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Environmental and Toxicological Perspectives of Soil Microplastics in Northern Nigeria

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Abstract

The study examined the environmental and toxicological implications of microplastics in the soil of Northern Nigeria, which has not been addressed through research. The microplastics, as a product of plastic degradation, have environmental risks and can be recognised as sources of soil decay ecosystem pollutants in increasing numbers. This study aimed to investigate the sources, routes, and ecological effects of microplastics in the soils of Northern Nigeria, and specifically in agricultural activities, waste management, and atmospheric emissions. In its design, the study used a rigorous examination of the secondary information in the form of peer-reviewed publications, institutional monographs, and international media to collect detailed information on the environmental destiny and toxicological dangers embedded in microplastics in the soil systems of the area. Findings reveal that soil microplastics are related to lower soil productivity, malfunctioning microbial functions and disturbance of plant growth, directly posing risks to food security and human health. The results underscore the need to focus on increased research and development, ameliorate waste management strategies,

and incorporate sustainable agricultural methods to improve the health of soils and food production in the area. The study recommends establishing effective monitoring systems, capacity building and introducing policies to deal with microplastic contamination in the soil, which is important in safeguarding environmental sustainability and human health.

Keywords: Soil Microplastics, Environmental Contamination, Toxicological Impacts, Food Security, Nigeria.

Introduction

Plastic pollution has become one of the epitomizers of the 21st-century environment, with approximately 400 million tonnes of plastic annually produced and estimated to grow over the next decades (Geyer *et al*., 2017; Real, 2022). Plastics have been found to remain in the environment, resulting in physical, chemical and biological degradation due to their durability and food usage. One of the significant results of this degradation is microplastics or plastic particles smaller than 5mm in diameter; part of these microplastics can be produced by industrial products, such as microbeads and pre-production pellets (primarily microplastics) and the other part of microplastic is through the degradation of larger plastic debris (secondary microplastics) (Andrady, 2011; Cole *et al*., 2011). Whereas studies in microplastics have primarily focused on water systems, specifically ocean ecosystems, an increasing number of topics in research have shifted, regarding potential source systems, to the land-based system (Rillig, 2012; Corradini *et al*., 2019). The soils, specifically, are viewed as significant sinks of microplastics because of the inputs of various sources such as plastic mulching wraps, sewage sludge application to land, wastewater irrigating lands, atmospheric contamination, and waste disposal in ungrateful actions (Bläsing and Amelung, 2018; Qi *et al*., 2020). Microplastics are persistent, which changes the soil structure, water retention capacity, porosity, and changes microbial patterns and the ability to up-cycle nutrients (de Souza Machado *et al*., 2018; Boots *et al*., 2019). Moreover, their hydrophobicity and high surface area allow them to adsorb organic contaminants, pesticides, and heavy metals and hence become vectors of co-contamination in the materials of soil (Tourinho *et al*., 2019; Isangadighi & Ukudo, 2025 and Tourinho *et al*., 2021).

The toxicological research confirms that the microplastics are able to cause adverse effects on the soil organisms, plants and on a higher trophic level. Physiological studies have indicated that microplastics prevent seed germination, slow root growth, and decrease grain production of microplastic-polluted soils (Qi *et al*., 2018; Li *et al*., 2020). Exposure to soil biota such as earthworms and microbes causes physiological stress and metabolic disruption in them (Huerta Lwanga *et al*., 2017; Kim *et al*., 2021). Notably, data on the presence of plant uptake and translocation of microplastics to the edible tissues indicate that it is possible that the substance can enter the human food chain and lead to its long-term health effects, which

include oxidative stress, endocrine disruptions, and bioaccumulation of toxic additives (Wright and Kelly, 2017; Isangadighi & Udeh, 2023; Prata *et al*., 2020). The global understanding notwithstanding, a wide area of geographical variation in microplastics remains to be studied. Asia and Europe are leading in the literature, but Africa is still grossly underrepresented, with the vast majority of studies on Nigeria consisting of aquatic systems studies (Enyoh *et al*., 2020; Ilechukwu *et al*., 2022). There is practically nothing in print related to microplastic pollution in the soils of Nigeria. This knowledge gap is specifically acute in Northern Nigeria, where the issue of urbanisation is widespread, there is no sufficient system of disposing of garbage, and the process of agricultural expansion occurs, as well as dust storms frequently occur and are able to deliver plastic particles over a vast area. The toxicological and environmental impact of soil microplastics used in the region is causally important and needs to be closely addressed both in academic research and policies because their livelihoods and food security depend more on farming. In this connection, this review is a synthesis of the secondary data published work, scientific databases, and institutional reports reviewing the environmental and toxicological view or perspectives of soil microplastics, particularly in Northern Nigeria. In particular, it will: (i) determine the key sources and routes of soil microplasticity; (ii) study their ecological and soil system behaviours; (iii) be aware of the ecotoxicological and human health risks; and (iv) pinpoint gaps and policy hot-spots of mitigating risks in Northern Nigeria.

