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A REVIEW OF THE POTENTIAL IMPACT OF MICROPLASTICS ON HUMAN HEALTH

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ABSTRACT

Background: Plastics are emerging sources of pollutants globally. The rise in global plastic output from 365.5 to 390.7 million tonnes between 2016 and 2021 depicts an unabating rise in the use of plastics worldwide. However, the resulting environmental pollution from microplastics (MPs) gotten from the degradation and weathering of large plastic wastes continues to negatively impact the health of humans that consumes fish, which serve as important sources of protein and vitamins. Bioaccumulated microplastics in fish gills and water bodies may lead to serious health issues, including cancer and developmental toxicity when consumed by humans.
Objectives: This study aims to review the literature to: examine the causes and fate of microplastics in aquatic habitats; determine how microplastics get to human body system; examine the effects possibly caused by MPs on fishes; aggregate the adverse effect of consuming contaminated fishes on human health; and identify the study gaps in microplastic pollution in aquatic habitats, especially in Nigeria.
Methods: The study adopts the narrative review approach and includes literature obtained through a search on PubMed, Google Scholar, ScienceDirect, and Jstor.
Conclusion: Findings from the study have implications for the need to direct research attention to the aquatic sources of microplastic pollution to save fish and humans.

Keywords: microplastic, aquatic pollution, human health impact, plastic wastes

INTRODUCTION

Globally, the use of plastic for various purposes has been on the increase, with the global plastic output growing from 365.5 Mt in 2018 to 390.7 Mt in 2021 (Plastic Europe, 2022). From these numbers, Polyethylene Terephthalate (PET), Polypropylene (PP), Polyvinyl Chloride (PVC), Polyethylene (PE), and Polyethylene (PE) are the most used plastic materials and collectively accounts for up to 90% of the total plastic production in the world (Fiore *et al.*, 2022; Espinosa *et al.,* 2016). They are also reffered to as virgin plastics (Fiore *et al.*, 2022). However, these materials have high molecular weight, non-biodegradable, persistent in the environment, and dangerous to human health.

Plastics are artificial carbon-based polymers derived from polymerization of hydrocarbons that can be formed into various products (De-la-Torre, 2020; Waring *et al.,* 2018). Generally, plastics are water and corrosion resistant, chemically inert, inexpensive and easy to mould. They also exhibit strong thermal and electrical insulating qualities (Obebe & Adamu, 2020). Plastics are persistent organic pollutants that disintegrate into bits or particles when introduced into the surroundings and subjected to ongoing processes such as chemical weathering, photooxidation, and decomposition (Amato-Lourenço *et al.,* 2020; De-la-Torre, 2020). An estimated 8.3 billion tonnes of virgin plastic have been produced since 1950, and an additional 6.3 billion tonnes are thought to have been converted to plastic garbage.

Of this amount of waste, 79% is estimated to have accumulated in landfills, while 8 to 9 million tons are assumed to enter the oceans every year (Rhodes, 2019).

Plastics when broken down to fragments or particles are called microplastics (below 5mm), nanoplastics (below 0.1mm in diameter), mesoplastics (between 5-25mm in diameter), and macroplastics (greater than 25mm in diameter) (Sana *et al.,* 2020; Hartmann et al., 2019). The environment is currently overflowing with microplastics (MPs) and a number of emerging environmental pollutants (EEPs) (Obebe & Adamu, 2020).

In a further classification, Hoellein et al. (2016) categorized microplastics (MPs) into two classes. First, the primary MPs, are plastic particles below 5000 µm (5mm) and are factory-made for polishing characteristics (e.g., microbeads and industrial scrubbers). The second is the secondary MPs, which are products of whole plastic substances, which include plastic waste and artificial textiles (Hoellein *et al.,* 2016). These microplastics are present everywhere. They exist in the air via dust and atmosphere at various concentrations (Dris *et al.,* 2016; Cai *et al.,* 2017; Liu *et al.,* 2019; Amato-Lourenço, 2020). Studies have also revealed their presence in rivers, aquifers, mountains, soil, ocean, sea, sediments, drinking water (Rhodes,2018; Rhodes,2019; Blackburn & Green, 2021), glaciers (Azzoni *et al.,* 2019), and insects (Jaibachi *et al.,* 2018). Microplastic contamination in the environment continues to have a detrimental effect on human health. Fish intake (which serves as essential sources of protein and vitamins) from plastic polluted rivers and the ocean allows MPs to enter the human body. When consumed by humans, bioaccumulated microplastics in the gills of fish and water bodies can result in debilitating health conditions. Rochman *et al.* (2015) reported alteration of gene expression, inflammation of tissues, and growth reduction in laboratory animals after ingesting plastic debris. Additionally, Poli *et al.* (2015) noted that microplastic ingestion could result in punctured stomachs and blockage in the gastrointestinal tracts.

The buildup of discarded plastic in the environment has sparked a rapidly developing field of ecosystem research. Jambeck *et al*., (2015) indicated that between 5 and 13 metric tons of plastic were thrown into the oceans in 2010, and it was anticipated to have escalated significantly by the year 2025. Hence, this study sought to analyse the literature to: identify the ways in which microplastics can enter the human body system; investigate the origins and destiny of microplastics in aquatic environments; investigate the negative impacts of MPs on fish. sum up the negative health effects of eating tainted fish and pinpoint research needs regarding microplastic pollution in aquatic environments, particularly in Nigeria.

