CORPUS PUBLISHERS

Current Trends in Engineering Science (CTES)

ISSN: 2833-356X

Volume 3 Issue 1, 2023

Article Information

Received date : January 10, 2023

Published date: February 14, 2023

***Corresponding author**

Olugbenga Olamigoke, Department of Chemical and Petroleum Engineering, University of Lagos, Lagos, Nigeria

DOI: 10.54026/CTES/1022

Keywords

Microplastics; Marine environments; Microplastic concentration; Deep-sea sediments; Gulf of Guinea

Mini Review

The Presence of Microplastics in Ocean Waters and Deep Marine Sediments: Implications for the Gulf of Guinea

Olugbenga Olamigoke*

Department of Chemical and Petroleum Engineering, University of Lagos, Lagos, Nigeria

Abstract

Microplastics are ubiquitous in marine environments as they are found in surface waters, across the water column and in deep-sea sediments. Microplastics could adversely affect marine biota on a cellular level by stretching lipid membranes thereby shortening the lifespan of the organism. The ingestion of microplastics has been reported among larger animals with the risk of neurotoxicity and genotoxicity. In this paper, the likely mechanisms determining distribution and abundance of microplastics in ocean waters and deep-sea sediments have been reviewed. While deep-sea sediment cores reveal high microplastic concentration in ocean trenches and submarine canyons, limited data is available on the abundance of microplastics especially in the Gulf of Guinea. The need for monitoring microplastic concentration and more importantly preventing further transport from land sources is expedient.

Introduction

Plastic is the most visible ocean pollutant with rapidly increasing presence in marine environments. It has been estimated that about 10 million metric tons of plastic waste accumulate in there annually [1]. Plastic waste in oceans is recognized as a global threat negatively impacting wildlife, tourism, and shipping [2]. There are several sources of plastic pollution and different pathways through which plastics get into oceans. Most of the waste plastic (75% to 90%) is from land sources primarily from poorly handled wastes from households and industrial activity. Maritime activities such as fishing vessels and cruise ships are the source of the remaining waste. The dominant pathway for plastics transport into oceans are rivers with debris entering channels via stormwater runoff, wastewater effluent or catastrophic events. Though large debris such as abandoned fishing nets constitute a significant percentage by weight of plastic waste floating in oceans around the world, microplastics are by far the more abundant [3-5].

The term "microplastics" was coined to describe small synthetic solid polymeric particles in form of either fragments or fibers with average size distribution ranging from 0.1μm to 5mm [6,7]. Microplastics are water insoluble particles which are either spherical or non-spherical in shape primarily manufactured to this size in the form of microbeads, pre-produced pellets, fibers, and granules. They are widely used in different industrial processes such as 3D-printing for cosmetic purposes and for tissue-specific drug delivery [1,8]. In addition to primary microplastics, secondary microplastics are generated from weathered, mechanically abraded or photo-degenerated larger sized plastic waste. This degradation of plastic waste via biological and chemical processes gradually increases the concentration of microplastics in marine environments [1,9]. In the process, components such as starch are biodegraded leaving behind non-degradable microplastic fragments; degradation is a function of both the core material and the prevailing weathering conditions [1,10].