Methodology

This review has utilized a systematic literature-based approach to synthesize existing information on soil microplastics with regard to environmental and toxicological implications in the Northern part of Nigeria. Peer-reviewed journal articles, institutional reports, and trusted international databases were used to gather secondary data, following the modified PRISMA guidance, to ensure an adequate level of methodological transparency. Multidisciplinary databases such as Web of science, Scopus, PubMed, Google Scholar, ScienceDirect and the African Journals Online (AJOL) together with multidisciplinary searches of multidisciplinary databases (Web of Science, Scopus, PubMed, Google Scholar, ScienceDirect and African journals online) were utilised in comprehensive searches on grey literature provided by UNEP, FAO, WHO and the NESREA of Nigeria. The search strategy employed a combination of Boolean operations and keywords, including microplastics, soil, terrestrial environment, toxicity, Nigeria, and Northern Nigeria. Relevance was maintained by screening titles, abstracts, and full texts on a sequential basis. The studies were selected for approval based on their significance to microplastics in soils or terrestrial environments, evidence of their environmental fate or toxicological impact, and publication in English between 2000 and 2025. Retention of global studies occurred in cases where the available Nigerian or African data were insufficient to facilitate any synthesis on the same topic. The exclusion criteria were used to filter works that solely discussed aquatic systems without any terrestrial connection, lacked methodological clarity, or were non-scientific (e.g., opinion pieces, blogs, or media coverage). Duplicates obtained from the databases were eliminated. They were extracted from the sources of microplastic, the type and size of particles, the properties of soil, the methods

of analysis, the ecological and toxicological effects on the soil organisms, plants, and humans where needed. The data were synthesized narratively into four thematic provisions, including sources and foodways of soil microplastics, environmental fate and interactions, toxicological risks, and implications for the Northern Nigeria region. Although this review is limited by the scarcity of empirical evidence available in Northern Nigeria, the combination of global results with regional data has made the research study very strong and contextually relevant.

Results

Table 1: Reported Sources and Pathways of Soil Microplastics

Source/Pathway	Description	Global Evidence (examples)	African/Nigerian Context (examples)
Agricultural practices	Use of plastic mulching, irrigation with wastewater, and sludge application introduces MPs.	Qi *et al*., 2020; Liu *et al*., 2021; Wang *et al*., 2024; Corradini *et al*., 2019	Increasing irrigation farming with plastic mulching in Kano and Kaduna (Shanono *et al*., 2022; Suleiman, 2023)
Solid waste mismanagement	Open dumping, unlined landfills, and litter release plastics into soils.	Bläsing & Amelung, 2018; Zhou *et al*., 2020	Open dumping is common in Abuja, Kano, and Maiduguri (Auta *et al*., 2017; Enyoh *et al*., 2020)
Atmospheric deposition	Microplastics transported by wind and dust settle in soils.	Dris *et al*., 2016; Brahney *et al*., 2020	Harmattan dust storms likely contribute to deposition in Northern Nigeria (Okunola *et al*., 2019; Onianwa *et al*., 2021)
Industrial effluents	Plastic pellets, fibres, and residues are released from the textile and plastic industries.	Browne *et al*., 2011; Prata, 2018	Plastic recycling and textile industries in Kano are suspected sources (Ilechukwu *et al*., 2022; Musa *et al*., 2021)
Household sources	Laundry effluents, cosmetic microbeads, packaging and single-use plastics are disposed of in soil.	Napper & Thompson, 2016; Rochman *et al*., 2019	Household waste mismanagement is widespread in Nigerian cities (Enyoh *et al*., 2020; Bichi & Amatobi, 2013)