Method of literature review

The study adopts the narrative review approach. To find papers about MPs in fish, aquatic environments, and their detrimental impacts on human health, a literature search was done on the PubMed, Google Scholar, ScienceDirect, and Jstor databases. Theses, conference proceedings, book chapters, reports, and other unpublished research were excluded. A combination of keywords, such as (“microplastics” OR “microplastic” AND “aquatic ecosystems”), (“microplastics” AND “aquatic environment”), (“microplastic” AND “human health”), and (“microplastics” AND “fishes”) were used in the literature search. Following a screening of the search results, 80 publications in all were included in this review, mainly from the last 10 years. Findings from articles were thematically categorised according to the objectives of the review.

Findings and Discussion

Sources and fate of microplastics in aquatic environments

Early in the 1970s, publications on fibre and plastic particle contamination in the marine environment were released. Since then, scientists have paid increased attention to the pollution caused by plastic particles in aquatic habitats. Microplastics (MPs) have been found in Nigerian freshwater and marine environments, according to studies (Olarinmoye *et al*., 2020; Abiodun *et al*., 2019; Ebere *et al*., 2019). Through a variety of routes, including wind movement, road runoff, maritime activities, and wastewater systems, MPs can enter aquatic ecosystems. However, waste-water treatment facilities are the main source of MPs discharged into the aquatic environment (Duis & Coors, 2016).

While the various treatment methods effectively remove bigger plastic particles, MPs frequently elude the treatment unit. After treatment, these effluents are usually released into nearby waterbodies (Vivekanand *et al.,* 2021). They may also enter wastewater through the cleaning of synthetic fibres such as clothing (Coverton *et al.*, 2019; Li *et al.,* 2019).

Furthermore, Hernandez *et al*., (2017) reported that MPs resembling filaments were discovered in the effluent of a laboratory-simulated washing machine. Nevertheless, runoffs from industrial plastic production sites could also contribute to MPs accumulation in the aquatic habitat (Wagner *et al.,* 2014). Usually, MPs undergo three types of degradation in the aquatic environment: biological degradation, (degradation by the activities of micro-organisms), physical degradation (includes thermal, photo or mechanical degradation), and chemical degradation, (which can be hydrolysis or oxidation degradation (Du *et al.,* 2021).

MPs can also be found in water body sediments because smaller density MPs stay on the water's surface whereas larger density MPs concentrate in the sediment following fragmentation (Dada & Bello, 2023; Sani *et al*., 2022). Through bioturbation, ingestion, and excretion, these MPs are exchanged between living organisms, water, and sediment (Chaukura, 2021). Invertebrates, fish, birds, and marine mammals can all swallow MPs in the aquatic environment (Adeogun *et al.,* 2020; Chaukura, 2021; Meaza *et al,* 2020).

A 2016 United Nations (UN) report indicated that over 800 animal species had been exposed to plastic through ingestion or entanglement. This value is 69% greater than the 247 infected species estimated from a review conducted in 1977 (United Nations Environment Programme (UNEP), 2016). Plastic is consumed by aquatic animals at all trophic levels (Gall and Thompson 2018). According to certain reports, MPs can be found in planktonic creatures, larvae at the base of the food chain, and fish-eating birds at the top (Issac and Kandasubramanian 2021; Smith *et al*., 2018). Organisms also accumulate microplastics from the sediments or MPs suspended in water (Smith *et al.,* 2018).

Furthermore, because MPs are hydrophobic, they carry harmful substances including heavy metals and persistent organic pollutants into waterbodies (Ta *et al*., 2020; Wang *et al*., 2020). Heavy metals that MPs frequently absorb include cadmium, copper, lead, chromium, and zinc (Godoy *et al*., 2019). The pace at which MPs absorb these metal ions is typically influenced by variables like the water's acidity and alkalinity, as well as the MPs retention period (Mammo *et al*., 2020).

Potential route for microplastics to enter the human body

By consuming contaminated seafood, bottled water, groundwater, salt, or by inhalation of atmospheric fallout of microplastic, humans are exposed to microplastics (Domenech & Marcos, 2021; Dris *et al.,* 2016). MPs resided in drinking water from groundwater as reported by Oni & Sanni (2022) and Mintening *et al.* (2018) in Nigeria and Germany respectively using Fourier-transformed infrared to quantify the MPs. Mu *et al.* (2022) also recorded elevated levels of MPs in groundwater from Jiaodong Peninsula, China. These were believed to be a result of anthropogenic activities of residents releasing MPs into the environment and contaminating groundwater through surface runoff and infiltration. In addition to MPs contaminating drinking water from groundwater sources, MPs in drinking water resulting from packaging operations were also documented by Schymanski *et al.*, (2018) and Elizalde-Velázquez and Gómez-Oliván (2021).

In addition, there have been reports that sea salt and table salts contain significant amounts of MPs from different countries (Sivagami *et al.,* 2021; Kim *et al.,* 2018; Iniguez *et al.,* 2017; Karami *et al.,* 2017;). This is an indication of the sea water MPs pollution as sea salt and table salt are gotten from the sea. However, MPs can also be added to table salt while it's being collected, transported, dried, or packaged (Lee *et al.,* 2019; Yang *et al*., 2015). In addition to consuming tainted water and table salt, MPs can also enter the human body from infected fish. Fish taken from aquatic environments have been found to have gills and gastrointestinal tracts that contain varied amounts of various MPs, including polyvinyl chloride, polyurethane, polyamide, polystyrene, etc. (Ilechukwu et al., 2021; Koongolla *et al*., 2020; Karbalaei *et al*., 2019).

