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Low-Density Microplastics in Recreational Parks of Al Ain, United Arab Emirates: Abundance, Composition, and Potential Effects on Soil Health

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Abstract

Microplastics (MPs) have been an emerging concern due to their harmful effects on the ecosystem and are ubiquitous in various habitats, from marine to terrestrial environments. However, studies on the presence of MPs in recreational areas are limited. One of the previous works has reported that urban recreational parks are considered "sinks" for plastic debris, including MPs. In this study, low-density MPs (LD-MPs) in soil samples collected from recreational parks of Al Ain, United Arab Emirates (UAE) were isolated by density flotation method. Results showed that these parks have varying levels of LD-MPs caused by various anthropogenic activities, such as sludge use and application of reclaimed water from wastewater treatment facilities in those areas. These plastic particles were isolated in 87% of the soil samples, with an average concentration of 1550 ± 340 MPs/kg. Predominantly, these comprised large LD-MPs (300 - 5000 μm), with red and blue being the most common colors. Fourier transform infrared (FTIR) spectroscopy identified possible synthetic polymers, including polyethylene and polypropylene. Additionally, a negative correlation was observed between LD-MP concentration and soil pH and moisture content, indicating potential adverse effects on soil health. These findings highlight the need for monitoring and managing microplastic pollution in urban recreational areas to mitigate its ecological impacts.

Keywords

Plastic Particles, FTIR Analysis, Microfibers, Soil Pollutants, Urban Parks

1. Introduction

In recent years, escalating concerns over environmental pollution have drawn significant attention to the ubiquitous presence of microplastics (MPs) and nanoplastics, particularly in urban ecosystems [1] [2] [3] [4]. Among these, recreational parks stand as vital green spaces within urban landscapes, offering respite and leisure to residents. However, the infiltration of plastic particles into these environments has raised questions about their potential impact on soil health and ecosystem integrity. The majority of research has focused on MPs in aquatic ecosystems [5] [6] [7], leaving knowledge gaps regarding other environments. Thus, studies on the occurrence of MPs in soils, especially in urban parks and recreational areas, are limited.

Researchers have referred to urban recreational parks as "sinks" of plastic debris, citing their capacity to accumulate substantial quantities of plastic particles [8]. In their study, MPs were found in 97% of the soil samples from parks and recreational areas in Amsterdam, Netherlands, with the average concentration of 4825 ± 6514 MPs/kg of soil. However, when examining the organic carbon content, moisture content and pH of the soils, no significant correlation was found between these properties and microplastic concentration. A variety of synthetic polymers in different shapes and sizes were documented in many recreational locations. For example, polystyrene fragments ranging in the size from 0.5 - 5 mm accounted for about 38% of the total collected particles (n = 3267) from national parks and protected areas in southern parts of the Baltic Sea [9]. Meanwhile, polyethylene (PE) and polypropylene (PP) MPs, mostly above 100 μm size, were found on sand and leaves in playgrounds [10].

Furthermore, MPs have the potential to induce adverse health effects in both humans and animals. Airborne plastic particles can be inhaled and may lead to disturbances in the respiratory system [11]. In various aquatic animals, such as brine shrimps [12], water fleas [13], pacific oysters [14], marine medaka [15], sea urchins [16], marine copepods [17], and zebrafish [18], exposure to MPs has been linked to reproductive toxicity. Recreational parks, characterized by the harmonious coexistence of human activity and biodiversity, serve as an ideal setting to investigate the extent and nature of microplastic contamination in such environments. The focus on low-density microplastics (LD-MPs) is particularly relevant due to their distinctive behaviors in soil matrices. These particles, often introduced through various sources including wind dispersion [19] [20], water runoff [21] [22], and anthropogenic activities [23] [24] have been shown to accumulate in soil.

Numerous studies have highlighted the significant impacts of plastic particles on the physicochemical properties of soil. For instance, MPs have been found to alter soil structure and texture [25] [26], which could hinder the distribution of soil organisms and affect soil aeration, thus disrupting soil's biological processes [27] [28]. Yet, MPs have also been found to stimulate microbial activity [29]. This suggests that while MPs might not directly reduce the number of bacteria in the soil, they can still cause significant changes in the soil's biological dynamics. These changes can have cascading effects on soil carbon and nutrient cycling, potentially altering the physicochemical properties and impacting overall soil health [29]. In the present study, a multidisciplinary approach was employed. Field surveys were conducted to quantify the abundance and types of MPs present within the recreational parks in Al Ain, UAE. The potential effects of these MPs on soil properties, in terms of soil pH and moisture content, were assessed. By establishing a link between the presence of MPs and soil property alterations, this study aims to contribute valuable insights into the potential repercussions of plastic particle contamination on urban ecosystems.

2. Materials and Methods

2.1. Sample Collection

Soil samples were taken from seven recreational parks in Al Ain, UAE (**Figure 1**). Using a sterile stainless-steel sample probe (HiHydro, T-style, 12 inch), the soil was collected from the top 30 cm of the soil layer near the boundary. Additional