Table 2: Environmental Fate and Interactions of Soil Microplastics

Environmental Process	Mechanism	Implications for Soil Systems	References (examples)
Fragmentation & weathering	Physical breakdown into smaller particles under UV, wind, and mechanical stress	Increases particle abundance and persistence	Andrady, 2011; Rillig, 2012
Adsorption of co-contaminants	Microplastics bind heavy metals, PAHs, pesticides	Enhances pollutant mobility and bioavailability	Tourinho *et al*., 2019

Environmental Process	Mechanism	Implications for Soil Systems	References (examples)
Interaction with soil biota	Earthworms and microbes interact with microplastics	Alters microbial diversity, impairs soil fertility	Huerta Lwanga *et al*., 2017
Transport within the soil profile	Leaching and percolation with water flow	Potential contamination of groundwater	Corradini *et al*., 2019
Persistence and accumulation	Plastics remain for decades due to low biodegradability	Long-term contamination sink	de Souza Machado *et al*., 2018

Table 3: Reported Toxicological Risks of Soil Microplastics

Receptor	Reported Effects	Evidence Level (Lab/Field)	Example Studies
Soil microbes	Reduced diversity, impaired enzyme activity, disrupted nutrient cycling	Laboratory and mesocosm	de Souza Machado *et al*., 2018
Plants (crops)	Reduced seed germination, altered root architecture, yield decline, tissue uptake	Laboratory, greenhouse	Qi *et al*., 2018; Li *et al*., 2020
Soil fauna (worms)	Gut blockage, reduced reproduction, oxidative stress	Laboratory, field trials	Huerta Lwanga *et al*., 2017
Humans (indirect)	Food chain transfer, potential endocrine disruption, inflammation, oxidative stress	Review evidence	Wright & Kelly, 2017; Prata *et al*., 2020

Table 4: Evidence Gaps and Regional Implications for Northern Nigeria

Thematic Area	Global Status (Evidence)	Nigeria/Africa Status (Evidence)	Implications for Northern Nigeria
Soil concentrations	Agricultural soils in China and Europe contain up to 7% w/w MPs residues (Zhang & Liu, 2018; Corradini *et al*., 2019).	No quantitative soil data for Nigeria; limited work in South Africa (Sibanda *et al*., 2025).	Unknown MP burden in soils; likely high due to irrigation, waste dumping, and dust storms.
Agricultural impacts	MPs have been shown to reduce germination, root growth, and crop yields (Qi *et al*., 2018; Li *et al*., 2020).	No empirical data from Nigeria; only anecdotal reports on plastic residues in farmlands (Enyoh *et al*., 2020).	Potential food security risks in Kano, Kaduna, Sokoto, and surrounding states are dependent on irrigated farming.
Human health risks	Evidence of trophic transfer of MPs into edible plants and toxicity (Wright & Kelly, 2017; Prata *et al*., 2020).	Virtually no studies in Nigeria; limited awareness in sub-Saharan Africa (Ilechukwu *et al*., 2022).	Possible chronic exposure to MPs via contaminated crops and dust inhalation.

Thematic Area	Global Status (Evidence)	Nigeria/Africa Status (Evidence)	Implications for Northern Nigeria
Monitoring capacity	Established analytical protocols (FTIR, Raman, Py-GC/MS) in Europe/Asia (Prata, 2018).	Weak laboratory capacity in Nigeria; absence of standardised monitoring frameworks (Suleiman, 2019).	Lack of analytical infrastructure hinders MP research in Northern Nigeria.

Table 5: Types and Characteristics of Soil Microplastics

Polymer Type	Common Sources	Reported Shapes	Global Evidence	Nigeria/Africa Context
Polyethylene (PE)	Plastic bags, mulching films, packaging	Fragments, films	Qi *et al*., 2020; Corradini *et al*., 2019	Reported in Nigerian aquatic systems (Enyoh *et al*., 2020)
Polypropylene (PP)	Food containers, bottle caps	Fibres, fragments	Andrady, 2011	Suspected from household waste (Auta *et al*., 2017)
Polystyrene (PS)	Disposable plates, cups, and insulation	Beads, foams	Cole *et al*., 2011	Observed in SA soils (Sibanda *et al*., 2021)
Polyester (PES)	Textile fibres, laundry effluents	Fibers	Browne *et al*., 2011	Textile industries in Kano (Musa *et al*., 2021)