MPs' effects on fish

Studies have indicated microplastic pollution in both freshwater and marine fishes. Plastics accumulate in different parts of aquatic organisms, hemolymph and gut lumen of mussels (Magni *et al*., 2018), the testicles, gills, brains and stomachs of crabs (Crooks et al., 2019), and in the liver, brain, gut and gills of fish (Zhang *et al.,* 2021). Accumulation of these plastic materials have been reported to have a debilitating effect on fishes. Ingestion of plastic particles

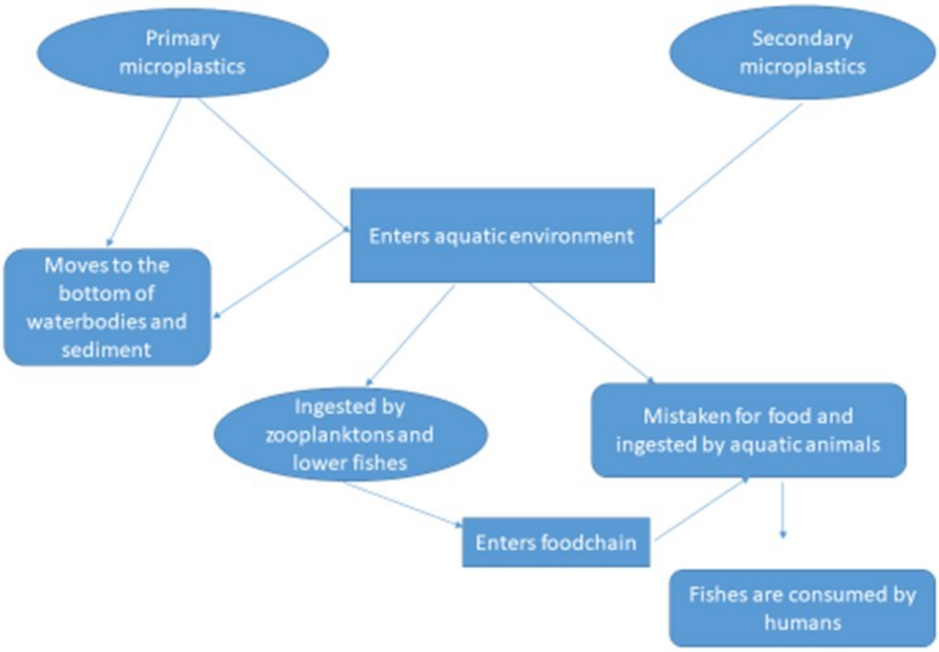

Figure 1: Pathway showing the sources and fate of MPs in an aquatic environment

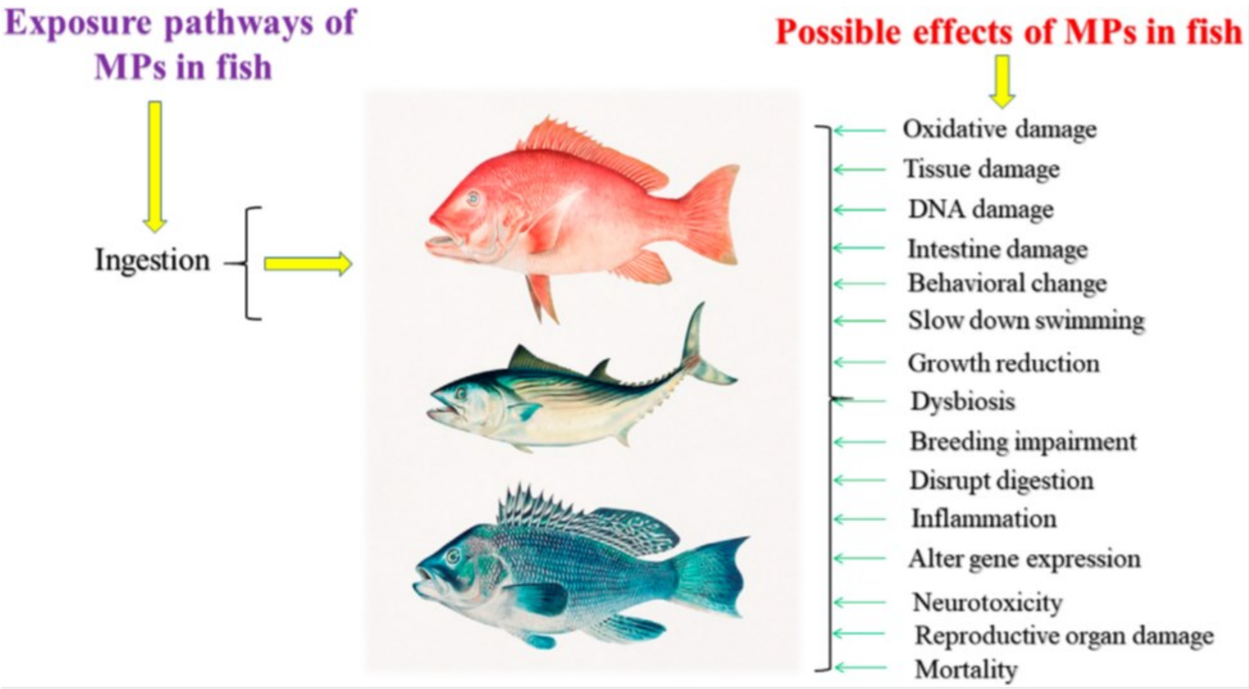

Figure 2: Possible effects of MP in fish (Bhuyan, 2022)

can lead to abrasions and lesions, or physical disruption of the GI tract, as plastics accumulate in fish guts (Yin *et al.,* 2022; Jaafar *et al.,* 2021). Indigestible particles can also fill aquatic organisms' stomachs, reducing their desire to eat, and ultimately leading to malnutrition (Du *et al.,* 2021; Tongo and Erhunmwunse 2022).

