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Microplastics in Freshwater Environments and Implications for Aquatic Ecosystems: A Mini Review and Future Directions in Ghana

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Abstract

Microplastics have a constant effect on aquatic life and are constantly being researched, they have been gradually observed and analysed in marine and freshwater ecosystems, and possible effects in freshwater ecosystems are rising in importance. A literature review has been completed to outline the present state of awareness of microplastics in freshwater ecosystems in Ghana; in particular, the environmental fate, sources, effects in aquatic life and implications on their environments. Although we found that there was a dramatic increase in research and publications on these subjects, relatively few studies had examined the sources, fate and impacts of microplastics in the water bodies of Ghana and there was insufficient data on the extent of microplastics in freshwaters in Ghana. Studies in which Ghanaian waterbodies had quantified microplastics were considered of the greatest importance. We further assess current depth of knowledge of microplastics in aquatic ecosystems in which Ghanaian ecosystem-specific information was not readily available. Although this study may not be a comprehensive overview of the findings, it is assumed that this is an objective representation of the existing state of awareness about microplastics in the aquatic environment in Ghana.

Keywords

Microplastics (MPs), Freshwater, Aquatic Ecosystem, Ghana

1. Introduction

What do we know about plastic? What do we know about microplastics? Why are they harmful and how does it affect freshwater or aquatic life? Well, microplastics are usually referred to as 5 mm or smaller plastic fragments and particles, and can be categorised as either primary or secondary microplastics based on its source. Microplastics (MPs) are present worldwide due to their higher mobility and longer periods of dwelling; across the coasts as well as in remote oceanic islands (Costa & Barletta, 2015; Lusher, 2015), inside the Antarctic flows (Lusher, 2015), Arctic seabed (Bergmann & Klages, 2012; La Daana et al., 2019), and even above glaciers (Bergmann et al., 2017). Briefly, no ecosystem on Earth seems to have avoided microplastic contamination (Taylor, Gwinnett, Robinson, & Woodall, 2016). The first studies on freshwater microplastics were reported in 2011, with an emphasis on Lake Huron (Zbyszewski & Corcoran, 2011) and Los Angeles rivers (Moore, Lattin, & Zellers, 2011) in the United States. Since that time, various researches have been conducted that cover all continents, except Antarctica, and all potentially affected habitats (sediment and water for the land banks, marine world). The aquatic ecosystem has seen a continuous increase in the levels of microplastics which can, of course, be tied to, as the years go by, the continued and ever-increasing production rates of plastics as a whole and plastics have a number of varying characteristics; be it durability (a big issue in why it is not biodegradable) or low production costs, etc. There has been increasing concern over the decades about the rising amounts of plastic debris contained in freshwater around the world. Plastic debris accumulated within aquatic and terrestrial ecosystems worldwide (Thompson et al., 2004). Of the environmental impacts of microplastics in freshwaters, little is understood (Wagner et al., 2014). For instance, while microplastic-associated microbial gatherings (archaeal, bacterial and picoeukaryotic) are expected to have a profound impact on the distribution consequences, and fate of those contaminants, research on this subject has centered on marine environments (Harrison et al., 2011; Keswani et al., 2016; Oberbeckmann et al., 2015).

There have been several objectives for this review, which were all discussed as the primary priority in Ghanaian freshwater ecosystems. The study attempted to summarize: the sources of microplastic products in the freshwater ecosystem in Ghana; the harmful potential and implications of microplastics in marine biota for their environmental fate. Lastly, gaps in knowledge were established to inform future research on freshwater microplastics especially in Ghana.

2. Freshwater Ecosystems in Ghana

Ghana is situated about 400 miles north of the equator in Africa along the Atlantic coast, Ghana has mainly tropical climatic conditions with alternating wet seasons and dry ones. The north of the country does have a rainy season in April through October, and from November to March is warm and dusty. The southern portion of Ghana rains from April through July, and from September through November. Guinea and Sudan savannah are habitats in northern Ghana. South of Ghana consists of evergreen forest, wet deciduous forest, tropical evergreen forest, and shoreline savannah (Csanyi, 2017).

Ghana has many freshwater systems including coastal lagoons, rivers, lakes, and coastal streams, etc. Ghana abounds in freshwater resources throughout the country in many of the river systems, as well as in two main lakes, Bosomtwi (natural lake) and Volta (manmade lake created after the Akosombo dam was built). Ghana's surface freshwater supplies are regulated by the Volta Basin (shown in Figure 1). Lake Volta, which stretches to the east in Ghana, originates from Burkina Faso, it meets the Gulf of Guinea at 0''42' East, 5''46' North. The very first hydroelectric dam Volta, built-in 1964, is located at Akosombo, 100 km from the source. Many of the main river sources include the Black and White Volta and their tributaries, the flowing River Oti and Afram into the Volta Lake, and also the flowing Tano, Ankobra, Pra, Densu, Ayensu into the sea.