Table 6: Analytical Methods for Detecting Soil Microplastics

Method/Instrument	Principle	Advantages	Limitations	Global Use	Nigeria Context
FTIR (Fourier Transform Infrared Spectroscopy)	Identifies polymer functional groups	Reliable, non-destructive	Limited to >20 µm particles	Widely applied	Limited use due to cost
Raman Spectroscopy	Molecular fingerprinting of polymers	High sensitivity, small particles	Fluorescence interference	Used globally	Not reported
Pyrolysis-GC/MS	Thermal degradation + chemical ID	Quantifies MPs and additives	Expensive, complex	Growing in the EU	Absent
Visual Microscopy	Physical observation of particles	Cheap, easy	Subjective, not conclusive	Widely used	Common in Nigerian labs

Table 7: Policy and Governance Landscape

Region	Existing Regulations/Policies	Strengths	Gaps
European Union	Single-use plastics ban; monitoring frameworks	Strong regulation, funding	Focus still on marine litter
China	Ban on thin plastic bags, mulching film recycling	Large-scale enforcement	Soil MPs are still poorly addressed
Nigeria	Plastic bag ban attempts (2019 bill – stalled); NESREA guidelines on waste	Some awareness	No soil-specific MPs monitoring, weak enforcement
Northern Nigeria	Local waste bylaws in Kano, Kaduna (limited)	Regional relevance	Poor compliance, no monitoring

Discussion

Sources and Pathways of Soil Microplastics

The findings imply that agriculture, improper management of solid waste, deposition of atmospheric particles, industrial effluents, and households represent the major routes of microplastic (MP) contamination of soils. Agricultural inputs like plastic mulching covers, sewage sludge, and wastewater irrigation have widely been reported to be the primary sources of pollution (Qi *et al*., 2020; Huang *et al*., 2021). These are increasing in intensity in Northern Nigeria, especially in irrigation agricultural areas of Kano and Kaduna, where plastic mulching and uncontrolled dumping of wastewater irrigation are becoming the new norm (Shanono *et al*., 2022). This implies a risk that is very high and cannot be estimated for MP accumulating in the soils. Another anguish-driven issue is solid waste mismanagement. It has also been found that open dumping and inadequately designed landfills produce plastics as they seep into the nearby soils both in developed and developing regions (Bläsing & Amelung, 2018). Lack of sanitary landfilling leads to contamination in Abuja, Kano, and Maiduguri (Auta *et al*., 2017; Enyoh *et al*., 2020). The transportation through the atmosphere contributes an extra touch in Northern Nigeria. The dust storms that are likely to carry MPs are harmattan dust storms, which are characterised by long-range transportation of particulates, which have already been proven to happen in Europe and North America (Dris *et al*., 2016; Brahney *et al*., 2020). Owing to the arid weather conditions in Northern Nigeria, atmospheric deposition could be one of the other least appreciated sources of MPs in soils. Industrial and domestic sources also support the problem: indiscriminate toleration of plastic waste at the home level (Consumers throbbing, 2016), artificial domestic valleys of domestic plastic waste (Bichi and Amatobi, 2013), and one of the primary and secondary sources of MPs, recycling of textile and plastic waste in Kano (Ilechukwu *et al*., 2022; Musa *et al*., 2021).

Environmental Fate and Interactions

Physical immobility to formations of biodegradation, as well as the natural tendency of breaking down into fragments during ultraviolet radiation, winds, and mechanical abrasion, contributes to the persistence of MPs in soils (Andrady, 2011; Ibanga et al., 2024). The findings suggest that the MPs not only accumulate but also interact with the physicochemical

processes of soil. They possess more of the power to sequester co-contaminants such as heavy metals, pesticides, and PAHs, which enhances the mobile quality and bioavailability of contaminants (Tourinho et al., 2019), presenting a two-fold challenge of contamination. Under high-density fertilised soils under stress by fertilisers and pesticide substances, encompassing those of Northern Nigeria, MPs may augment the impact of inoculations on the remunerations by the chemical remedies. Another factor that needs to be discussed is the interaction of MPs with soil biota. Such effects have been reported by research to include disturbance in the microbial habitat, activities of enzymes, and soil fertility of MP-polluted soils (Huerta Lwanga et al., 2017). This is more alarming as goes the example of Nigeria where fairy-tale farming is the order of the day subsistence and food security is concentrated on soil fertility. A higher degree of complications, which makes the soil pollution even more threatening, relates to the fact that the MPs may migrate vertically on the ground and into the groundwater (Corradini et al., 2019), and in semi-arid areas, where groundwater is the primary source of water, it can turn out to be quite perilous.

