



Received: 06-01-2026
Accepted: 16-02-2026

ISSN: 2583-049X

Effect of Sodium Hydrogen Bicarbonate Treatment on Microplastic Polluted Soil

¹ Ishaya Jerry Magai, ² Baba Nwunuji Hikon, ³ Ataitiya Hyelalibiya, ⁴ Adamu Ibrahim, ⁵ Moses Adondua Abah
^{1,5} Department of Biochemistry, Faculty of Biosciences, Federal University Wukari, Wukari, Taraba State, Nigeria
^{2,3,4} Department of Chemistry, Faculty of Physical Sciences, Federal University Wukari, Wukari, Taraba State, Nigeria

DOI: <https://doi.org/10.62225/2583049X.2026.6.1.5903>

Corresponding Author: Ishaya Jerry Magai

Abstract

The contamination of soil caused by the degradation of plastics introduced through disposal has been increasing globally and exposure to microplastic triggers a wide variety of toxic chemicals which affect disrupts reproductive performance, metabolism, and changes liver physiology. This study was carried out to examine the effect of Sodium hydrogen bicarbonate treatment on microplastic-polluted soil. The soil samples were collected from three sites in Wukari, Taraba State (Kwararafa University Wukari). 4 treatments were set up and consisted of the control, polluted and unpolluted soil treated with NaHCO₃ grouped into three different samples. The microplastic level in the soils was determined using HPLC technique (model 5020A) and the obtained results showed that eight microplastics were present in all the soil samples. Polyamide, polystyrene, polypropylene, polyethylene, ethylene glycol, terephthalic acid, acrylic acid and polyester in the soil samples ranged

from 479.94 to 1241.78 µg/kg, 331.45 to 857.78 µg/kg, 222.83 to 576.54 µg/kg, 721.18 to 1865.96 µg/kg, 257.49 to 666.23 µg/kg, 124.675 to 322.56 µg/kg, 64.22 to 122.52 µg/kg and 171.41 to 327.02 µg/kg, respectively. Polyethylene was identified as the most abundant type of microplastic and acrylic acid was the least abundant microplastic in the soil samples across all groups. The highest total detectable microplastics were observed in the untreated unpolluted soil samples (5943.12 µg/kg) and the least was recorded in the NaHCO₃ treated microplastic polluted soil samples (2373.20 µg/kg). From the findings, the study concluded that NaHCO₃ treatment is effective in reducing microplastic contamination in soil samples and recommended that effective waste management strategies should be implemented to reduce the accumulation and degradation of plastic litter into microplastic.

Keywords: Sodium Hydrogen Bicarbonate, Microplastic, Polluted, Soil, Wukari, Treatment

Introduction

Microplastics in the environment have raised public attention in recent years due to their slow degradation and potential risks to the ecosystems (Wu *et al.*, 2019) [36]. Developing nations discard a significant volume of plastic waste, contributing extensively to the pollution of rivers and ultimately, the ocean, primarily through runoffs (Geyer *et al.*, 2017) [12]. Presently, plastic, including micro and nanoplastics, constitutes approximately 80% of marine debris (Hernandez *et al.*, 2017; Malakar and Snow, 2020) [15, 25]. Globally, the production of plastic products amounts to 6300 million tons, with more than 75% ending up in landfills and various ecological environments (Sheldon and Norton, 2020; Wojnowska-Baryła *et al.*, 2022 [35]; Sharma *et al.*, 2023 [33]). In 2017, global plastic production totaled 368 million tons, with China leading at 114 million tons, followed by Europe at 59 million tons. Projections suggest a twofold increase in production by 2040 (Geyer *et al.*, 2017; Brooks, 2021) [12, 4]. Microplastic particles can infiltrate the food chain and be consumed by humans, posing potential health risks (Blair *et al.*, 2017; Hernandez *et al.*, 2017; Malakar and Snow, 2020) [3, 15, 25].

Microplastic are small plastic particles that measure less than 5 millimeters in size (Mai *et al.* 2018) [24] and are categorized into primary and secondary microplastic based on their sources (Malankowska *et al.*, 2021) [26]. Common sources of primary microplastic include cosmetics and personal care products, medical and health-related products and industrial abrasives (Landeros *et al.*, 2022) [20]. Secondary microplastic originates from various sources, including plastic waste, synthetic textiles and rubber products (Acharya *et al.*, 2021) [2]. Polyethylene, polypropylene, polystyrene, polyvinylchloride, and polyethylene terephthalate are the most frequently detected compositions of Microplastic in the environment (He *et al.*, 2018) [13].

