environ. Pollut.*, vol. 230, pp. 829-837, 2017.

[26] V. Hidalgo-Ruz, L. Gutow, R. C. Thompson and M. Thiel, "Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification," *Environ. Sci. Technol.*, vol. 46, no. 6, pp. 3060-3075, 2012.

[27] Z. Ren, X. Gui, X. Xu, L. Zhao and H. a. C. Qiu, "Microplastics in the soil-groundwater environment: Aging, migration, and co-transport of contaminants – A critical review," *J. Hazard. Mater.*, vol. 419, p. 126455, 2021.

[28] M. B. K, U. Natesan, V. R, P. K. R, R. R and S. S, "Spatial distribution of microplastic concentration around landfill sites and its potential risk on groundwater," *Chemosphere*, vol. 277, p. 130263, 2021.