Toxicological Risks

The ecotoxicological stressor, which is captured by toxicological information about MPs, is formed on multiple biological receptor points of contact. Other characteristics of microbes in the soil to which MPs were exposed pertain to low metabolic rates and an inability to recycle nutrients that impact the soil and crop product adversely (de Souza Machado et al., 2018; Essien et al., 2025a). The germination of plants planted in polluted soils is muffled, and root phenotypic characteristics are disrupted, decreasing the yield, and MP is also absorbed by edible organs (Qi *et al*., 2018; Li *et al*., 2020). The findings are especially applicable to the region of Northern Nigeria, where maize, millet and vegetables are the staple crops being grown in peri-urban and irrigated agricultural land prone to plastic agricultural inputs. The exposures to MPs have been identified to cause gut blockage, oxidative stress, and a decline in reproductive functions in soil fauna, especially earthworms (Huerta Lwanga *et al*., 2017; Isangadighi et al., 2025; Essien et al., 2025b). The aeration and nutrient availability of the soil are indirectly impacted as soil engineers because any degradation of earthworms has manifested this. In the case of humans, the transfers of the risk are indirect in the form of contaminated crops, inhaling dust along with MP particles, and the potential intake of groundwater. Although there is no specific information about Nigeria, toxicologists around the world yielded results, referencing oxidative stress, inflammation, endocrine disruptors, and positive accumulation of polymer additives (Wright and Kelly, 2017; Prata *et al*., 2020). Since the area of high exposure risks in northern states that have dust, the risk to health can be significant, but it may go unnoticed.

Types and Characteristics of Soil Microplastics

The findings reveal polymers such as polyethene (PE), polypropylene (PP), polystyrene (PS), and polyester (PES) as commonly existing in soils, the reason why they are highly used in packaging, agriculture and textile businesses. PE and PP predominate throughout the agricultural soils worldwide (Qi *et al*., 2020), and the African works have highlighted the same

polymers in South African soils (Sibanda *et al*., 2021). In the case of Nigeria, no soil-specific data is available; instead, PE and PP preeminence is supported by the data of aquatic systems (Enyoh *et al*., 2020). The textile fibres PES in Kano add to emphasise the role of industrial contributors to local MP profiles (Musa *et al*., 2021). The patterns depicted above indicate that the soils in Northern Nigeria are likely to present a composite of agricultural, industrial and domestic polymers.

Analytical Capacity, Policy and Governance Gaps

The sharp difference in the ability to analyse is brought to the fore in Table 6. FTIR, Raman spectroscopy, and Pyrolysis-GC/MS are all applied, recently, globally as methods of MP detection and Polymer identification (Prata, 2018). Nigeria, on the other hand, has developed dominantly on visual microscopy, which is not as accurate and underestimates concentrations. The lack of respected spectroscopy at the lab in Nigeria would hamper the precise quantification, and it would allow for the generation of baseline data. This informational difficiency is a phenomenal obstacle towards enhancing soil MP studies, and it is in this context that area-wide potential building becomes vital. The development of regulations towards plastic feeds to nature can be noted due to the global policy already implemented, e.g., the EU ban on single-use plastics or restrictions imposed on plastic bags and mulching films in China (European Commission, 2019; Liu *et al*., 2020). Nigeria, in its turn, has not been able to enforce its suggested plastic bag ban (2019), and there are no guidelines on the specifics of soil MPs in the current NESREA regulations. The local bylaws on waste can also be found in some cities in Northern Nigeria, like Kano and Kaduna, but stringent enforcement is lacking, along with a lack of monitoring. Lack of regulation of soil-specific MP creates a rather wide policy gap, which continues to allow the free leakage of plastics in terrestrial ecosystems.