Some toxic chemicals additives which are incorporated into microplastics at manufacture such as phthalates, antioxidants, brominated flame retardants, ultraviolet stabilizers, and pigments give the plastics specific characteristics such as flexibility, ultraviolet protection, water repellence and colour. These additives could constitute based on total weight as high as 60% of any plastic product. In addition, microplastics can absorb toxic chemicals from the marine environment such as polycyclic aromatic hydrocarbons, polybrominated biphenyls and dichlorodiphenyltrichloroethane [1]. Thus, microplastics adversely affect biological systems of different organisms leading to neurotoxicity, and genotoxicity. There is reduced feeding, filtration, reproductive ability, and consequently reduced survival of marine organisms [11]. Through a combination of experiments using microbeads and phenomenological modelling, it has been inferred that microplastics could limit the life span of organism even at cellular level with adsorption of microplastics resulting in the stretching of lipid cell membranes. The increased tension is beyond what can be relived naturally thus lengthening and weakening cell membranes [12]. The smaller the size of the microplastics the higher the potential for ingestion by zooplankton and phytoplankton. It was observed that plankton such as rotifers, cladocerans, and copepods can ingest fluorescent plastics with diameter between 0.1 and 9.9μm diameter. Microplastics have been found in the digestive system of larger animals. There were significant changes in the fish that ingested micro- and nano-sized polystyrene particles in terms of body weight, cholesterol content in muscle and liver, serum triglyceride to cholesterol ratio, and other metabolic parameters [13]. Microplastic particles were found in the feces of sea turtles in the Northwestern Adriatic Sea with an average of 0.2g in each sample [14]. It is recorded that as high as 700 aquatic species have been negatively affected by microplastics including penguins and different crustaceans globally [15].

Discussion

The distribution of microplastics in ocean waters

Reconciling the plastic waste that has been transported into the oceans to the proportion sampled in the waters globally reveals a large discrepancy in ocean plastic budget [2]. It was estimated using marine debris data obtained from plankton net trawling and ocean circulation modelling studies that microplastics floating on the surface of oceans in 2014 around the world range from 15 to 51 trillion particles which translate to between 93 and 236 thousand metric tons. These estimates only account for about 1% of all plastics that have entered the oceans from predominantly land-based sources [16]. Of this percentage, some of these plastic particles have been found in large patches in oceans across the globe. Using the Lagrangian numerical modelling and confirmed by sampling expeditions across the world, large accumulations of the plastic waste have been identified in convergence zones of the five subtropical gyres across all oceanic regions namely the North and South Pacific, North and South Atlantic, and Indian Oceans. Though the plastic waste concentration across these five gyres were comparable, the North Pacific Ocean contributed about 34% to the global plastic load due to both the large size of the gyre and the high human population on the Asian eastern coast which constitutes a third of the global coastal population [17]. In a later study conducted between 2017 and 2018 in which 96 samples were taken across the world from ocean waters, the maximum microplastic concentration in the survey was about 350 particles per m^3 with an average abundance of 50 particles per m^3. The highest concentrations of microplastic waste were sampled off West Tropical North Atlantic Ocean, the Western Mediterranean and the Gulf of Cadiz with concentrations which ranged from 180 to 349 particles per m^3 [18]. Contrary to the suggestion of a potential for a sixth accumulation zone within the Barents Sea in the Arctic Ocean [19], simulations based on a Eulerian approach have shown that the high likelihood of a plastic accumulation in the Gulf of Guinea, with high inputs from Nigeria. The formation of a large anticyclonic gyre due to the combination of the Guinea and Angola currents travelling northward provide a zone for positively buoyant plastic particles to be trapped and accumulate [20]. Microplastics are moved throughout oceans by prevailing winds and surface currents such that the number of plastics found in the southern hemisphere are within a similar range of those in the northern hemisphere which has higher inputs from land sources [1,3,6]. Thus winds, tides, wave currents and cyclones provide alternate pathways (to rivers and storm-water run-off) for plastic waste entering the ocean and largely define microplastic distribution across marine environments [4-5,21].

Microplastics have been sampled widely in surface waters of oceans around the world. Large concentrations of microplastic debris have been detected even outside the subtropical gyres. These concentrations vary with the mode of sample collection, extraction, spectroscopic analysis, and the units reported. The particle size distribution of microplastics in ocean surface waters (as accounted for from sampling) is highly skewed to much smaller particle sizes with a significant proportion between 150 and 500μm [6,22-24]. To further underscore this, microplastics sampled with 100μm mesh in the coastal waters of Gulf of Maine and the western English Channel (off the Northern Atlantic Ocean) showed a 2.5-fold increase in concentration as compared to standard sampling with 330μm mesh [25]. Examination of the particle size distribution of plastic waste floating on ocean surface waters shows that the distribution follows a power law for particles larger than about 1mm such that the relative abundance of debris declines with size with a pronounced gap is noticed below 1mm [17,22]. This maximum particle size has been observed to vary, with the distance to the nearest coast been a determinant [23]. It has been hypothesized that the gap in size distribution of floating plastic debris as compared to input rates is due to several mechanisms: nano-fragmentation, sedimentation, shore deposition, and biological uptake [17,23,24].