Microplastic can enter agroecosystems through a variety of pathways, including fertilizer spraying, wastewater irrigation, compost addition, and biological compost application, and with the plastic film having the greatest impact (Zou *et al.*, 2022) [43]. In general, the degradation cycle of microplastic in the soil is very long, and it usually takes hundreds or even thousands of years to fully mineralize (Zhou *et al.*, 2021) [39]. Once microplastic enters the soil, it can directly or indirectly affect ecosystem function and plant-soil health (Zhou *et al.*, 2021) [39]. Microplastic can alter the physical and chemical properties of soil, in turn; it has different effects on microbial functions as well as plant growth indexes (Lozano *et al.*, 2021) [22]. It was found that the addition of microplastic led to the change of soil physical parameters which affected hydrodynamics and microbial activity (de Souza Machado *et al.*, 2019) [9]. Li *et al.* (2021) [21] found that microplastic reduced the adsorption capacity of soil to metals and improved the exchangeable fractionation and bioavailability of metals in soil.

Sodium hydrogen bicarbonate (NaHCO_3) is a common household item and has gained attention as a potential solution for mitigating microplastic pollution in soil (Zhang *et al.*, 2021) [38]. Its alkaline nature and mild abrasive properties make it a suitable weak base for physically and chemically breaking down microplastic in soil (Das *et al.*, 2021) [8]. Sodium hydrogen bicarbonate has been recognized for its various applications in agriculture, remediation, and environmental science. When applied to soil contaminated with microplastic, Sodium hydrogen bicarbonate treatment can potentially influence the soil ecosystem (Zhou *et al.*, 2020) [42]. Microplastic pollution alters soil pH due to the materials released or interactions with other substances (Zhao *et al.*, 2021) [37]. Sodium hydrogen bicarbonate can act as a buffering agent, helping to regulate soil pH (Lacroix *et al.*, 2014) [19].

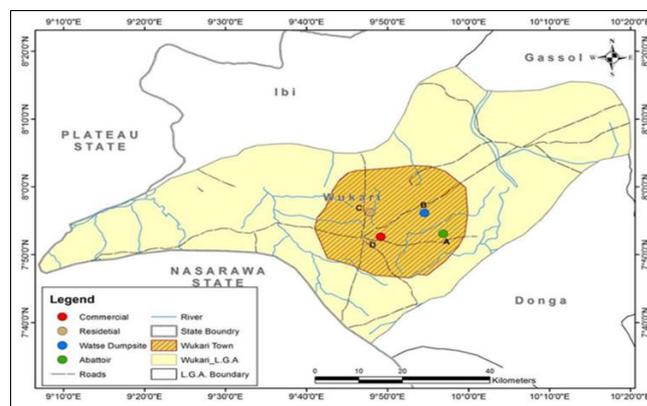
Spectroscopic and chromatographic techniques are essential to assess changes in soil properties and microplastic degradation (Huang *et al.*, 2021) [17]. The effect of Sodium hydrogen bicarbonate treatment on microplastic-polluted soil is dependent on different concentrations, application methods, and durations of treatment (Chand *et al.*, 2022) [5]. Studies on the direct impact of microplastic degradation on soil needs further exploration as Sodium hydrogen bicarbonate might facilitate physical or chemical processes that aid in reducing the size or altering the properties of microplastic, potentially influencing their environmental fate (Abdolahpur *et al.*, 2023) [1]. This research therefore examined the direct impact of Sodium hydrogen bicarbonate on the degradation or breakdown of microplastic present in the soil and the findings will reveal whether Sodium Hydrogen bicarbonate treatment influenced the fragmentation, degradation rates, or bioavailability of microplastic.

Materials and Methods

Study Area

The study area is Wukari Local Government Area which is a famous city located formerly in Gongola State of Nigeria (Figure 1) Wukari is located at latitude $7^{\circ}51' \text{N}$ and longitude $9^{\circ}47' \text{E}$ from November 2023 to April 2024. Wukari lies between Taraba State and Benue State and it is an agricultural center. It is bounded in the south by Benue state, north by Gassol LGA, east by Donga LGA and west by Ibi

LGA. Wukari Local Government Area covers an area of $4,308 \text{ km}^2$ and with a population of about 241,546 at the 2006 census, a traditional state rich with various cultures, norms and value. Fishing, farming and trading are the major occupation of the people (Otitoju and Lewis, 2021) [28].