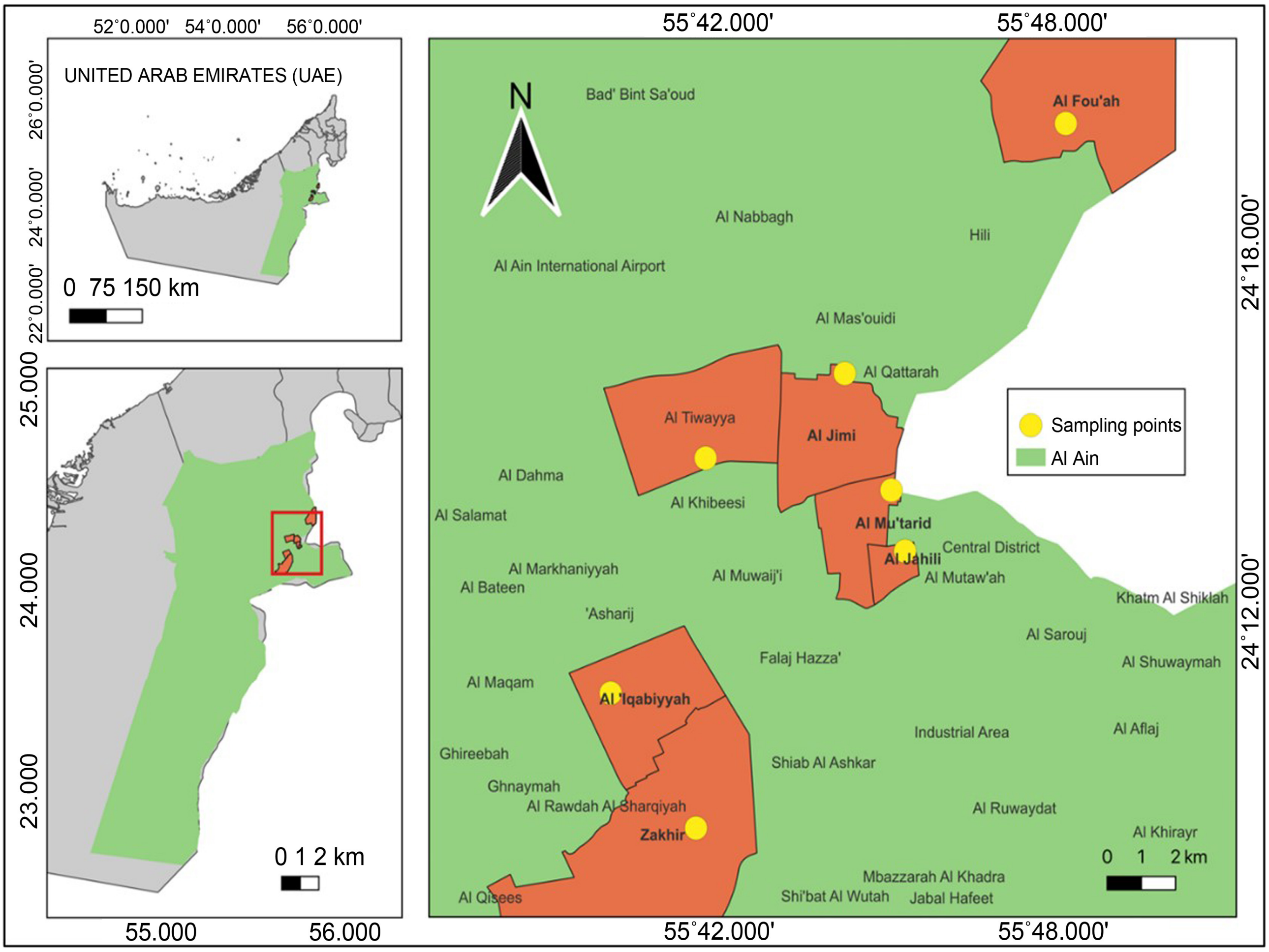

Figure 1. Map of recreational parks in Al Ain, UAE. This figure illustrates the location of the recreational parks studied within Al Ain. Al Ain is situated at approximately 24.2075˚N latitude and 55.7442˚E longitude.

samples were collected randomly in the area. A total of 10,701 g (n = 104) of soil samples were gathered. The global positioning coordinates of each sampling point were recorded using a handheld GPS (Garmin e Trex®10) (**Supplementary Information**; https://doi.org/10.17632/nthrjr322s.1). Each sample was placed in a brown paper bag (29 × 9.2 × 5 cm) by scraping the soil off from the probe using a clean, stainless-steel spatula. The samples were transported immediately to the laboratory and stored in a refrigerator at 5˚C until further analysis.

2.2. Microplastic Extraction

Each sample (10.0 ± 0.1 g) was dried at 40˚C for 24 h. The dried sample was then filtered through a stack of 8" dm stainless-steel sieves (Glenammar™) with apertures of 5 mm and 1 mm, followed by the density flotation method (DFM). The 1 mm sieve was rinsed with saturated sodium chloride (NaCl) solution (1.2 g/cm^3) and the rinse was added later into the flask. An aliquot of 5.0 ± 0.1 g from each filtered sample was placed in a clean Erlenmeyer flask. To each flask, 50 mL of the saturated NaCl solution was added, along with the rinse from the 1mm sieve. The mixture was stirred with a magnetic bar at ~240 rpm for 30 min. After stirring, the flask was left undisturbed for 48 h. The liquid portion contains LD-MPs. This liquid was then siphoned, transferred into a clean beaker, and subjected to vacuum filtration. The filter paper used was a glass microfiber filter (Whatman® pore size 1.2 μ, 4.7 cm), and the filtration process was performed twice.

2.3. Microplastic Verification and Identification

To verify LD-MPs, residues on the filter were brushed onto a glass Petri dish using a sable series 16 (Winsor & Newton) paintbrush (no. 3) with weasel hairs, to prevent contamination. The dish was then viewed under a stereomicroscope (AmScope™) at a magnification of 40×. A hot needle test [30] was performed for isolation of suspected LD-MPs. Controls included low-density polyethylene (LDPE) microbeads and cotton fibers. Each plastic particle was photographed and measured using ImageJ 1.53t Java 1.8.0_345 (64-bit). Digital images of LD-MPs were processed to accurately quantify particle size. This involved setting scale parameters, and employed "analyze and measure" feature of the software to record particle dimensions (mm). Prior to the hot needle test, the isolated LD-MPs underwent visual color identification using a 120-palette code. This palette comprises a range of 13 major colors along the vertical axis and nine hues along the horizontal axis, spanning from black to white, in addition to the option of transparency or translucency [31] (**Supplementary Information**; https://doi.org/10.17632/nthrjr322s.1). Descriptive statistical analysis was conducted to summarize the measurements and observe microplastic color, including the calculation of the mean and standard deviation. A Kruskal-Wallis test was performed to analyze microplastic concentration and size distribution between sampling sites.

2.4. Spectroscopic Analysis

Representative LD-MPs were subjected to spectroscopic analysis using Fourier transform infrared (FTIR) spectrometer (Thermo Nicolet Nexus 470 FTIR, USA), equipped with a deuterated triglycerine sulfate detector. Briefly, a nujol mull was prepared by grinding up LD-MPs (0.002 g) with 0.2 g potassium bromide (Sigma-Aldrich®). The transmittance spectra were recorded over 128 scans in the infrared range of 4000 cm^{-1} to 500 cm^{-1}, at a resolution of 4 cm^{-1}. The resulting spectra were then downloaded and graphs generated.