The microplastic concentration in deep-sea sediments

Microplastics are not limited to surface waters, as there is evidence to show that deep-sea sediments are the likely sink for microplastics [2]. They are found across entire ocean water columns and in underlying sediments [5,10,26]. The presence of microplastics had been identified as early as year 2004 among sediments collected from estuarine and subtidal sediments in the vicinity of Plymouth, UK with Fourier Transform infrared (FT-IR) spectroscopy. Microplastics were found in archived plankton samples collected along sea routes between Aberdeen, Shetlands, Sule Skerry and Iceland over a cumulative distance of 1165 km from the 1960s. It was discovered that there was significant increase in microplastic concentration over time with similar polymer types found in both the sediments and the water columns. Thus, polymer density is not the sole determinant of microplastic distribution in the ocean water column [10]. This is because the buoyancy of microplastics is influenced by other factors such as biofouling and ingestion by benthic organisms. The sinking of microplastics to the seabed has been attributed to biofouling by benthic organisms as 77% of the plastic items retrieved from the South African continental shelf by trawls consisted of polymers less dense than seawater once cleaned up [27,28]. Thus, it has been inferred that the two major determinants of the debris path and destination are microplastic density and biofilm thickness [29]. The sinking of microplastics is further facilitated by the adherence of organic detritus and in particular the ingestion by zooplankton which forage at night in surface waters then migrate to great depths during the day thereby increasing the presence of microplastics in marine sediments [17,22,23]. Using mathematical modeling and numerical simulations, it was shown that bio-fouled buoyant microplastics tend to oscillate vertically in a well-mixed ocean with particle depth being a function of algal growth and their sensitivity to the penetration of light intensity. The period and characteristics of the oscillation profile are dependent on the particle size which vary from a few hours to tens of days. In a stratified ocean bio-fouled debris do not return to surface waters but rather oscillate within a plastic trapping layer deep with the ocean due to interaction with density changes within the ocean water column [30].

A few deep-sea sediment sampling studies have proven the accumulation of microplastics at the sampled depths. Microplastic were extracted from 11 sediment samples obtained from locations in the North Atlantic Ocean, Southern Ocean, Gulf of Guinea, and the Mediterranean Sea. Sampling depths ranged from 1176 to 4844m. Average microplastic concentration was 1 particle per 50cm^3 (20 pieces per L) with particle size diameter between 0.075 and 0.161mm and less than 0.137mm in length. This study was able to show that microplastics are present in the top sediment of the ocean floor. The detection of microplastics was however impeded by high organic content in the samples. One of the key inferences from this study is that microplastic concentration is much higher in coastal sediments as compared to shelf and deep-sea sediments [31]. Fibrous microplastics were identified from cores collected between 2001 and 2012 across the Mediterranean Sea, Southwestern Indian Ocean and Northeastern Atlantic Ocean from depths ranging from 300 to 3500m. The microplastics, typically 2 to 3mm in length and less than 0.1mm in diameter, were abundant in all sediment samples ranging from 1.4 to 40 particles per 50ml of sampled sediment (28 to 400 pieces/L). Rayon, a synthetic non-plastic polymer was found in all the samples contributing 56.9% of the fibers while polyester which was half as abundant contributed 53.4% of the plastic content [2]. There was an abundance of microplastics with 44.43 to 3394.63 pieces/L in nine samples taken from deep-sea Artic sediments in the Hausgarten observatory at a depth of 2340 to 5570m. This is equivalent to a microplastic concentration of 0.042 to 6.59 particles per gram. Sea ice was considered the possible means of microplastic transport as the stations closest to the North Pole had the highest concentration of microplastics. Chlorinated polyethylene, polyamide and polypropylene constituted 38%, 22% and 16% of the microplastic in the deep sediments respectively. While no significant correlation could be established between microplastic presence and depth, both microplastic presence and polymer diversity were positively correlated with chlorophyll content indicating that biofouling is at play [32]. The presence of microplastics in deep sediments of the Arctic Ocean was further confirmed via 11 core samples retrieved in 2016 between 855 and 4353 m with a mix of synthetic polymers detected in form of fibers and fragments with maximum concentration of 0.5 particles per gram dry sediment. This study was however limited by the analytical technique which most likely resulted in low microplastic detection [33]. Microplastics were identified in halal sediments of the Mariana Trench located in the western Pacific Ocean with a concentration of 200 to 2200 pieces per L which is equivalent to 0.27 to 6.20 particles per gram from depths ranging from 5108 to 10908m. The microplastics in the sediment samples are varied in shape with some fibrous in nature with the others spherical and rod-like. The abundance of microplastics in the deep sediments were much higher than that sampled in surface waters with concentration of 2.06 to 13.51 pieces/L. The high microplastic concentration at the bottom waters of the Mariana trench is comparable to the reported concentration in some heavily polluted coastal waters [34]. The highest microplastic concentration in sampled deep-sea sediments is in submarine canyons and ocean trenches. It has been opined that the continental shelf serves as a conduit especially for highstand sea-level conditions with the configurations shelf and slope major determinants of microplastic transport from the land to the ocean [35,36].