Source: www.google.com

Fig 1: Map of Taraba state showing Wukari Local Government Area

Sample Collection

Soil samples were obtained from a landfill situated 500 meters away from Kwararafa University Wukari, Wukari, and Taraba State. On 19th, February 2024. The specimens were gathered using a stainless steel hand trowel, reaching a depth of 0 to 10 centimeters, and placed into a brown envelope equipped with a sieve. Soil samples from each sub-site were combined and thoroughly mixed to ensure uniformity and representativeness of the sample.

Sample Preparation

Collected soil samples were air dried then sieved using mesh size of 8 mm to help improve the accuracy, reliability, and consistency of microplastic analysis while minimizing sample contamination and ensuring compatibility with established protocols (Hikon *et al.*, 2021) [16]. 2.5 g of the soil samples were measured into a container.

Sample Treatment

A total of 4 treatments were set up in the experiment and consisted of the control or blank group, polluted and unpolluted soil treated with NaHCO_3 were treated into three different samples. 5 mL of 27% NaCl solution was added into the container which was stirred for 10 min centrifuged at 3450 rpm for 30min, 1mL of 35% H_2O_2 , 0.1 mL of 10% FeSO_4 and 3 mL of NaHCO_3 were added into the sample which were allowed to settled for 24 hrs., 8.2 mL of deionized water was added to the sample agitated for 20 min using sunflower mini-shaker PS-3D the samples were furthered centrifuged for 20 min at 2300 rpm which the supernatant were filtered with 0.45 micrometer membrane filter. The samples were then being kept in the laboratory for 10 days prior to further analysis.

Extraction

2.0 g of sample each was weighed into a 250 ml beaker and swirled properly. Also 40 ml of aqueous 0.05 M of Fe (ii) solution was added. The above was followed by the addition of 40 ml of 35% hydrogen peroxide (H_2O_2) (Hikon *et al.*, 2021) [16]. All were mixed properly for 5 mins at room temperature. A stir bar was added to the beaker containing

the sample and heated on a hot plate at 75°C, with watch glass cover on it. At the point gas bubbles were observed. The beaker were removed from the hot plate and placed in fumehood until the boiling subsided. The mixtures were allowed to cool down and filter through whatman No.4 filter paper into a 200 ml volumetric flask each. The filtrate was subjected into centrifugation using a centrifuge machine at 5000 RPM (revolution per a minute). The extract or supernatants were transferred into a set of 50 ml centrifuge tubes and stored in the fridge for the analysis of detectable microplastic with High performance Liquid Chromatography (HPLC).

Data Analysis

The Special Package for Social Sciences (SPSS) was used to check for significant levels of all parameters measured. The level of significance were analyzed using Analysis of Variance and means comparison was at $p < 0.05$. The concentrations of microplastic in all samples were expressed in $\mu\text{g}/\text{kg}$.

Results and Discussion

Microplastic Levels in NaHCO_3 Treated Microplastic-Polluted and Unpolluted Soil Samples

The table below showed that a total of 8 microplastics were found in all the soil samples analyzed. Presented in the table below, Group 1 represents untreated microplastic-polluted soil samples, Group 2 represents untreated unpolluted soil samples, Group 3 represents NaHCO_3 treated microplastic-polluted soil samples and Group 4 represents NaHCO_3 treated unpolluted soil samples.

The following microplastics were found present in all the assayed soil samples: Polyamide, Polystyrene, Polypropylene, Polyethylene, Ethylene glycol, Terephthalic acid, Acrylic acid and Polyester. The result showed that Group 2 had the highest total detectable microplastic (5943.12 ± 203.24) compared to other groups followed by Group 1 with value 5191.01 ± 399.14 , and then Group 4 which has 3323.29 ± 1457.78 . However, Group 3 had the lowest total detectable microplastic (2373.20 ± 314.83) compared to other groups. Notwithstanding, Group 1 showed higher total detectable microplastic compared to Group 3.

The result also revealed polyethylene to be the most abundant microplastic present in all the assayed soil samples whereas the least microplastic present in all assayed soil samples was Acrylic acid which had different values in the various as Group 1 (122.52 ± 40.10), Group 2 (112.42 ± 3.48), Group 4 (104.52 ± 56.13) and Group 4 (64.22 ± 28.73) respectively.