2.5. Soil pH and Moisture Content Measurement

To measure soil pH, distilled water extraction was performed, followed by measuring the pH of the extracts using a benchtop pH meter (Denver Instrument, Basic pH meter 13,183). For moisture content measurement, each sample (5.0 ± 0.1 g) was weighed before air-drying. The samples were then placed in a hot-air oven at 105˚C until a constant mass was achieved. Moisture content was calculated using the formula: moisture content (%) = (weight of sample before oven drying − weight of sample after oven drying/weight of sample before oven drying) × 100. Simple linear regression was employed to evaluate the correlation between soil pH, moisture content, and the number of LD-MPs per sampling site. The strength of the correlation values was categorized as follows: very weak (0 to ±0.19), weak (±0.20 to ±0.39), moderate (±0.40 to ±0.59), strong (±0.60 to ±0.79), and very strong (±0.80 to 1). Additionally, the Kruskal-Wallis test was performed to determine if there were significant differences between sampling sites in terms of the LD-MPs concentration.

2.6. Quality Control and Spiked-Recovery Experiment

Quality control is essential in microplastic studies to ensure accurate and reliable results. Various aspects of the study, from sampling to laboratory analysis, require careful consideration. During sampling, proper protocols were followed to minimize contamination. This included using clean sampling equipment, avoiding cross-contamination between samples, wearing nitrile gloves, and using a cotton lab coat. The work surface was thoroughly cleaned with 70% ethyl alcohol before each experiment. A Petri dish with a wet membrane filter was placed on bench as a control to collect potential airborne MPs, and no plastic particles were found in these controls. Type 1 grade water was used for cleaning the glassware and other materials before the experiment.

A spiked-recovery experiment was conducted to assess the efficiency of DFM in extracting LD-MPs from the soil samples. LDPE microbeads with densities ranging from ~1.08 g/cm^3 to 1.32 g/cm^3 were used. A known number of microbeads (100 particles) were spiked into the soil matrix (10.0 ± 0.1 g). The spiked samples were subjected to DFM, and the recovered microbeads were counted. The recovery rate (%) was computed using the formula: recovery rate (%) = (no. of total microbeads recovered/no. of total microbeads spiked in the matrix) ×

100. This experiment yielded a recovery rate of 87% - 93% for the microbeads from the soil matrices.

3. Results

3.1. Microplastic Concentration

Plastic particles are consistently been isolated from various environments. However, MPs in urban recreational areas have received comparatively less documentation. In the present study, LD-MPs were isolated in 87% of the soil samples (n = 104) collected from seven recreational parks in Al Ain, UAE. The average microplastic concentration was 1550 ± 340 MPs/kg. The highest concentration of LD-MPs was found in "Towayya" (3160 ± 2620 particles/kg), while the site with the lowest concentration was "Al_Sulaimi" with 600 ± 482 MPs/kg. Furthermore, there were significant differences between sampling locations ($p < 0.05$) in which outliers were not observed in all sampling sites (**Figure 2**), suggesting that anthropogenic activities substantially contributed to the presence of MPs.

3.2. Physical Characteristics and Polymer Types of MPs

The physical characteristics and polymer types of isolated LD-MPs (n = 711) were analyzed (**Supplementary Information**; https://doi.org/10.17632/nthrjr322s.1). Using a stereomicroscope, only three shapes

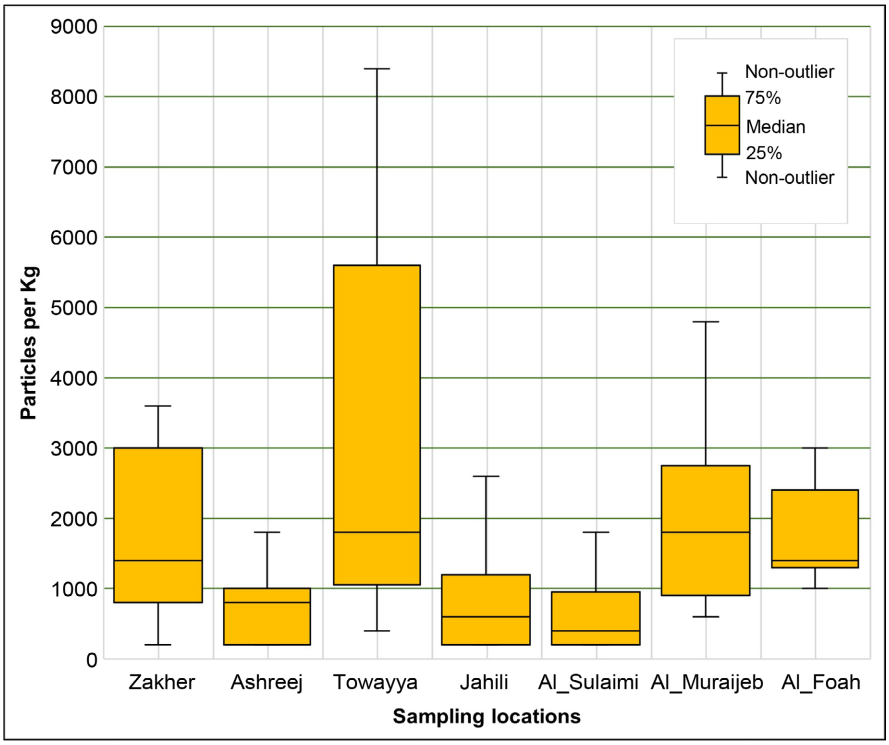

Figure 2. Microplastic concentrations at seven sampling locations in Al Ain, UAE. A significant difference ($p < 0.05$) between the sampling locations was observed, as determined by a Kruskal-Wallis test.

were visually identified. The predominant shape was microfibers (90.7%), followed by microfragments (9.0%) and micropellets (0.3%). Regarding size ranges, the majority were large LD-MPs (300 - 5000 μm; 86.35%), then fine (45 - 149 μm; 7.11%) and medium (150 - 300 μm; 6.54%) LD-MPs. The study revealed that the location with the highest median size was "Al_Foah" (1.84 mm), while the lowest median was observed in "Towayya" (0.86 mm). In Figure 3, although outliers were shown in all recreational parks except "Al_Foah", the Kruskal-Wallis test indicated a significant difference ($p < 0.05$) in size distribution between sampling sites. This suggests the presence of multiple sources of MPs. Furthermore, the most abundant colors identified were red (20.7%) and blue (20.3%), as shown in Figure 4.