Conclusion

The role of microplastics as potential tracers within sediments has been recognized such that the presence of microplastics can be radiometrically dated to a period after the production of plastics began industrially (typically the 1950s). This provides a veritable tool for studying the deposition of deep-sea sediments and the dynamics of ocean processes. However, fibers have been found in sediment cores dated to more than 100 years prior to this period for which the migration of groundwater with microplastics has suspected to be primarily responsible [35,37].

Technologies for handling microplastic pollution in marine environments have been considered from two perspectives: prevention of debris into waterways and collection of accumulated microplastic waste. As regards prevention, existing technologies address the removal of microplastics from wastewater using filters fitted to effluent streams which capture microfibers. As regards removal of microplastics two solutions have been proffered - the use of fine mesh for microplastic debris removal from beaches and a mixture of oil and magnetite unto which the microplastics bind in the presence of a magnetitic field [38]. The use of spaceborne measurements for the detection and imaging of microplastic concentration has been proposed as it correlates well with the degree to which the roughening of ocean surface by winds is suppressed [39].

While there is evidence of microplastic abundance in deep-sea sediments, further sampling is necessary to confirm basin-wide microplastic presence. The depositional environment must be considered as some cores retrieved at depths beyond 3000 m have shown microplastic presence. The only deep-sea core sample taken from the Gulf of Guinea revealed no presence of microplastics [2]. It should be noted however that shore sediment samples obtained along the Lagos Lagoon (Gulf of Guinea) revealed a microplastic abundance of 310 – 2319 particles/kg [40] which is higher than microplastic presence in beach sediments obtained across Asia, Europe, and North America except for some sampled sediments in the North Sea [41]. This is even more important because the microplastic fragments were contaminated with phthalic esters which pose significant ecological risk to biota [42].

Acknowledgment

Sincere gratitude goes to the Department of Chemical and Petroleum Engineering, University of Lagos for their support towards the completion of this work.

Conflict of interest

The author states that there is no conflict of interest in this work. No funding grant was used in carrying out this work.