Zhang *et al.* (2021) examined the relationship between MP ingestion in fishes and their types of feeding under laboratory settings. The study showed that carnivorous fishes ingested fewer MPs when compared to the omnivores and filter feeders. The filter feeders were better at removing microplastics than omnivores. Similarly, Nano microplastics (NMPs) have been shown to alter the gut microbiome in larval zebrafish (Wan *et al.,* 2019). Iheanacho and Odo (2020) reported disparities in the haematology results, acetylcholinesterase activities, malondialdehyde, catalase, superoxide dismutase, and glutathione transaminase which are indications of brain toxicity and oxidative stress in African catfish. Jabeen *et al.* (2017) reported that there are more plastics in certain fish species' intestines than their stomachs. Kaloyianni *et al.,* (2021) observed Apoptosis, lipid peroxidation, DNA damage and metabolism alteration after exposure of two freshwater fishes to polystyrene MPs. Figure 2 shows the possible effects of MPs in fish as compiled by Bhuyan (2022).

Human health impacts of consuming contaminated fishes.

MPs usually accumulate in fish gills and livers. By consuming fish, therefore, humans could be exposed to MPs. While MPs are not likely to penetrate deeply into mammalian organs, they can cause local inflammation (Yong *et al.,* 2020). MP-based in vitro research has also documented oxidative stress-induced damage in human brain and epithelial cell lines (Bahadur *et al*., 2023; Hu & Palic, 2020; Rubio *et al.,* 2020). This indicates the possible impact of MPs on the guts and immunity of humans (Waring *et al.,* 2018). Microplastics travel from the gut cavity to the circulatory and lymphatic systems, where they are exposed throughout the body and accumulate in the kidney, brain, and liver tissues, according to other research on rodents, aquatic species, and human cells in culture (Prust *et al.,* 2020; Vethaak & Legler, 2021; Yuan *et al.,* 2022). Additionally, it has been discovered that mice's gut microbiota is altered by nano microplastics (NMPs) (Brachner *et al.,* 2020). While Zhang *et al.* (2018) reported finding plastic pieces in the placenta of mice, Wright and Kelly (2017) also reported finding PVC materials in the portal vein of dogs, suggesting that MPs may interact with the human reproductive system.

Research gaps in microplastics pollution in aquatic environments and its impact on human health, especially in Nigeria.

Insufficient information regarding human exposure and risk to MPs suggests important knowledge gaps that should be addressed in order to better understand the possible effects of MPs on human health. The reason for this is that Nigeria lacks the analytical tools necessary to sample, isolate, detect, measure, and characterise microplastics (Pantil *et al.,* 2022; Alimi *et al.,* 2021). Fish consumption of microplastics in Nigeria's aquatic ecosystem has not received much attention, and the few studies that have been conducted have mostly focused on the marine environment (Aragaw, 2021). Therefore, research on the impact of plastic contamination on Nigeria's freshwater resources is lacking.

The lack of data on the consumption of MPs in the aquatic food chain could also help identify lower-risk species. Furthermore, there is a knowledge gap on MPs quantification in fishmeal. MPs' detrimental effects on marine life are understudied and the potential effect of MPs on human health, especially through ingestion, is still under-explored. This includes its effect on the DNA, gastrointestinal tract (GIT), kidney, liver, heart, and other organs.

In addition, in vitro data on MPs ingestion by fish is still understudied in Nigeria. Research gaps regarding the distribution, absorption, metabolism, and excretion of MPs in aquatic organisms and humans also exist. To check for microplastics and nanoplastics overcoming biological barriers and exposing their main absorption pathways, sophisticated cell culture models should be created. Health risk assessment of MPs ingestion using mathematical models to determine its carcinogenic effects is still under study, owing to the unavailability of relevant reference materials, lack of definitions, analytical obstacles, and standardized study designs. There's therefore a need for policymakers and researchers to emphasize the urgency and importance of studying MPs in Nigeria. To address these study gaps in Nigeria, researchers need to include more studies on microplastics pollution in the aquatic environment in grant proposals. Policymakers and the government also need to fund universities to provide the equipment that can analyse and quantify MPs.

Conclusion

Plastic particle pollution in the aquatic environment is an area of concern to environmental scientists. MPs have been reported to reach both freshwater and marine habitats through runoffs, wastewater discharge and wind movement of plastic particles. Aquatic organisms, including fish, accumulate MPs from sediments and water in their gills and gastrointestinal tract and spread them to other tissues resulting in debilitating effects on fish and humans who consumed the fish. Hence, efficient waste management methods are important to save the fish and humans from chronic illnesses resulting from MPs pollution in the aquatic environment.

References

Abiodun, O. A., Osuala, F. I., Otitoloju, A. A., Fotsing, C. M. and Ndinteh, D. T. (2019). Micropellet Particles: A Vector of Hydrophobic Endocrine Disrupting Chemicals in Lagos Lagoon. *Current J. Appl. Sci. Tech*. 36, 1. doi:10.9734/cjast/2019/v36i630262. Assessed on 15th June, 2023

Adeogun, A. O., Ibor, O. R., Khan, E. A., Chukwuka, A. V., Omogbemi, E. D., Arukwe, A. (2020). Detection and occurrence of microplastics in the stomach of commercial fish species from a municipal water supply lake in southwestern Nigeria. *Environ. Sci. Pollut. Res. Int.* 27(25):31035-31045.