Representative LD-MPs from soil samples were analyzed for polymer composition using an FTIR spectrometer. The FTIR spectra indicated that the synthetic polymer types of isolated plastic particles were potentially PP, PE, polyethylene terephthalate (PET), or polyvinyl chloride (PVC) (**Supplementary Information**; https://doi.org/10.17632/nthrjr322s.1). The spectra exhibited C-H stretching in the frequency range of 3000 - 2840 cm^{-1} and C-H bending in the fingerprint region of 600 - 1400 cm^{-1}. Furthermore, the peak at 2850 cm^{-1} is characteristic of PET, PE, or PVC, the peak at 2916 cm^{-1} corresponds to PE, PP, or PVC, and the peak at 1472 cm^{-1} is assigned to PE [32] [33] [34].

3.3. Potential Effects on Soil pH and Moisture Content

Two soil biophysical traits, soil pH and moisture content were analyzed

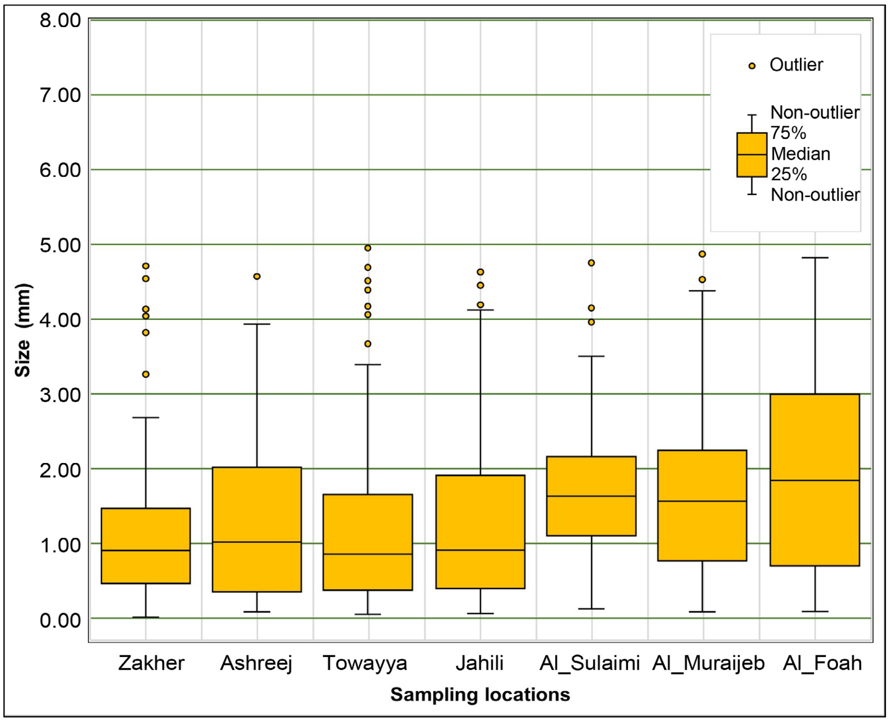

Figure 3. Size distribution of LD-MPs in soil samples. A significant difference ($p < 0.05$) in size distribution between the sampling locations was determined using the Kruskal-Wallis test.

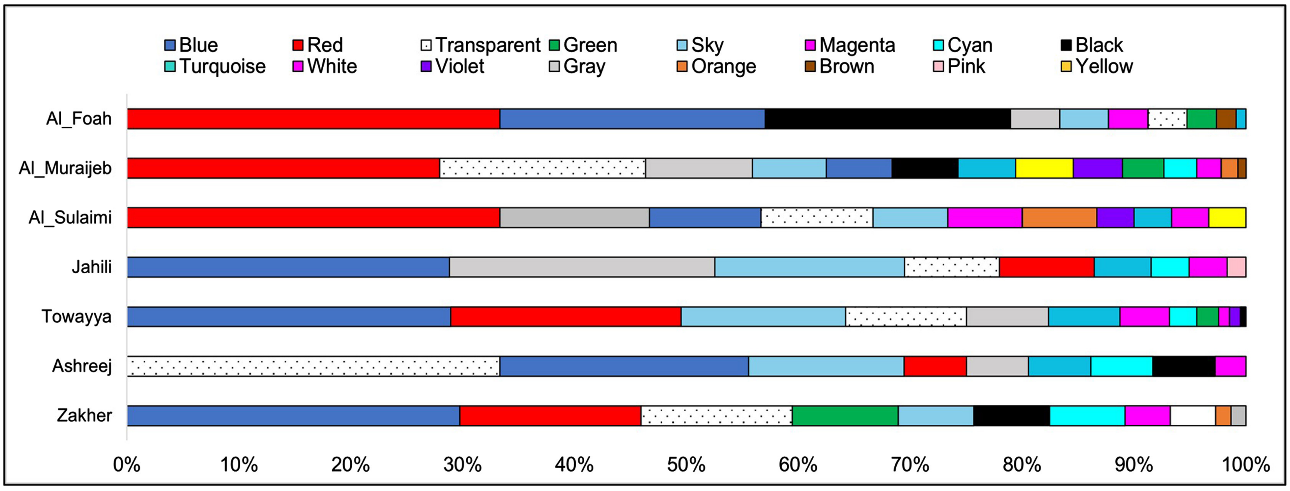

Figure 4. Color distribution of isolated MPs (n = 711) where x-axis is the quantity of LD-MPs isolated from each location. Each plastic particle's color was visually observed under a stereomicroscope and compared with a 120-palette code to ensure accurate classification.