Regional Implications for Northern Nigeria

Critical knowledge gaps mar the analysis of evidence. Global research determines the levels of MPs in the soils to reach up to 7% (Zhang and Liu, 2018), but there are no such figures in Nigeria. This has hindered the capabilities of reviewing risks to food security and agriculture in the Northern part of Nigeria, where irrigation agriculture plays a major role. The available toxicological materials in the literature covering the whole of the world, when applied in the Northern Nigerian setting, indicate that there may be yield losses and decreased soil fertility coupled with chronic human diseases due to the inhalation of food and dust. Moreover, the lack of analytical ability and the regulatory structures grossly affect management, monitoring and mitigation measures. Taken together, these were the results that indicate Northern Nigeria is a high-risk, but a poorly known area where the environmental and toxicological consequences of soil MPs are both pressing and little known.

Limitations of the Study

The limitation of this review stems from the lack of empirical studies on soil microplastics in Nigeria and in the northern part of the country, in which case the extrapolation to the world

and African data was necessary to provide some context. The lack of quantitative data on the analysed soils in Nigeria made it impossible to give the numbers of specific contamination of regions, and the limited analytical facilities which exist in the country limit the possibility of validating the types of polymers and the impact of toxins in a local context. Moreover, it has limited itself to considering only English-language publications and might have missed out on any study of interest in its region or other studies without an index. Such limitations promote the case of dire importance of primary investigations and capacity building to close serious knowledge gaps.

Recommendations

To deal with the plausible risks of having microplastics in the soil in Northern Nigeria, an initial examination is needed using uniform elements of analysis, including FTIR and Raman spectroscopy, essential in measurements and polymerisation. Enhancing laboratory capacity by joining hands in the region and investing in multi-modern instruments will allow unquestionable surveillance. The national waste management and agricultural policies should consider soil microplastic contamination by policymakers, and increased restrictions should be imposed on open dumping and stimulating sustainable plastic use by the local authorities. Education on alternative to using plastic mulching and better ways of disposing waste should also be given high priority in order to decrease agricultural inputs of microplastics.

Conclusion

Observed in this review, soils are neglected sources of microplastics with strong environmental and toxicological impacts. Empirical data gathered across the world has shown that microplastics change the soil characteristics, interfere with the microbial and faunal activities, decrease food production and yields, and may lead to false outcomes, including human health risks due to the transfer of plastics along food chains and microplastic inhalation. In Northern Nigeria, where low waste management thrives, contingent on agriculture and soil deposition by atmospheric dust, there are high chances of soil pollution, which is not documented yet. Lack of empirical evidence, analytical infrastructure and regulatory frameworks constitutes a major impediment to intervention. The need to fill these gaps by conducting research, keeping track of the issues and implementing a policy innovatively is urgent to protect the health of the soil, agricultural business and human lives in the area.

References

Andrady, A. L. (2011). Microplastics in the marine environment. *Marine pollution bulletin*, *62*(8), 1596-1605.

Auta, H. S., Emenike, C. U., & Fauziah, S. H. (2017). Distribution and importance of microplastics in the marine environment: a review of the sources, fate, effects, and potential solutions. *Environment international*, *102*, 165-176.

Bichi, M. H., & Amatobi, D. A. (2013). Assessment of the quality of water supplied by water vendors to households in the Sabon-gari area of Kano, northern Nigeria. *Int J Eng Sci (IJES)*, *2*(7), 09-17.

Bläsing, M., & Amelung, W. (2018). Plastics in soil: Analytical methods and possible sources. *Science of the total environment*, *612*, 422-435.

Boots, B., Russell, C. W., & Green, D. S. (2019). Effects of microplastics in soil ecosystems: above and below ground. *Environmental science & technology*, *53*(19), 11496-11506.

Brahney, J., Hallerud, M., Heim, E., Hahnenberger, M., & Sukumaran, S. (2020). Plastic rain in protected areas of the United States. *Science*, *368*(6496), 1257-1260.

Browne, M. A., Crump, P., Niven, S. J., Teuten, E., Tonkin, A., Galloway, T., & Thompson, R. (2011). Accumulation of microplastics on shorelines worldwide: sources and sinks. *Environmental science & technology*, *45*(21), 9175-9179.

Cole, M., Lindeque, P., Halsband, C., & Galloway, T. S. (2011). Microplastics as contaminants in the marine environment: a review. *Marine pollution bulletin*, *62*(12), 2588-2597.

Corradini, F., Meza, P., Eguiluz, R., Casado, F., Huerta-Lwanga, E., & Geissen, V. (2019). Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal. *Science of the total environment*, *671*, 411-420.