Polyester level was also revealed to be highest in Group 1 (327.02 ± 107.03), followed by Group 2 (300.06 ± 9.29) in the soil samples.

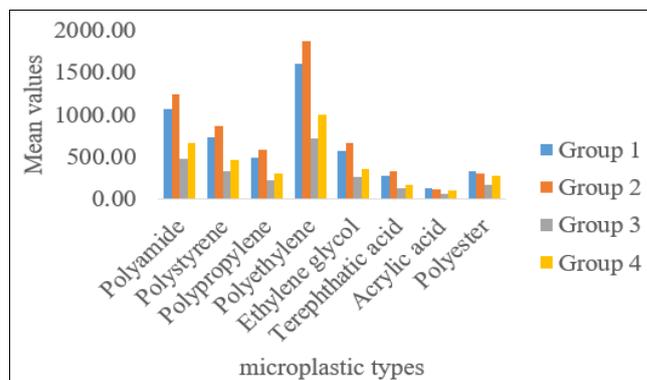


Fig 2: Microplastic levels in NaHCO_3 treated microplastic-polluted and unpolluted

The result from the study showed that eight types of microplastic were present in all the soil samples. They include polyamide, polystyrene, polypropylene, polyethylene, ethylene glycol, terephthalic acid, acrylic acid, and polyester. This shows that the soil was contaminated by a wide range of synthetic polymers contaminating the soil environment. Polyamide, polystyrene, polypropylene, polyethylene, ethylene glycol, terephthalic acid, acrylic acid and polyester in the soil samples ranged from 479.94 to 1241.78 $\mu\text{g}/\text{kg}$, 331.45 to 857.78 $\mu\text{g}/\text{kg}$, 222.83 to 576.54 $\mu\text{g}/\text{kg}$, 721.18 to 1865.96 $\mu\text{g}/\text{kg}$, 257.49 to 666.23 $\mu\text{g}/\text{kg}$, 124.675 to 322.56 $\mu\text{g}/\text{kg}$, 64.22 to 122.52 $\mu\text{g}/\text{kg}$ and 171.41 to 327.02 $\mu\text{g}/\text{kg}$, respectively.

The untreated unpolluted soil samples had the highest polyamide, polystyrene, polypropylene, polyethylene, ethylene glycol and terephthalic acid levels and were significantly ($p < 0.05$) different with other soil samples. However, the untreated microplastic-polluted soil samples had the highest acrylic acid and polyester levels and were significantly ($p < 0.05$) different with other soil samples. The lowest polyamide, polystyrene, polypropylene, polyethylene, ethylene glycol, terephthalic acid, acrylic acid and polyester levels were observed in the NaHCO_3 treated microplastic-polluted soil samples.

Polyethylene was identified as the most abundant type of microplastic in the soil samples across all groups. This finding was consistent with the findings of Scheurer and Bigalke (2018) [31] who reported that polyethylene was the most abundant (88%) among the Microplastic identified in Swiss floodplain soils. Another study by Zhou *et al.* (2019) [41] also observed highest abundance of polyethylene (36.1%) among Microplastic identified in suburban soil of central China. The high polyethylene observed in this study suggests that polyethylene pollution is prevalent in the soil environment, regardless of the specific group or conditions. Polyethylene particles could easily be migrated and transferred in the soil due to the lighter density (Machado *et al.*, 2018) [23]. The high proportion of polyethylene could

also be related to greater plastic film mulching and sewage sludge application (Zhou *et al.*, 2018) [40]. Polyethylene microplastic can accumulate in soil, potentially altering its physical properties. High concentrations of polyethylene may reduce soil porosity and water infiltration rates, leading to decreased soil aeration and water retention capacity (Qi *et al.*, 2020) [29].

Acrylic acid was the least abundant microplastic in all soil samples, with relatively low levels across all groups. This indicates that acrylic acid microplastic is less abundant in soil samples and may have a reduced environmental impact compared to more prevalent microplastic types.