References

1. Landrigan PJ, Stegeman JJ, Fleming LE, Allemand D, Anderson DM, et al. (2020) Human Health and Ocean Pollution. Annals of Global Health 86(1): 1-64.
2. Woodall LC, Sanchez VA, Canals M, Paterson GLJ, Coppock R, et al. (2014) The deep sea is a major sink for microplastic debris. R Soc open sci 1(4): 140317.
3. Rochman CM (2020) The story of plastic pollution: From the distant ocean gyres to the global policy stage. Oceanography 33(3): 60-70.
4. Lebreton L, Slat B, Ferrari F, Sainte RB, Aitken J, et al. (2018) Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific Reports 8(1): 4666.
5. Law KL (2017) Plastics in the marine environment. Annual Review of Marine Science 9(1): 205-229.
6. Eriksen M, Lebreton LCM, Carson HS, Thiel M, Moore CJ, et al. (2014) Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. PLoS ONE 9(12): e111913.
7. Andrady AL (2011) Microplastics in the marine environment. Marine Pollution Bulletin 62(8): 1596-1605.
8. Kerubo JO, Muthumbi AW, Onyari JM, Kimani EN, Robertson AD (2020) Microplastic pollution in the surface waters of creeks along the Kenyan coast, Western Indian Ocean (WIO). WIO Journal of Marine Science 19(2): 75-88.
9. Halle A, Landrat L, Gendre X, Goudouneche D, Pusineri C, et al. (2016) Understanding the fragmentation pattern of marine plastic debris. Environmental Science and Technology 50(11): 5668-5675.
10. Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, et al. (2004) Lost at sea: Where is all the plastic? Science 304(5672): 838.
11. Amelia TSM, Khalik WMAWM, Ong MC, Shao YT, Pan H, et al. (2021) Marine microplastics as vectors of major ocean pollutants and its hazards to the marine ecosystem and humans. Progress in Earth and Planetary Science 8: 12.
12. Fleury JB, Baulin VA (2021) Microplastics destabilize lipid membranes by mechanical stretching. PNAS 118(31): e2104610118.
13. Li Y, Sun Y, Li J, Tang R, Miu Y, et al. (2021) Research on the Influence of Microplastics on Marine Life. IOP Conf Ser Earth Environ Sci 631: 012006.
14. Biagi E, Musella M, Palladino G, Angelini V, Pari S, et al. (2021) Impact of Plastic Debris on the Gut Microbiota of Caretta caretta From Northwestern Adriatic Sea. Front Mar Sci 8: 637030.
15. Marn N, Jusup M, Kooijman SALM, Klanjscek T (2020) Quantifying impacts of plastic debris on marine wildlife identifies ecological breakpoints. Ecol Lett 23(10): 1479-1487.
16. Van SE, Wilcox C, Lebreton L, Maximenko N, Hardesty BD, et al. (2015) A global inventory of small floating plastic debris. Environmental Research Letters 10(12): 124006.
17. Cózar A, Echevarría F, González GJI, Irigoien X, Úbeda B, et al. (2014) Plastic debris in the open ocean. Proceedings of the National Academy of Sciences of the United States of America 111(28): 10239–10244.
18. Tanhua T, Gutekunst SB, Biastoch A (2020) A near-synoptic survey of ocean microplastic concentration along an around-the world sailing race. PLoS ONE 15(12): e0243203.
19. Van Sebille E, England MH, Froyland G (2012) Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. Environmental Research Letters 7(4): 044040.
20. Mountford AS, Morales MMA (2019) Eulerian Modeling of the Three-Dimensional Distribution of Seven Popular Microplastic Types in the Global Ocean. Journal of Geophysical Research: Oceans 124(12): 8558-8573.
21. Lorenz C, Roscher L, Meyer MS, Hildebrandt L, Prume J, et al. (2019) Spatial distribution of microplastics in sediments and surface waters of the southern North Sea. Environmental Pollution 252: 1719-1729.
22. Alfaro NA, Astorga D, Cáceres FL, Bastidas L, Villegas CS, et al. (2021) Microplastic pollution in seawater and marine organisms across the Tropical Eastern Pacific and Galápagos. Sci Rep 11(1): 6424.