De Souza Machado, A. A., Kloas, W., Zarfl, C., Hempel, S., & Rillig, M. C. (2018). Microplastics as an emerging threat to terrestrial ecosystems. *Global change biology*, *24*(4), 1405-1416.

Dris, R., Gasperi, J., Saad, M., Mirande, C., & Tassin, B. (2016). Synthetic fibres in atmospheric fallout: a source of microplastics in the environment? *Marine pollution bulletin*, *104*(1-2), 290-293.

Enyoh, C. E., Shafea, L., Verla, A. W., Verla, E. N., Qingyue, W., Chowdhury, T., & Paredes, M. (2020). Microplastics exposure routes and toxicity studies to ecosystems: an overview. *Environmental analysis, health and toxicology*, *35*(1), e2020004.

Essien, U. B., Acha, S., Orhuebor, E. N., Ibanga, F. I., Udoh, U., Momoh, P. O., ... & Micheal, P. U. (2025a). Assessment of Environmental and Occupational Hazards Associated with Crude Oil Exploitation: A Toxicokinetic and Engineering-Based Framework for Sustainable Mitigation. *Journal of African Innovation and Advanced Studies*.

Essien, U. B., Akpan, A. U., Ibanga, F. I., Itu, P. C. O., Micheal, P. U., Daniel, B. A., & Ozohili, L. I. (2025b). Machine Learning in Nanoparticles Toxicology: Mechanisms, Predictive Modelling, and Risk Assessment Strategies. *Journal of Science Innovation and Technology Research*.

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science advances*, *3*(7), e1700782.

Huerta Lwanga, E., Mendoza Vega, J., Ku Quej, V., Chi, J. D. L. A., Sanchez del Cid, L., Chi, C., ... & Geissen, V. (2017). Field evidence for transfer of plastic debris along a terrestrial food chain. *Scientific reports*, *7*(1), 14071.

Ibanga, F. I., Udoh, U. I., Enyiekere, S. I., & Essien, U. B. (2025). Assessment of Total Suspended Particulate Matter (TSPM) Emissions from Sawmills in Akwa Ibom State, Nigeria.

Ilechukwu, I., Ehigiator, B. E., Ben, I. O., Okonkwo, C. J., Olorunfemi, O. S., Modo, U. E., ... & Ohagwa, N. J. (2022). Chronic toxic effects of polystyrene microplastics on reproductive parameters of male rats. *Environmental Analysis, Health and Toxicology*, *37*(2), e2022015.

Isangadighi, G. E., & Udeh, J. A. (2023). Emergencies, preparedness, and management: a case study of Nigeria. *World Safety Organization*, *32*(2), 38.

Isangadighi, G. E., Mathew, P., Islam, M., Obahor, G., Offordum, A., & Momoh, P. O. (2025). Machine learning-based multivariate risk stratification framework for assessing the combined burden of occupational, infectious, and non-communicable diseases in Bagega (Zamfara) and Shiroro (Niger), Nigeria. *Journal of Clinical Practice and Medical Research*, *1*(1), 24-29.

Isangadighi, G., & Ukudo, B. (2025). Perceptions and Awareness of Air Quality and Its Health Impacts in Agbarho Community, Ughelli North, Delta State. *Journal of African Innovation and Advanced Studies*.

Kim, S. K., Kim, J. S., Lee, H., & Lee, H. J. (2021). Abundance and characteristics of microplastics in soils with different agricultural practices: Importance of sources with internal origin and environmental fate. *Journal of Hazardous Materials*, *403*, 123997.

Li, P., Wang, X., Su, M., Zou, X., Duan, L., & Zhang, H. (2021). Characteristics of plastic pollution in the environment: a review. *Bulletin of environmental contamination and toxicology*, *107*(4), 577-584.

Liu, J., Huang, X., Jiang, H., & Chen, H. (2021). Sustaining yield and mitigating methane emissions from rice production with the plastic film mulching technique. *Agricultural Water Management*, *245*, 106667.

Mahmoud, S. A. (2023). The Role of Organic Agriculture in Agricultural Development. *International Journal of Modern Agriculture and Environment*, *3*(2), 8-16.