Alimi, O. S., Fadare, O. O., Okoffo, E. D. (2021). Microplastics in African ecosystems: Current knowledge, abundance, associated contaminants, techniques, and research needs. *Science of the Total Environment,* Volume 755, Part 1, 142422. https://doi.org/10.1016/j.scitotenv.2020.142422.

Amadi, L. O., Nosayame, T. O. and Williams, J. O. (2020). Assimilation of Microplastics and Bacteria Associated with the Organs of Wild Mullet Harvested from an Estuary in Rivers State, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT*. www.iosrjournals.org. DOI: 10.9790/2402 (accessed July 14 2023).

Amato-Lourenço, L. F., Galvão, L. S., Weger, L. A., Hiemstra, P. S., Vijver, M. G., Mauad, T. (2020). An emerging class of air pollutants: Potential effects of microplastics to respiratory human health? *Science of the Total Environment* 749, 141676.

Aragaw, T.A. (2021) Microplastic pollution in African countries' water systems: a review on findings, applied methods, characteristics, impacts, and managements. *SN Appl. Sci.* 3, 629. https://doi.org/10.1007/s42452-021-04619-z.

Azzoni, R. S, Ambrosini, R., Pittino, F. (2019). First evidence of microplastic contamination in the supraglacial debris of an Alpine glacier. *Geophys Res Abs* 21: EGU2019-7100, https:// meetingorganizer. copernicus.org/EGU2019/EGU2019-7100.pdf (2019, accessed 4 May 2023).

Bahadur, P. K. C., Maharjan, A., Acharya, M., Lee, D., Kusma, S., Gautam, R., Kwon, J., Kim, C., Kim, K., Kim, H., Heo, Y. (2023). Polytetrafluorethylene microplastic particles mediated oxidative stress, inflammation, and intracellular signaling pathway alteration in human derived cell lines. *Science of the Total Environment,* 897,165295. https://doi.org/10.1016/j.scitotenv.2023.165295.

Bhuyan, M. S. (2022). Effects of Microplastics on Fish and in Human Health. *Front. Environ. Sci.* 10:827289. doi: 10.3389/fenvs.2022.827289

Blackburn, K. and Green, D. (2021). The potential effects of microplastics on human health: What is known and what is unknown. https://doi.org/10.1007/s13280-021-01589-9. Assessed March 1st 2023.

Brachner, A., Fragouli, D., Duarte, I. F., Patricia, M. A., Dembski, S., Ghosh, M., Barisic, I., Zdzieblo, D., Vanoirbeek, J., Schwabl, P., and Neuhaus, W. (2020). Assessment of human health risks posed by nano-and microplastics is currently not feasible. *Int. J. Environ. Res. Public Health* 17(23): 8832; https://doi.org/10.3390/ijerph17238832

Cai, L.,Wang, J.,Peng, J., Tan, Z., Zhan, Z., Tan, X., and Chen Q. (2017). Characteristic of microplastics in the atmospheric fallout from Dongguan city, China: preliminary research and first evidence. *Environ. Sci. Pollut. Res*. 24, 24928–24935.

Chaukura, N., Kefeni, K. K., Chikurunhe, I., Nyambiya, I., Gwenzi, W., Moyo, W., Nkambule, T.T., Mamba, B. B., and, Abulude, F. O. (2021). Microplastics in the aquatic environment—the occurrence, sources, ecological impacts, fate, and remediation challenges. *Pollutants*, 1(2), 95-118; https://doi.org/10.3390/pollutants1020009

Covernton, G. A., Collicutt, B., Gurney-Smith, H. J., Pearce, C. M., Dower, J. F., Ross, P. S. and Dudas, S. E. (2019). Microplastics in bivalves and their habitat in relation to shellfish aquaculture proximity in coastal British Columbia, Canada. *Aquaculture Environment Interactions, 11,* 357-374.

Crooks, N., Parker, H. and, Pernetta, A. P., (2019). Brain food? trophic transfer and tissue retention of microplastics by the velvet swimming crab (*Necora puber*). *J. Exp. Mar. Biol. Ecol.* 519, 151187.

Dada, O. A. and, Bello, J. O. (2023). Microplastics in carnivorous fish species, water and sediments of a coastal urban lagoon in Nigeria**.** *Environ. Sci. Pollut. Res. Int.* 30 (19):55948-55957.

De-La-Torre G. E. (2020). Microplastics: an emerging threat to food security and human health. *Journal of Food Science and Technology –Mysore* 57:1601–1608. doi: 10.1007/s11356-023-26410-w.

Domenech, J. and Marcos R. (2021). Pathways of Human Exposure to Microplastics, and Estimation of the Total Burden. *Current Opinion in Food Science* 39:144–151.

Dris, R., Gasperi, J., Saad, M., Mirande, C. and, Tassin, B., (2016). Synthetic fibers in atmospheric fallout: a source of microplastics in the environment? *Mar. Pollut. Bull.* 104 (1–2); 290–293.

Du, S., Zhu, R., Cai, Y., Xu, N., Yap, P., Zhang, Y., He, Y. and, Zhang Y. (2021). Environmental fate and impacts of microplastics in aquatic ecosystems: a review. *RSC Adv*. 11, 15762.