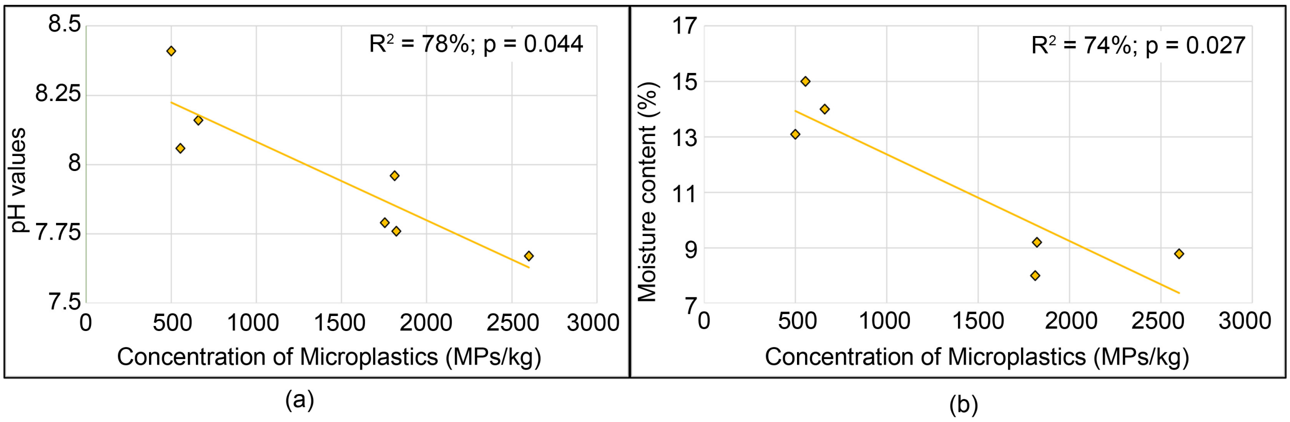

Figure 5. Correlation of soil pH and moisture content with the concentration of LD-MPs. (a) The illustration indicates a potential relationship between the presence of LD-MPs and soil pH, suggesting that the higher concentrations of LD-MPs might lead to a decrease in pH levels. (b) Shows a significant negative correlation between microplastic concentration and moisture content, implying that areas with higher concentrations of MPs tend to have lower moisture content. It is important to consider other potential factors that could influence soil pH and moisture content and recognize that MPs might not be the sole drivers of these changes in the soil.

(**Supplementary Information**; https://doi.org/10.17632/nthrjr322s.1). The highest median pH was observed in "Ashreej" (pH = 8.62), while the lowest was in "Zakher" (pH = 7.75). Outliers were not observed in any locations, except "Jahili". Moreover, a negative correlation (r = −0.89, n = 7, $p = 0.044$) was found between the microplastic concentration and soil pH (**Figure 5(a)**). The negative r-value for the correlation between soil pH and concentration of plastic particles suggests very strong negative correlation. This might imply that as the concentration increases, the soil pH decreases. The highest moisture content was recorded in "Al_Sulaimi" (14.89%) and the lowest was in "Al_Muraijeb" (7.67%), with a significant difference ($p < 0.05$) observed between parks. Similarly, a negative correlation (r = −0.87, n = 7, $p = 0.027$) was found between microplastic concentration and soil moisture content (**Figure 5(b)**), suggesting that as the concentration decreases, the moisture content of the soil increases. Similarly, the r-value for the correlation between moisture content and concentration of plastic particles also indicates a very strong negative correlation.

4. Discussion

Urban recreational parks, designated spaces for leisure activities that offer aesthetic and recreational benefits, also harbor imminent environmental hazards, including microplastic deposition. The presence of MPs in recreational areas has been documented worldwide, with concentrations in these areas showing variability [8] [35] [36]. Specifically, LD-MPs were isolated from soil samples collected from seven recreational parks in Al Ain, UAE (**Figure 2**). These particles have different shapes, sizes, colors, and polymer types (**Figure 3** and **Figure 4**; **Supplementary Information**; https://doi.org/10.17632/nthrjr322s.1). Various studies have identified the potential sources of MPs.

Focusing on human-related activities, wastewater treatment facilities (WWTFs) have been identified as one of the major sources of microplastic distribution in terrestrial and marine ecosystems. It has been reported that WWTFs release 65 million MPs daily [37], including $22.7 \pm 12.1 \times 10^3$ particles per kilogram in sludge discharges. This results in an estimated 1.56×10^{14} sludge-based MPs entering the environment annually [38]. A recent study reported that the sewage sludge collected from a wastewater treatment plant in Abu Dhabi, UAE has a monthly average abundance of 152 MPs/g [39]. In this context, the soil samples collected from recreational parks in Al Ain were found to contain sludge. The amendment and application of sludge and reclaimed water in recreational parks and related areas (*i.e.* date palm farms) is a common practice in UAE to satisfy plant nutritional requirements and for aesthetic purpose. However, sludge contains harmful pollutants, including plastic particles and toxic chemicals, that poses environmental threats. Consequently, MPs from sludge were directly transferred to and deposited in the soils of the recreational parks.

In addition, reclaimed waters from WWTF that are used for nonpotable purposes, such as irrigation, contain MPs as well. But they are not identified as a major contributor of MP pollution in the environment, as 63.5% - 95.4% of the particles are eliminated during the wastewater treatment process [40]. Nonetheless, a small number of MPs from reclaimed water could still be transferred to and accumulated in the soil. A significant concentration of atmospheric plastic particles has been reported in metropolitan areas [41] [42]. Due to their low densities, MPs are passively transported to different locations, including remote regions [43] and urban recreational areas [2] [8] [10], with deposition rates ranging from 575 - 10,008 particles per square meter per day [44]. This raises public health concerns, such as ingestion, inhalation, and dermal contact. Exposure to plastic particles can lead to toxicity in humans through oxidative stress, inflammatory lesions, and increased uptake or translation, potentially resulting in chronic illnesses [45]. Therefore, further study is warranted to understand the link between atmospheric deposition of MPs and urban parks.

A wide variety of MPs in soil and water samples, coupled with their distinct physical and chemical properties, pose challenges to their detection and characterization. In this study, microfibers are predominant, and textile (e.g. clothes) have been indicated as a major source of MPs [46] [47] [48]. Textiles shed an average of 7360 fibers [49], resulting in a significant presence of microplastic fibers being discarded in WWTF [50]. Additionally, FTIR analysis revealed that PP, PE, PET, and PVC are possible polymers of the isolated LD-MPs in this study. Plastics, composed of complex synthetic polymers are present in various materials, including textile and disposable items (e.g. water bottles, carry bags, bottle caps, plastic cutlery, drink cups, etc.) commonly used in outdoor activities in recreational parks. Nevertheless, since 90.7% of the isolated LD-MPs are fibers, observation suggests that sludge and reclaimed waters from WWTF are the sources of MPs present in recreational parks.

Establishing a relationship between soil properties and MPs poses a challenging task. Prior studies have attempted to demonstrate the effects of MPs on soil pH and moisture content. Here, a negative correlation was observed between high concentration of LD-MPs and a decrease in pH (**Figure 5(a)**). For instance, "Towayya", which had the highest concentration (3160 ± 2720 particles per kilogram), had a mean pH of 7.75. In contrast, "Jahili" (880 ± 766 particles per kilogram) and "Al_Sulaimi" (600 ± 482 particles per kilogram), with the lowest concentrations, had mean pH values of 8.34 and 8.17, respectively. It has been reported that the size and shape of MPs are key attributes influencing soil properties [25] [51] [52], such as soil pH. For instance, plastic foams and fragments have been reported to cause an increase in soil pH [52], and a mixture of MPs has been found to shift soil pH towards alkalinity [53]. However, the relationship between MPs and soil moisture content remains elusive. Researchers have observed a nonsignificant negative correlation between microplastic concentration and the moisture content of collected soil samples but were unable to determine the exact cause [8]. In contrast, this study found a significant negative correlation (**Figure 5(b)**), where "Towayya" had the highest concentration with a mean moisture content of 8.80%, while "Al_Sulaimi" with the lowest concentration had a mean of 14.89%. Based on these observations, MPs might influence soil properties; thus, further study is recommended to explore the exact causes of these effects.