23. Kaandorp MLA, Dijkstra HA, Van Sebille E (2021) Modelling size distributions of marine plastics under the influence of continuous cascading fragmentation. Environ Res Lett 16: 054075.
24. Aoki K, Furue R (2021) A model for the size distribution of marine microplastics: A statistical mechanics approach. PLoS ONE 16(11): 1-19.
25. Lindeque PK, Cole M, Coppock RL, Lewis CN, Miller RZ, et al. (2020) Are we underestimating microplastic abundance in the marine environment? A comparison of microplastic capture with nets of different mesh-size. Environmental Pollution 265: 114721.
26. Zhou Q, Zhang H, Fu C, Zhou Y, Dai Z, et al. (2018) The distribution and morphology of microplastics in coastal soils adjacent to the Bohai Sea and the Yellow Sea. Geoderma 322: 201-208.
27. Lebreton L, Egger M, Slat B (2019) A global mass budget for positively buoyant macroplastic debris in the ocean. Sci Rep 9: 1-10.
28. Ryan PG, Weideman EA, Perold V, Durholz D, Fairweather TP (2020) A trawl survey of seabed macrolitter on the South African continental shelf. Mar Pollut Bull 150: 1-6.
29. Jalon RI, Wang XH, Fredj E (2019) A 3d numerical model to track marine plastic debris (trackmpd): Sensitivity of microplastic trajectories and fates to particle dynamical properties and physical processes. Mar Pollut. Bull 141: 256-272.
30. Kreczak H, Willmott AJ, Baggaley AW (2021) Subsurface dynamics of buoyant microplastics subject to algal biofouling. Limnol Oceanogr 66(9): 3287-3299.
31. Van Cauwenberghe L, Vanreusel A, Mees J, Janssen CR (2013) Microplastic pollution in deep-sea sediments. Environ Pollut 182: 495-499.
32. Bergmann M, Wirzberger V, Krumpen T, Lorenz C, Primpke S, et al. (2017) High quantities of microplastic in Arctic deep-sea sediments from the HAUSGARTEN observatory. Environ Sci Technol 51(19): 11000-11010.
33. Kanhai LDK, Johansson C, Frias JPGL, Gardfeldt K, Thompson RC, et al. (2019) Deep sea sediments of the Arctic Central Basin: A potential sink for microplastics. Deep-sea Research Part I 145: 137-142.
34. Peng X, Chen M, Chen S, Dasgupta S, Xu H, et al. (2018) Microplastics contaminate the deepest part of the world's ocean. Geochem. Persp Let 9: 1-5.
35. Harris PT (2020) The fate of microplastic in marine sedimentary environments: A review and synthesis. Marine Pollution Bulletin 158: 1-25.
36. Kane IA, Clare MA (2019) Dispersion, accumulation, and the ultimate fate of microplastics in deep-marine environments: a review and future directions. Front Earth Sci 7(80): 1-27.
37. Van Sebille E, Aliani S, Law KL, Maximenko N, Alsina JM, et al. (2020) The physical oceanography of the transport of floating marine debris. Environmental Research Letters 15(2): 023003.

38. Schmaltz E, Melvin EC, Diana Z, Gunady EF, Rittschof D, et al. (2020) Plastic pollution solutions: emerging technologies to prevent and collect marine plastic pollution. Environment International 144: 106067.

39. Evans MC, Ruf CS (2022) Toward the Detection and Imaging of Ocean Microplastics with a Spaceborne Radar. IEEE Transactions on Geoscience and Remote Sensing 60: 1-9.

40. Olarinmoye OM, Stock F, Scherf N, Whenu O, Asenime C, et al. (2020) Microplastic Presence in Sediment and Water of a Lagoon Bordering the Urban Agglomeration of Lagos. Southwest Nigeria. Geosciences 10(494): 1-14.

41. Hamid FS, Bhatti MS, Anuar N, Anuar N, Mohan P, et al. (2018) Worldwide distribution and abundance of microplastic: How dire is the situation? Waste Management & Research 36(10): 873-897.

42. Benson NU, Fred AOH (2020) Occurrence and distribution of microplastics-sorbed phthalic acid esters (PAEs) in coastal psammitic sediments of tropical Atlantic Ocean, Gulf of Guinea. Science of the Total Environment 730: 1-12.