The total detectable Microplastic ranged from 2373.20 to 5943.12 $\mu\text{g}/\text{kg}$ and was highest in the untreated unpolluted soil samples (5943.12 $\mu\text{g}/\text{kg}$). The total detectable Microplastic of the soil samples were significantly ($p < 0.05$) different with other soil samples. The lowest total detectable Microplastic were observed in the NaHCO_3 treated microplastic-polluted soil samples (2373.20 $\mu\text{g}/\text{kg}$). Crossman *et al.* (2020) [7] used ATR-FTIR to identify Microplastic in agricultural soils and reported a MP abundance of 18-541 n/kg and 25-298 n/kg with and without biosolid amendment, respectively, in Ontario, Canada. He *et al.* (2019) [14] reported the presence of microplastic in the leachate from both active and closed landfills, with an abundance between 0.42 and 24.58 particles/L from four cities in southern China and also revealed that the mean concentration of Microplastic in leachate and refuse were 8 ± 3 and 62 ± 23 particles/g, respectively in megacity Shanghai.

A study by Chen *et al.* (2020) [6] identified an average abundance of Microplastic at 320-12560 n/kg in farmland soils in Wuhan, China using Raman spectroscopy and concluded that PA (33%) and PP (29%) were the dominant polymer types. Wang *et al.* (2017) [34] detected polycarbonate (PC) and PET Microplastic in landfill sludge, marine sediments and indoor dusts through coupled LC-MS with mass spectroscopy (MS). They observed recovery rate of 87.2% to 97.1%. In a study conducted by Eo *et al.* (2019) [11], it was observed that the sediment samples from Nakdong River, South Korea contained 22 polymer types with varying MP levels which are 24.8% PP, 24.5% PE, 5.5% PES, 5.4% PVC, 5.3% PS, 4.6% acrylic, 4.5% polydimethylsiloxane, 3.9% PU, 3.7% poly(acrylate-styrene), and 3.6% poly(lauryl acrylate).

The higher total detectable Microplastic observed in the untreated unpolluted soil samples indicates that the soils in the study area were highly contaminated with microplastic. The microplastic observed in this study may result from agricultural activities, domestic sewage and agricultural runoff which carry microplastic from household products and farming activities into the soil (Kumar *et al.*, 2020; Schell *et al.*, 2022) [18, 30]. The use of fertilizers and pesticides in the area contributes to the microplastic load in the soils since they contain plastic-based components or additives. Poor waste management practices exacerbate the issue, as plastic litter accumulates in rural environments and undergoes degradation into microplastic particles (Dey *et al.*, 2024) [10]. Microplastic pollution at low levels pose ecological and environmental concerns as wildlife and livestock may ingest microplastic, leading to potential bioaccumulation and transfer through the food chain (Huang *et al.*, 2021) [17].

Conclusion

The study confirms the presence of eight different types of microplastics (polyamide, polystyrene, polypropylene, polyethylene, ethylene glycol, terephthalic acid, acrylic acid, and polyester) in all analyzed soil samples. The untreated unpolluted soil samples exhibited the highest total detectable microplastics, followed by the untreated microplastic-polluted soil samples, NaHCO_3 treated unpolluted soil samples. The NaHCO_3 treated microplastic-polluted soil samples had the lowest total detectable microplastics. Polyethylene being the most abundant microplastic type across all soil samples, may have significant implications for soil health and ecosystem functioning. From the findings of this research, it can be concluded that NaHCO_3 treatment is effective in reducing microplastic contamination in soil samples.

References

1. Abdolapur MF, Baun A, Hartmann NB, Kortet R, Akkanen J, Lee JS, Kukkonen JV. Exposure protocol for ecotoxicity testing of microplastic and nanoplastics. *Nature Protocols*, 2023, 1-31.
2. Acharya S, Rumi SS, Hu Y, Abidi N. Microfibers from synthetic textiles as a major source of microplastic in the environment: A review. *Textile Research Journal*. 2021; 91(17-18):2136-2156.
3. Blair RM, Waldron S, Phoenix V, Gauchotte-Lindsay C. Micro-and nanoplastic pollution of freshwater and wastewater treatment systems. *Springer Science Reviews*. 2017; 5:19-30.
4. Brooks AL. From the Ground up: Measurement, Review, and Evaluation of Plastic Waste Management at Varying Landscape Scales (Doctoral dissertation, University of Georgia), 2021.
5. Chand R, Kohansal K, Toor S, Pedersen TH, Vollertsen J. Microplastic degradation through hydrothermal liquefaction of wastewater treatment sludge. *Journal of Cleaner Production*. 2022; 335:130383.
6. Chen Y, Leng Y, Liu X, Wang J. Microplastic pollution in vegetable farmlands of suburb Wuhan, Central China. *Environmental Pollution*. 2020; 257:113449.
7. Crossman J, Hurley RR, Futter M, Nizzetto L. Transfer and transport of microplastic from biosolids to agricultural soils and the wider environment. *Science of The Total Environment*. 2020; 724:138334.
8. Das SK, Eshkalak SK, Chinnappan A, Ghosh R, Jayathilaka WADM, Baskar C, *et al.* Plastic recycling of polyethylene terephthalate (PET) and polyhydroxybutyrate (PHB)-A comprehensive review. *Materials Circular Economy*. 2021; 3(1):9.
9. De Souza Machado AA, Lau CW, Kloas W, Bergmann J, Bachelier JB, Faltin E, *et al.* Microplastic Can Change Soil Properties and Affect Plant Performance. *Environmental Science & Technology*. 2019; 53:6044-6052.
10. Dey S, Veerendra GTN, Babu PA, Manoj AP, Nagarjuna K. Degradation of plastics waste and its effects on biological ecosystems: A scientific analysis and comprehensive review. *Biomedical Materials & Devices*. 2024; 2(1):70-112.
11. Eo S, Hong SH, Song YK, Han GM, Shim WJ. Spatiotemporal distribution and annual load of microplastic in the Nakdong River, South Korea. *Water*