5. Conclusion

The present study highlights that while urban recreational parks offer valuable leisure activities, they also serve as repositories for environmental pollutants such as MPs. The study concluded that these parks exhibit varying levels of LD-MPs, predominantly originating from anthropogenic activities, including use of sludge and the application of reclaimed water. Additionally, atmospheric deposition might play a significant role in the accumulation of MPs in the soil, although establishing a direct link within the scope of this study remains challenging. The pervasive presence of plastic particles, primarily deriving from human activities, underscores a looming environmental threat. Therefore, it is imperative to raise public awareness and implement eco-friendly practices to mitigate the impact of microplastic pollution effectively.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Chen, Z., Shi, X., Zhang, J., Wu, L., Wei, W. and Ni, B.J. (2023) Nanoplastics Are Significantly Different from Microplastics in Urban Waters. *Water Research*, **19**, Article ID: 100169. https://doi.org/10.1016/j.wroa.2023.100169

[2] Leitão, I., van Schaik, L., Ferreira, A., Alexandre, N. and Geissen, V. (2023) The Spatial Distribution of Microplastics in Topsoils of an Urban Environment—Coimbra City Case-Study. *Environmental Research*, **218**, Article ID: 114961. https://doi.org/10.1016/j.envres.2022.114961

[3] Townsend, K.R., Lu, H.C., Sharley, D.J. and Pettigrove, V. (2019) Associations between Microplastic Pollution and Land Use in Urban Wetland Sediments. *Environmental Science and Pollution Research*, **26**, 22551-22561. https://doi.org/10.1007/s11356-019-04885-w

[4] Xu, Y., Chan, F., Johnson, M., Stanton, T., He, J. Jia, T., *et al.* (2021) Microplastic Pollution in Chinese Urban Rivers: The Influence of Urban Factors. *Resources, Conservation and Recycling*, **173**, Article ID: 105686. https://doi.org/10.1016/j.resconrec.2021.105686

[5] Arias-Andres, M., Kettner, M., Miki, T. and Grossart, H.-P. (2018) Microplastics: New Substrates for Heterotrophic Activity Contribute to Altering Organic Matter Cycles in Aquatic Ecosystems. *Science of the Total Environment*, **635**, 1152-1159. https://doi.org/10.1016/j.scitotenv.2018.04.199

[6] Ivleva, N.P., Wiesheu, A.C. and Neissner, R. (2016) Microplastic in Aquatic Ecosystems. *Angewandte Chemie*, **56**, 1720-1739. https://doi.org/10.1002/anie.201606957

[7] Nguyen, M.K., Lin, C., Nguyen, H.L., Le, V.R., Kl, P., Singh, J., *et al.* (2023) Emergence of Microplastics in the Aquatic Ecosystem and Their Potential Effects on Health Risks: The Insights into Vietnam. *Journal of Environmental Management*, **344**, Article ID: 118499. https://doi.org/10.1016/j.jenvman.2023.118499

[8] Cohen, Q.M., Glaese, M., Meng, K., Geissen, V. and Huerta-Lwanga, E. (2022) Parks and Recreational Areas as Sinks of Plastic Debris in Urban Sites: The Case of Light-Density Microplastics in the City of Amsterdam, the Netherlands. *Environments*, **9**, Article 5. https://doi.org/10.3390/environments9010005

[9] Esiukova, E., Lobchuk, O., Haseler, M. and Chubarenko, I. (2021) Microplastic Contamination of Sandy Beaches of National Parks, Protected and Recreational Areas in Southern Parts of the Baltic Sea. *Marine Pollution Bulletin*, **173**, Article ID: 113002. https://doi.org/10.1016/j.marpolbul.2021.113002

[10] Koutnik, V.S., Leonard, J., El Rassi, L.A., Choy, M.M., Brar, J., Glasman, J.B., *et al.* (2023) Children's Playgrounds Contain More Microplastics than Other Areas in Urban Parks. *Science of the Total Environment*, **854**, Article ID: 158866. https://doi.org/10.1016/j.scitotenv.2022.158866

[11] Amato-Lourenço, L.F., dos Santos Galvão, L., de Weger, L.A., Hiemstra, P.S., Vijver, M.G. and Mauad, T. (2020) An Emerging Class of Air Pollutants: Potential Effects of Microplastics to Respiratory Human Health? *Science of the Total Environment*, **749**, Article ID: 141676. https://doi.org/10.1016/j.scitotenv.2020.141676

[12] Wang, Y., Zhang, D., Zhang, M., Mu, J., Ding, G., Mao, Z., *et al.* (2019) Effects of Ingested Polystyrene Microplastics on Brine Shrimp, *Artemia parthenogenetica. Environmental Pollution*, **244**, 715-722. https://doi.org/10.1016/j.envpol.2018.10.024

[13] Isinibilir, M., Eryalçin, K.M. and Kideys, A.E. (2023) Effect of Polystyrene Microplastics in Different Diet Combinations on Survival, Growth and Reproduction Rates of the Water Fleas (*Daphnia magna*). *Microplastics*, **2**, 27-38. https://doi.org/10.3390/microplastics2010002

[14] Sussarellu, R., Suquet, M., Thomas, Y., Lambert, C., Fabioux, C., Pernet, M.E.J., *et al.* (2016) Oyster Reproduction Is Affected by Exposure to Polystyrene Microplastics. *Proceedings of the National Academy of Sciences*, **113**, 2430-2435. https://doi.org/10.1073/pnas.1519019113

[15] Di Bona, E., Haley, C., Geist, S. and Seemann, F. (2022) Developmental Polyethylene Microplastic Fiber Exposure Entails Subtle Reproductive Impacts in Juvenile Japanese Medaka (*Oryzias latipes*). *Environmental Toxicology and Chemistry*, **41**, 2848-2858. https://doi.org/10.1002/etc.5456