Duis, K. and Coors, A. (2016). Microplastics in the Aquatic and Terrestrial Environment: Sources (with a specific focus on personal care products), Fate and Effects. *Environmental Sciences Europe* 28(1):1-25.

Ebere, E. C., Wirnkor, V. A., Ngozi, V. E., Chukwuemeka, I. S. (2019). Macrodebris and microplastics pollution in Nigeria: first report on abundance, distribution and composition. *Environ Anal Health Toxicol*. 34 (4):e2019012-0. doi: 10.5620/eaht.e2019012.

Espinosa, M., Esteban, A., and Cuesta, A. (2016). Microplastics in aquatic environments and their toxicological implications for fish. http://dx.doi.org/10.5772/ (Assessed online on 8th August, 2023).

Fiore, L., Serranti, S., Mazziotti, C., Riccardi, E., Benzi, M., Bonifazi, G. (2022). Classifcation and distribution of freshwater microplastics along the Italian Po river by hyperspectral imaging. *Environmental Science and Pollution Research*, 29:48588–48606.

Gall, S. C. and Thompson, R. C. (2018). The impact of debris on marine life. *Marine Pollution Bulletin,* 9(1): 170-179.

Godoy, V., Blazquez, G, Calero, M., Quesada, L., and Martin-Lara, M. A. (2019). The potential of microplastics as carriers of metals, *Environ. Pollut.,* 255, 113363.

Hartmann, N. B., Huffer, T., Thompson, R. C., Hassellov, M., Verschoor, A., Daugaard, A. E., Rist, S., Karlsson, T., Brennholt, N., Cole, M., Herrling, M. P., Hess, M. C., Ivleva, N. P., Lusher, A. L. and, Wagner, M. (2019). Are we Speaking the Same Language? Recommendations for a Definition and Categorization Framework for Plastic Debris, *Environ. Sci. Technol*., 53, 1039-1047.

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 Sci. and Techno.* 51(12): 7036-7046. doi:10.1021/acs.est.7b01750

Hu, M. and, Palić, D. (2020). Micro- and nanoplastics activation of oxidative and inflammatory adverse outcome pathways, *Redox Biology*, Volume 37, 101620. https://doi.org/10.1016/j.redox.2020.101620.

Iheanacho, S. C., and Odo, G. E. (2020). Neurotoxicity, oxidative stress biomarkers and haematological responses in African catfish (*Clarias gariepinus*) exposed to polyvinyl chloride microparticles. *Comp. Biochem. Physiol. C. Toxicol. Pharmacol.* 232:108741. doi: 10.1016/j.cbpc.2020.108741. Assessed on May 11, 2023.

Ilechukwu, G. I., Ndukwe, B. E., Ehigiator, C. S., Ezeh, S. L., and Asogwa(2021). Ghana J. Sci. 62 (2), , 16 – 24 Microplastics in Silver Catfish (Chrysichthys Nigrodigitatus) From New Calabar River In Niger Delta, Nigeria I.

Iñiguez, M. E., Conesa, J. A. and, Fullana, A. (2017). Microplastics in Spanish Table

Salt. *Sci Rep* **7**, 8620 https://doi.org/10.1038/s41598-017-09128-x.

Issac, M., Kandasubramanian, B. (2021). Effect of Microplastics in Water and Aquatic Systems. *Environ Sci Pollut Res* 28:19544–19562.

Jaafar, N., Azfaralariff, A., Musa, S. M., Mohamed, M., Yusoff, A. and, Lazim, A. (2021). Occurrence, distribution and characteristics of microplastics in gastrointestinal tract and gills of commercial marine fish from Malaysia. *Science of the Total Environment*, 799, 149457. https://doi.org/10.1016/j.scitotenv.2021.149457.

Jabeen, K., Su, L. and, Li, J. N. (2017). Microplastics and mesoplastics in fish from coastal and fresh waters of China. *Environ Pollut*. 221:141–149.

Jaibachi, R., Cuthbert, R. N. and Callaghan, A. (2018). Up and away: ontogenic transference as a pathway for aerial dispersal of microplastics. *Biol Lett*; 14(9): 479-485.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., and, Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science* 347 (6223): 768-771 DOI: 10.1126/science.12603.

Kaloyianni, M., Bobori, D. C., Xanthopoulou, D., Malioufa, G., Sampsonidis, I., Kalogiannis, S., Feidantsis, K., Kastrinaki, G., Dimitriadi, A., Koumoundouros, G., Lambropoulou, D. A., Kyzas, G. Z., Bikiaris, D. N. (2021).Toxicity and functional tissue responses of two freshwater fish after exposure to polystyrene microplastics. *Toxics* 9 (11):289. doi: 10.3390/toxics9110289. PMID: 34822680; PMCID: PMC8625933.

Karami, A., Golieskardi, A., Keong Choo, C., Larat, V., Galloway, T. S., Salamatinia, B. (2017). The presence of microplastics in commercial salts from different countries. *Sci Rep* **7**, 46173. https://doi.org/10.1038/srep46173.

Karbalaei, S., Golieskardi, A., Hamzah, H., Abdulwahid, S., Hanachi, P., Walker, T. R., and Karami, A. (2019). Abundance and characteristics of microplastics in commercial marine fish from Malaysia. *Marine Pollution Bulletin*, 148, 5-15. https://doi.org/10.1016/j.marpolbul.2019.07.072.