- Research. 2019; 160:228-237.
12. Geyer J, Jambeck JR, Lavender KL. Production, use, and fate of all plastics ever made, *Law Sci. Adv.* 2017; 3:e1700782.
 13. He D, Luo Y, Lu S, Liu M, Song Y, Lei L. Microplastic in soils: Analytical methods, pollution characteristics and ecological risks. *TrAC Trends in Analytical Chemistry.* 2018; 109:163-172.
 14. He P, Chen L, Shao L, Zhang H, Lü F. Municipal solid waste (MSW) landfill: A source of microplastic? Evidence of microplastic in landfill leachate. *Water Research.* 2019; 159:38-45.
 15. Hernandez LM, Yousefi N, Tufenkji N. Are there nanoplastics in your personal care products? *Environmental Science & Technology Letters.* 2017; 4(7):280-285.
 16. Hikon BN, Yebpella GG, Jafiya L, Ayuba S. Preliminary investigation of microplastic as a vector for heavy metals in Bye-ma salt mine, Wukari, Nigeria. *Journal of the Nigerian Society of Physical Sciences,* 2021, 250-255.
 17. Huang W, Song B, Liang J, Niu Q, Zeng G, Shen M, *et al.* Microplastic and associated contaminants in the aquatic environment: A review on their ecotoxicological effects, trophic transfer, and potential impacts to human health. *Journal of Hazardous Materials.* 2021; 405:124187.
 18. Kumar M, Xiong X, He M, Tsang DC, Gupta J, Khan E, *et al.* Microplastic as pollutants in agricultural soils. *Environmental Pollution.* 2020; 265:114980.
 19. Lacroix E, Brovelli A, Barry DA, Holliger C. Use of silicate minerals for pH control during reductive dechlorination of chloroethenes in batch cultures of different microbial consortia. *Applied and Environmental Microbiology.* 2014; 80(13):3858-3867.
 20. Landeros L, Williams I, Shaw P, Hudson M, Dominguez Cortinas G. A review of the origins of microplastic arriving at wastewater treatment plants. *Detritus.* 2022; 20:41-55.
 21. Li M, Liu Y, Xu G, Wang Y, Yu Y. Impacts of Polyethylene Microplastic on Bioavailability and Toxicity of Metals in Soil. *Science of the Total Environment.* 2021; 760, Article ID: 144037
 22. Lozano YM, Aguilar-Trigueros CA, Onandia G, Maaß S, Zhao T, Rillig MC. Effects of microplastic and drought on soil ecosystem functions and multifunctionality. *Journal of Applied Ecology.* 2021; 58(5):988-996.
 23. Machado AAD, Kloas W, Zarfl C, Hempel S, Rillig MC. Microplastic as an emerging threat to terrestrial ecosystems. *Global Change Bio.* 2018; 24:1405-1416.
 24. Mai L, Bao LJ, Shi L, Wong CS, Zeng EY. A review of methods for measuring microplastic in aquatic environments. *Environmental Science and Pollution Research.* 2018; 25:11319-11332.
 25. Malakar A, Snow DD. Nanoparticles as sources of inorganic water pollutants. In *Inorganic pollutants in water.* Elsevier, 2020, 337-370.
 26. Malankowska M, Echaide-Gorritz C, Coronas J. Microplastic in marine environment: A review on sources, classification, and potential remediation by membrane technology. *Environmental Science: Water Research & Technology.* 2021; 7(2):243-258.
 27. Ola-Buraimo AO, Ologe O, Benemaikwu DO. Field geology and microbiological investigation of borehole, public tap water and hand-dug wells in some parts of Birnin Kebbi, Kebbi State, northwestern Nigeria. *Nigerian Journal of Scientific Research (In Press),* 2019.