[16] Lekatompessy, V.C., Marhendra, A.P.W. and Kurniawan, N. (2023) Accumulation of Microplastics in the Digestive Tract and Gonads and Its Effects on Gonad Quality of Sea Urchins *Tripneustes gratilla*. *Biotropika*: *Journal of Tropical Biology*, **11**, 53-63. https://doi.org/10.21776/ub.biotropika.2023.011.01.07

[17] Bai, Z., Wang, N. and Wang, M. (2021) Effects of Microplastics on Marine Copepods. *Ecotoxicology and Environmental Safety*, **217**, Article ID: 112243. https://doi.org/10.1016/j.ecoenv.2021.112243

[18] Teng, M., Zhao, X., Zhao, L., Shi, D., Li, Y., Sun, J., *et al.* (2022) Zebrafish (*Danio rerio*) Reproduction Is Affected by Lifecyle-Exposure to Differently Charged Polystyrene Nanoplastics with Sex-Specific Responses. *ACS Environmental Science & Technology*, **2**, 2558-2566. https://doi.org/10.1021/acsestwater.2c00348

[19] Bullard, J.E., Ockelford, A., O'Brien, P. and Neuman, C. (2021) Preferential Transport of Microplastics by Wind. *Atmospheric Environment*, **245**, Article ID: 118038. https://doi.org/10.1016/j.atmosenv.2020.118038

[20] Rezaei, M., Riksen, M., Sirhani, E., Sameni, A. and Geissen, V. (2019) Wind Erosion as a Driver for Transport of Light Density Microplastics. *Science of the Total Environment*, **669**, 273-281. https://doi.org/10.1016/j.scitotenv.2019.02.382

[21] Ashiq, M., Jazaei, F., Bell, K., Ali, A., Bakhshaee, A. and Babakhani, P. (2023) Abundance, Spatial Distribution, and Physical Characteristics of Microplastics in Stormwater Detention Ponds. *Frontiers of Environmental Science & Engineering*, **17**, Article No. 124. https://doi.org/10.1007/s11783-023-1724-y

[22] Hajiouni, S., Mohammadi, A., Ramavandi, B., Arfaeinia, H., De-la Torre, G.E.,

Tekle-Röttering, A., *et al.* (2022) Occurrence of Microplastics and Phthalate Esters in Urban Runoff: A Focus on the Persian Gulf Coastline. *Science of the Total Environment*, **806**, Article ID: 150559. https://doi.org/10.1016/j.scitotenv.2021.150559

[23] Rafique, A., Irfan, M., Mumtaz, M. and Qadir, A. (2020) Spatial Distribution of Microplastics in Soil with Context to Human Activities: A Case Study from the Urban Center. *Environmental Monitoring Assessment*, **192**, Article No. 671. https://doi.org/10.1007/s10661-020-08641-3

[24] van Schothorst, B., Beriot, N., Huerta Lwanga, E. and Geissen V. (2021) Sources of Light Density Microplastic Related to Two Agricultural Practices: The Use of Compost and Plastic Mulch. *Environments*, **8**, Article 36. https://doi.org/10.3390/environments8040036

[25] de Souza-Machado, A., Lau, C.W., Kloas, W., Bergmann, J., Bachelier, J.B., Faltin, E., *et al.* (2019) Microplastics Can Change Soil Properties and Affect Plant Performance. *Environmental Science & Technology*, **53**, 6044-6052. https://doi.org/10.1021/acs.est.9b01339

[26] Yang, X., Zhang, Z. and Guo, X. (2023) Impact of Soil Structure and Texture on Occurrence of Microplastics in Agricultural Soils or Karst Areas. *Science of the Total Environment*, **902**, Article ID: 166189. https://doi.org/10.1016/j.scitotenv.2023.166189

[27] He, D., Luo, Y., Lu, S., Liu, M., Song, Y. and Lei, L. (2018) Microplastics in Soils: Analytical Methods, Pollution Characteristics and Ecological Risks. *Trends in Analytical Chemistry*, **109**, 163-172. https://doi.org/10.1016/j.trac.2018.10.006

[28] Ingraffia, R., Amato, G., Bagarello, V., Carollo, F.G., Giambalvo, D., Iovino, M., *et al.* (2022) Polyester Microplastic Fibers Affect Soil Physical Properties and Erosion as a Function of Soil Type. *Soil*, **8**, 421-435. https://doi.org/10.5194/soil-8-421-2022

[29] Lin, D., Yang, G., Dou, P., Qian, S., Zhao, L., Yang, Y., *et al.* (2020) Microplastics Negatively Affect Soil Fauna but Stimulate Microbial Activity: Insights from a Field-Based Microplastic Addition Experiment. *Proceedings Royal Society B*, **287**, Article ID: 20201268. https://doi.org/10.1098/rspb.2020.1268

[30] De Witte, B., Devriese, L., Bekaert, K., Hoffman, S., Vandemeersch, G., Cooreman, K. and Robbens, J. (2014) Quality Assessment of the Blue Mussel (*Mytilus edulis*): Comparison between Commercial and Wild Types. *Marine Pollution Bulletin*, **85**, 146-155. https://doi.org/10.1016/j.marpolbul.2014.06.006

[31] Martí, E., Martin, C., Galli, M., Echevarria, F., Duarte, C.M. and Cózar, A. (2020) The Colors of the Ocean Plastics. *Environmental Science and Technology*, **54**, 6594-6601. https://doi.org/10.1021/acs.est.9b06400

[32] Fan, C., Huang, Y.Z., Lin, J.N. and Li, J. (2021) Microplastic Constituent Identification from Admixtures by Fourier-Transform Infrared (FTIR) Spectroscopy: The Use of Polyethylene Terephthalate (PET), Polyethylene (PE), Polypropylene (PP), Polyvinyl Chloride (PVC) and Nylon (NY) as the Model Constituent. *Environmental Technology & Innovation*, **23**, Article ID: 101798. https://doi.org/10.1016/j.eti.2021.10179

[33] Fotopoulou, K. and Karapanagioti, H.K. (2015) Surface Properties of Beached Plastics. *Environmental Science and Pollution Research*, **22**, 11022-11032. https://doi.org/10.007/s11356-015-4332-y

[34] Smith, B.C. (2021) The Infrared Spectra of Polymers III: Hydrocarbon Polymers. *Spectroscopy*, **36**, 22-25. https://doi.org/10.56530/spectroscopy.mh7872q7