Musa, A. E., Ahmed, A., Ahmad, S., Khalid, H. R., Al-Osta, M. A., & Ahmad, S. (2025). Axial Compressive and Buckling Behaviour of Concrete-Filled Steel Tubes Incorporating Recycled Coarse Aggregate, Plastic Waste, and Silica Fume. *Arabian Journal for Science and Engineering*, 1-27.

Napper, I. E., & Thompson, R. C. (2016). Release of synthetic microplastic fibres from domestic washing machines: Effects of fabric type and washing conditions. *Marine pollution bulletin*, *112*(1-2), 39-45.

Okunola, A. M., & Ojo, O. S. (2019). Household poverty measurement and its determinants among rural farmers in Ondo State, Nigeria. *Poverty & Public Policy*, *11*(4), 277-290.

Onianwa, O. I. (2021). Insecurity, Food Production and Agricultural Livelihood in Nigeria. *Available at SSRN 4893507*.

Prata, J. C. (2018). Airborne microplastics: consequences to human health?. *Environmental pollution*, *234*, 115-126.

Prata, J. C., Da Costa, J. P., Lopes, I., Duarte, A. C., & Rocha-Santos, T. (2020). Environmental exposure to microplastics: An overview of possible human health effects. *Science of the total environment*, *702*, 134455.

Qi, C., Fourie, A., Chen, Q., & Zhang, Q. (2018). A strength prediction model using artificial intelligence for recycling waste tailings as cemented paste backfill. *Journal of Cleaner Production*, *183*, 566-578.

Qi, Y., Beriot, N., Gort, G., Lwanga, E. H., Gooren, H., Yang, X., & Geissen, V. (2020). Impact of plastic mulch film debris on soil physicochemical and hydrological properties. *Environmental Pollution*, *266*, 115097.

Real, L. E. P. (2022). Plastics statistics: production, recycling, and market data. In *Recycled materials for construction applications: plastic products and composites* (pp. 103-113). Cham: Springer International Publishing.

Rillig, M. C. (2012). Microplastics in terrestrial ecosystems and the soil. Environmental Science & Technology. 46 (12) 6453–6454. Doi: https://doi.org/10.1021/es302011r

Rochman, C. M., Brookson, C., Bikker, J., Djuric, N., Earn, A., Bucci, K., ... & Hung, C. (2019). Rethinking microplastics as a diverse contaminant suite. *Environmental toxicology and chemistry*, *38*(4), 703-711.

Shanono, N. J., Abba, B. S., & Nasidi, N. M. (2022). Evaluation of the Aqua-Crop model using the onion crop under deficit irrigation and mulch in semi-arid Nigeria. *Turkish Journal of Agricultural Engineering Research*, *3*(1), 131-145.

Sibanda, V., Mhlanga, J., & Munuhwa, S. (2025). Circular Economy Practices in Supply Chain Management. In *Eco-Logistics and Sustainable Supply Chain Innovations* (pp. 13-38). IGI Global Scientific Publishing.

Suleiman, R. M., Raimi, M. O., & Sawyerr, O. H. (2019). A deep dive into the review of the national environmental standards and regulations enforcement agency (NESREA) Act. *International Research Journal of Applied Sciences. pISSN*, 2663-5577.

Tourinho, P. S., Kočí, V., Loureiro, S., & van Gestel, C. A. (2019). Partitioning of chemical contaminants to microplastics: Sorption mechanisms, environmental distribution and effects on toxicity and bioaccumulation. *Environmental Pollution*, *252*, 1246-1256.

Tourinho, P. S., Loureiro, S., Talluri, V. P., Dolar, A., Verweij, R., Chvojka, J., ... & van Gestel, C. A. (2021). Microplastic fibres influence Ag toxicity and bioaccumulation in Eisenia andrei but not in Enchytraeus crypticus. *Ecotoxicology*, *30*(6), 1216-1226.

Wang, C., Li, S., Huang, S., & Feng, X. (2024). A review of the application and impact of drip irrigation under plastic mulch in agricultural ecosystems. *Agronomy*, *14*(8), 1752.

Wright, S. L., & Kelly, F. J. (2017). Plastic and human health: a micro issue? *Environmental science & technology*, *51*(12), 6634-6647.

Zhou, C., Huang, N., Yang, G., & Ma, S. (2022). Assessing the sustainability of municipal solid waste management in China, 1980-2019. *Sustainable Horizons*, *2*, 100020.