 28. Otitoju O, Lewis CC. Health risk assessment of pesticide residues in bean samples from Wukari, Taraba State, Nigeria. *Journal of Environmental Chemistry and Ecotoxicology.* 2021; 13(1):1-13.
 29. Qi Y, Beriot N, Gort G, Lwanga EH, Gooren H, Yang X, *et al.* Impact of plastic mulch film debris on soil physicochemical and hydrological properties. *Environmental Pollution.* 2020; 266:115097.
 30. Schell T, Hurley R, Buenaventura NT, Mauri PV, Nizzetto L, Rico A, *et al.* Fate of microplastic in agricultural soils amended with sewage sludge: Is surface water runoff a relevant environmental pathway? *Environmental Pollution.* 2022; 293:118520.
 31. Scheurer M, Bigalke M. Microplastic in Swiss floodplain soils. *Environ. Sci. Technol.* 2018; 52:3591-3598.
 32. Sharma S, Chatterjee S. Microplastic pollution, a threat to marine ecosystem and human health: A short review. *Environmental Science and Pollution Research.* 2017; 24:21530-21547.
 33. Sharma U, Sharma S, Rana VS, Rana N, Kumar V, Sharma S, *et al.* Assessment of Microplastic Pollution on Soil Health and Eco-toxicological Risk in Horticulture. *Soil Systems.* 2023; 7(1):7.
 34. Wang L, Zhang J, Hou S, Sun H. A simple method for quantifying polycarbonate and polyethylene terephthalate microplastic in environmental samples by liquid chromatography tandem mass spectrometry. *Environmental Science & Technology Letters.* 2017; 4:530-534.
 35. Wojnowska-Baryła I, Bernat K, Zaborowska M. Plastic waste degradation in landfill conditions: The problem with microplastic, and their direct and indirect environmental effects. *International Journal of Environmental Research and Public Health.* 2022; 19(20):13223.
 36. Wu P, Huang J, Zheng Y, Yang Y, Zhang Y, He F, *et al.* Environmental occurrences, fate, and impacts of microplastic. *Ecotoxicology and Environmental Safety.* 2019; 184:109612.
 37. Zhao T, Lozano YM, Rillig MC. Microplastic increase soil pH and decrease microbial activities as a function of microplastic shape, polymer type, and exposure time. *Frontiers in Environmental Science.* 2021; 9:675803.
 38. Zhang Y, Zhou G, Yue J, Xing X, Yang Z, Wang X, *et al.* Enhanced removal of polyethylene terephthalate microplastics through polyaluminum chloride coagulation with three typical coagulant aids. *Science of the Total Environment.* 2021; 800:149589.
 39. Zhou J, Wen Y, Marshall MR, Zhao J, Gui H, Yang Y, *et al.* Microplastic as an emerging threat to plant and soil health in agroecosystems. *Science of the Total Environment.* 2021; 787:147444.
 40. Zhou Q, Zhang HB, Fu CC, Zhou Y, Dai ZF, Li Y. The distribution and morphology of microplastic in coastal soils adjacent to the Bohai Sea and the Yellow Sea. *Geoderma.* 2018; 322:201-208.

41. Zhou Y, Liu X, Wang J. Characterization of microplastic and the association of heavy metals with microplastic in suburban soil of central China. *Science of the Total Environment*. 2019; 694:133798.
42. Zhou Y, Wang J, Zou M, Jia Z, Zhou S, Li Y. Microplastic in soils: A review of methods, occurrence, fate, transport, ecological and environmental risks. *Science of the Total Environment*. 2020; 748:141368.
43. Zou J, Wang C, Li J, Wei J, Liu Y, Hu L, *et al.* Effect of polyethylene (LDPE) microplastic on remediation of cadmium contaminated soil by *Solanum nigrum* L. *Journal of Geoscience and Environment Protection*. 2022; 10(1):49-64.