[35] Huerta Lwanga, E., Vega, J., Quej, V., Chi, J., del Cid, L., Chi, C., *et al.* (2017) Field Evidence for Transfer of Plastic Debris along a Terrestrial Food Chain. *Scientific Re-*

ports, **7**, Article No. 14071. https://doi.org/10.1038/s41598-017-14588-2

[36] Tunali, M., Myronyuk, O., Tunali, M. and Yenigün, O. (2022) Microplastic Abundance in Human-Influenced Soils in Recreational, Residential, and Industrial Areas. *Water*, *Air and Soil Pollution*, **233**, Article No. 433. https://doi.org/10.1007/s11270-022-05901-5

[37] Murphy, F., Ewins, C., Carbonnier, F. and Quinn, B. (2016) Wastewater Treatment Works (WwTW) as a Source of Microplastics in the Aquatic Environment. *Environmental Science & Technology*, **50**, 5800-5808. https://doi.org/10.1021/acs.est.5b05416

[38] Li, X., Chen, L., Mei, Q., Dong, B., Dai, X., Ding, G., *et al*. (2018) Microplastics in Sewage Sludge from the Wastewater Treatment Plants in China. *Water Research*, **142**, 75-85. https://doi.org/10.1016/j.watres.2018.05.034

[39] Habib, R. (2022) Sources and Distribution of Microplastics in the United Arab Emirates. Ph.D. Thesis, United Arab Emirates University, Abu Dhabi.

[40] Wang, R., Ji, M., Zhai, H. and Liu, Y. (2020) Occurrence of Phthalate Esters and Microplastics in Urban Secondary Effluents, Receiving Water Bodies and Reclaimed Water Treatment Processes. *Science of the Total Environment*, **737**, Article ID: 140219. https://doi.org/10.1016/j.scitotenv.2020.140219

[41] Cai, L., Wang, J., Peng, J., Tan, Z., Zhan, Z., Tan, X., *et al*. (2017) Characteristic of Microplastics in the Atmospheric Fallout from Dongguan City, China: Preliminary Research and First Evidence. *Environmental Science and Pollution Research*, **24**, 24928-24935. https://doi.org/10.1007/s11356-017-0116-x

[42] Shruti, V.C., Kutralam-Muniasamy, G., Pérez-Guevara, F., Roy, P.D. and Elizalde Martínez, I. (2022) Occurrence and Characteristics of Atmospheric Microplastics in Mexico City. *Science of the Total Environment*, **847**, Article ID: 157601. https://doi.org/10.1016/j.scitotenv.2022.157601

[43] Evangeliou, N., Grythe, H., Klimont, Z., Heyes, C., Eckhardt, S., Lopez-Aparicio, S., *et al*. (2020) Atmospheric Transport Is a Major Pathway of Microplastics to Remote Regions. *Nature Communication*, **11**, Article No. 3381. https://doi.org/10.1038/s41467-020-17201-9

[44] Wright, S.L., Ulke, J., Font, A., Chan, K.L.A. and Kelly, F.J. (2020) Atmospheric Microplastics Deposition in an Urban Environment and an Evaluation of Transport. *Environment International*, **136**, Article ID: 105411. https://doi.org/10.1016/j.envint.2019.105411

[45] Prata, J.C., da Costa, J., Lopes, I., Duarte, A.C. and Rocha-Santos, T. (2020) Environmental Exposure to Microplastics: An Overview on Possible Human Health Effects. *Science of the Total Environment*, **702**, Article ID: 134455. https://doi.org/10.1016/j.scitotenv.2019.134455

[46] Dris, R., Gasperi, J., Mirande, C., Mandin, C., Guerrouache, M., Langlois, V., *et al*. (2017) A First Overview of Textile Fibers, Including Microplastics, in Indoor and Outdoor Environments. *Environmental Pollution*, **221**, 453-458. https://doi.org/10.1016/j.envpol.2016.12.013

[47] Hernandez, E., Nowack, B. and Mitrano, D.M. (2017) Polyester Textiles as a Source of Microplastics from Households: A Mechanistic Study to Understand Microfiber Release during Washing. *Environmental Science & Technology*, **51**, 7036-7046. https://doi.org/10.1021/acs.est.7b01750

[48] Sillanpää, M. and Sainio, P. (2017) Release of Polyester and Cotton Fibers from Textiles in Machine Washings. *Environmental Science and Pollution Research*, **24**, 19313-19321. https://doi.org/10.1007/s11356-017-9621-1

[49] Carney Almroth, B.M., Åström, L., Roslund, S., Petersson, H., Johansson, M. and Persson, N.K. (2017) Quantifying Shedding of Synthetic Fibers from Textiles; a Source of Microplastics Released into the Environment. *Environmental Science and Pollution Research*, **25**, 1191-1199. https://doi.org/10.1007/s11356-017-0528-7

[50] Ziajahromi, S., Neale, P.A., Rintoul, L. and Leusch, F.D. (2017) Wastewater Treatment Plants as a Pathway for Microplastics: Development of a New Approach to Sample Wastewater-Based Microplastics. *Water Research*, **112**, 93-99. https://doi.org/10.1016/j.watres.2017.01.042

[51] Lozano, Y.M., Lehnert, T., Linck, L.T., Lehmann, A. and Rillig, M.C. (2021) Microplastic Shape, Polymer Type, and Concentration Affect Soil Properties and Plant Biomass. *Frontiers in Plant Science*, **12**, Article ID: 616645. https://doi.org/10.3389/fpls.2021.616645

[52] Zhao, T., Lozano, Y.M. and Rillig, M.C. (2021) Microplastics Increase Soil pH and Decrease Microbial Activities as a Function of Microplastic Shape, Polymer Type, and Exposure Time. *Frontiers in Environmental Science*, **9**, Article ID: 675803. https://doi.org/10.3389/fenvs.2021.675803

[53] Qi, Y., Ossowicki, A., Yang, X., Huerta Lwanga, E., Dini-Andreote, F., Geissen, V., *et al*. (2020) Effects of Plastic Mulch Film Residues on Wheat Rhizosphere and Soil Properties. *Journal of Hazardous Materials*, **387**, Article ID: 121711. https://doi.org/10.1016/j.jhazmat.2019.121711

Supplementary Information

Supplementary information related to this study, including additional data, is available for reference. This material can be accessed online at https://doi.org/10.17632/nthrjr322s.1, providing further insights and comprehensive details that complement the findings presented in this paper.