Kim, J., Lee, H., Kim, S. and, Kim, H. (2018). Global Pattern of Microplastics (MPs) in Commercial Food-Grade Salts: Sea Salt as an Indicator of Seawater MP Pollution. *Environ. Sci. Technol.* 2018, 52, 21, 12819–12828.

Koongolla, J. B., Lin, L., Pan, Y., Yang, C., Sun, D., Liu, S., Xu, X., Maharana, D., Huang, J., Li, H. (2020). Occurrence of microplastics in gastrointestinal tracts and gills of fish from Beibu Gulf, South China Sea. *Environmental Pollution,* 258, 113734. https://doi.org/10.1016/j.envpol.2019.113734.

Lee, H., Kunz, A., Shim, W. J. and, Walther, B. A. (2019). Microplastic contamination of table salts from Taiwan, including a global review. *Sci. Rep*. 9 (1): 1–9.

Li, C., Busquets R., Campos L. C. (2019). Assessment of microplastics in freshwater systems: A review. *Sci. Total Environ*. doi: 10.1016/j.scitotenv.2019.135578.

Liu, K.,Wang, X., Fang, T., Xu, P., Zhu, L. and Li, D. (2019). Source and potential risk assessment of suspended atmospheric microplastics in Shanghai. *Sci. Total Environ*. 675, 462–471. https://doi.org/10.1016/j.scitotenv.2019.04.110 (Assessed Apr 9, 2023).

Magni, S., Gagne, F., Andre, C., Della, T.C., Auclair, J., Hanana, H., Parenti, C.C., Bonasoro, F. and, Binelli, A., (2018). Evaluation of uptake and chronic toxicity of virgin polystyrene microbeads in freshwater zebra mussel *Dreissena polymorpha* (Mollusca: bivalvia). *Sci. Total Environ*. 631–632: 778–788.

Mammo, F. K., Amoah, I. D., Gani, K. M., Pillay, L., Ratha, S. K., Bux, F. and Kumari, S. (2020). Microplastics in the environment: Interactions with microbes and chemical contaminants, *Sci. Total Environ*., 743, 140518.

Meaza, I., Toyoda, J., Wise, J.P. (2020). Microplastics in Sea Turtles, Marine Mammals and Humans: A One Environmental Health Perspective. Available Online at https://doi.org/10.3389/fenvs.2020.575614. Assessed on 25th March, 2023.

Mintenig, S. M., Löder, M. G., Primpke, S. and, Gerdts, G. (2018). Low numbers of microplastics detected in drinking water from ground water sources. *Science of the Total Environment,* 648, 631–635.

Mu, H., Wang, Y., Zhang, H., Guo, F., Li, A., Zhang, S., Liu, S. and Liu, T. (2022). High abundance of microplastics in groundwater in Jiaodong Peninsula, China. *Science of the Total Environment*, 839, 156318.

Obebe, S. B. and Adamu, A. A. (2020). Plastic pollution: causes, effects and preventions. *International Journal of Engineering Applied Sciences and Technology,* Vol. 4, Issue 12, ISSN No. 2455-2143, Pages 85-95.

Olarinmoye, O. M., Stock, F., Scherf, N., Whenu, O. O., Asenime C. E. and, Ganzallo, S. (2020). Microplastic Presence in Sediment and Water of a Lagoon Bordering the Urban Agglomeration of Lagos, Southwest Nigeria. *Geosciences* 10, 494. doi:10.3390/geosciences10120494. Assessed on 8th May, 2023.

Oni, B. A., and Sanni, S. E. (2022). Occurrence of microplastics in borehole drinking water and sediments in Lagos, Nigeria**.** *Environmental Toxicology and Chemistry Journal* 41(7); 1721-1731. https://doi.org/10.1002/etc.5350.

Patil, S. M., Rane, N. R., Bankole, P. O., Krishnaiah, P., Ahn, Y., Park, Y., Yadav, K. K., Amin, M. A., Jeon, B. (2022). An assessment of micro- and nanoplastics in the biosphere: A review of detection, monitoring, and remediation technology. *Chemical Engineering Journal,* Volume 430, Part 2, 132913, ISSN 1385-8947,https://doi.org/10.1016/j.cej.2021.132913.

Plastic Europe. (2022). Plastics – the Facts 2022**.** https://plasticseurope.org/knowledge-hub/plastics-the-facts-2022. Assessed on 8th June, 2023.

Prüst, M., Meijer, J., and Remco, H. S. (2020). The plastic brain: neurotoxicity of micro and nanoplastics. *Particle and Fibre Toxicology* 17:24. https://doi.org/10.1186/s12989-020-00358-y

Rhodes, C. J. (2019). Solving the plastic problem. *Science Progress*, Vol. 102 (3): 218-248

Rhodes. C .J. (2018). Plastic pollution and potential solutions. *Sci Prog* 2; 101(3): 207–260.

Rochman, C. M., Tahir, A., Williams, S. L., Baxa, D. V., Lam, R., Miller, J. T., Teh, F. C., Werorilangi, S., and, Teh, S. J. (2015). Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. *Scientific Reports*, 5, 1–10. https://doi.org/10.1038/srep14340

Rubio, L., Marcos, R., and, Hernández, A. (2020). Potential adverse health effects of ingested micro- and nanoplastics on humans. Lessons learned from *in vivo* and *in vitro* mammalian models. *Journal of Toxicology and Environmental Health,* Part B, 23:2, 51-68, DOI: 10.1080/10937404.2019.1700598.

Sana, S. S., Dogiparthi, L. K., Gangadhar, L., Chakravorty, A., and, Abhishek, N. (2020). Effects of microplastics and nanoplastics on marine environment and human health. *Environmental Science and Pollution Research*. Available online at https://doi.org/10.1007/s11356-020-10573-x. Assessed on 15th July, 2023.

Sani, A., Darma, A. I., and Diso, F. A. (2022). Microplastics profile in fishes from selected burrow pits: a case of plastic pollution in Kano metropolis, Nigeria. E*nvironmental Forensics,* Available online at 10.1080/15275922.2022.2125116. Assessed on June 25th, 2023.

Schymanski, D., Goldbeck, C., Humpf, H. U. and, Fürst, P. (2018). Analysis of microplastics in water by micro-Raman spectroscopy: release of plastic particles from different packaging into mineral water. *Water Res*. 129: 154–162.

Sivagami, M., Selvambigai, M., Devan, U., Joseph, A., Velangani, A., Karmegam, N., Biruntha, M., Arun, A., Kim, W., Govarthanan, M., Kumar, P. (2021). Extraction of microplastics from commonly used sea salts in India and their toxicological evaluation. *Chemosphere,* 263, 128181. https://doi.org/10.1016/j.chemosphere.2020.128181.

Smith, M., Love, D.C., and Rochman, C.M. (2018). Microplastics in seafood and the implications for human health. *Curr Envir Health Rpt* 5, 375–386. https://doi.org/10.1007/s40572-018-0206-z

Ta, A. T. and Babel, S. 2020. Microplastic contamination on the lower Chao Phraya: Abundance, characteristic and interaction with heavy metals, *Chemosphere*, 257, 127234.

Tongo, I., and Erhunmwunse, N. O. (2022). Effects of ingestion of polyethylene microplastics on survival rate, opercular respiration rate and swimming performance of African catfish (*Clarias gariepinus*). *J.Hazard Mater* 423(Pt B):127237. Available online at doi: 10.1016/ j.jhazmat.2021.127237. Assessed on 5th September, 2023.

Vethaak, A. D., & Legler, J. (2021). Microplastics and human health. *Science, 371(6530), 672–674.* doi:10.1126/ science.abe5041. Assessed on 23rd May, 2023.

Vivekanand, A. C., Mohapatra, S. and, Tyagi, V. K. (2021). Microplastics in aquatic environment: Challenges and perspectives. *Chemosphere* 282, 131151.

Wagner, M., Scherer, C., Alvarez-Munoz, D., Brennholt, N., Bourrain, X., Buchinger, S., Fries, E., Grosboi, C., Klasmeier, J., Marti, T., Rodriguez-Mozaz, S., Urbatzka, R., Vethaak, A., Winther-Nielsen, M., and, Reifferscheid, G. (2014), Microplastics in freshwater ecosystems: what we know and what we need to know. *Environ. Sci. Eur*. 26, 12. https://doi.org/10.1186/s12302-014-0012-7.

Wan, Z., Wang, C., Zhou, J., Shen, M., Wang, X., Ota, T. and, Jin, Y. (2019). Effects of polystyrene microplastics on the composition of the microbiome and metabolism in larval zebrafish. *Chemosphere*, 217, 646–658.

Wang, T., Wang, L., Chen, Q., Kalogerakis, N., Ji, R., and Ma, Y. (2020). Interactions between microplastics and organic pollutants: Effects on toxicity, bioaccumulation, degradation, and transport. *Sci. Total Environ*. 748, 142427.

Waring, R.H., Harris, H.M., and Mitchell, S.C. (2018). Plastic contamination of the food chain: A threat to human health? *Maturitas 115,* 64-68.

Wright, S. L. and, Kelly, F. J. (2017). Plastic and human health: a micro issue? 2017. *Environ. Sci.Technol.* 5(12): 6634-6647.

Yang, D., Shi, H., Li, L., Li, J., Jabeen, K. and, Kolandhasamy, P. (2015). Microplastic pollution in table salts from China. *Environmental science & technology* 49 (22): 13622–13627.

Yin, X., Wu, J., Liu, Y., Chen, X., Xie, C., Liang, Y., Li, J., Jiang, Z. (2022). Accumulation of microplastics in fish guts and gills from a large natural lake: Selective or non-selective?, *Environmental Pollution,* 309, 119785. https://doi.org/10.1016/j.envpol.2022.119785.

Yong, C. Q. Y., Valiyaveettil, S., Tang, B. L. (2020). Toxicity of Microplastics and Nanoplastics in Mammalian Systems. *Int. J. Environ. Res. Public Health, 17, 1509.* https://doi.org/10.3390/ijerph17051509

Yuan, Z., Nag, R., and Cummins, E. (2022). Human health concerns regarding microplastics in the aquatic environment -From marine to food systems. *Science of the Total Environment,* 823, 153730.

Zhang, C., Wang, J., Zhou, A., Ye, Q., Feng, T., Wang, Z., Wang, S., Xu, G., Zou, J. (2021). Species-specific effect of microplastics on fish embryos and observation of toxicity kinetics in larvae. *Journal of Hazardous Materials* 403, 123948

Zhang, Y., Wu, J., Eng., X. F.,Wang, R., Chen, A., and, Shao, L. (2018). Current understanding of the toxicological risk posed on the fetus following maternal exposure to nanoparticles. *Exp. Opin. Drug Metab. Toxicol.* 13(12): 1251-1263.