The main uses of Ghana's freshwater supplies are mainly for residential and commercial water supply, farming, fishing, aquaculture, and transport. The Volta Lake system is vital for people as well as large amounts of products to be fished and transported by freshwater. It is calculated conservatively that the main rivers in Ghana are inhabited by about 124 species of fish from 62 genera

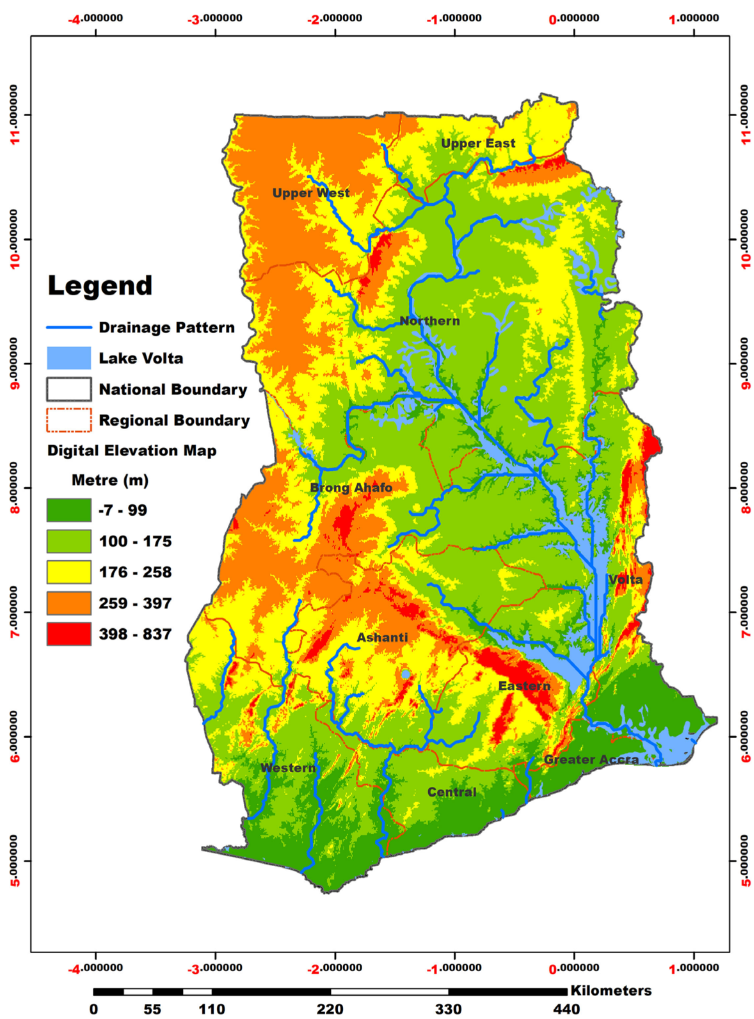

Figure 1. The drainage pattern in Ghana.

and 26 families. Freshwater fish fauna in Ghana is comprised of twenty-eight (28) families, seventy-three (73) genera, and one hundred and fifty-seven (157) species. Around one hundred and twenty-one (121) species were reported within Ghana's Volta system, draining more than a third of the nation as a whole. Around nine separate species viz. *Synodontis arnoulti, Barbus subinensis, Chrysichthys walkeri, Irvinea voltae (Schibeidae), S. Maccrophthalm, S. Velifer* (Mochokidae), *Steatocranus irvinea* (Cichilidae and Mastacembelidae), *Limbochromis robertsi,* are native to Ghana's freshwater scheme (Dankwa, Abban, & Teugels, 1999).

Certain freshwater habitats include the White Volta, Black Volta, Lower Volta, and Oti main rivers. Some include Bia, Pra, Todzie-Aka, Ankobra, Tano. Ghana's shore, which is part of the Gulf of Guinea, at Cape Three Points varies all latitudes 4"30' North and 6" North to the far east and extends between 3' West and 10' East for a total of 550 kilometres (**Figure 2**). There are about fifty lagoons in this region, in which more than half are relatively low, that is lesser than 5 km sq. in a total area (Boughey, 1957; Mensah, 1979). Many impediments which serve as drinkable water and/or drainage sources are also included. It is reported conservatively, that is, the main rivers host about 124 fish species from 62 families (Okoree, 2008). That it is reported that Ghana presently has an average per capita daily waste produced of 0.45 kg, attributing to 3.0 million tons of solid waste per year. Only 10 percent of solid waste produced is expected to be disposed of properly primarily via landfill sites, but alternatives are increasingly replenishing (Himans, 2013). If not reversed, this pattern will lead to significant improvements in environmental conditions, or interdependent relationships

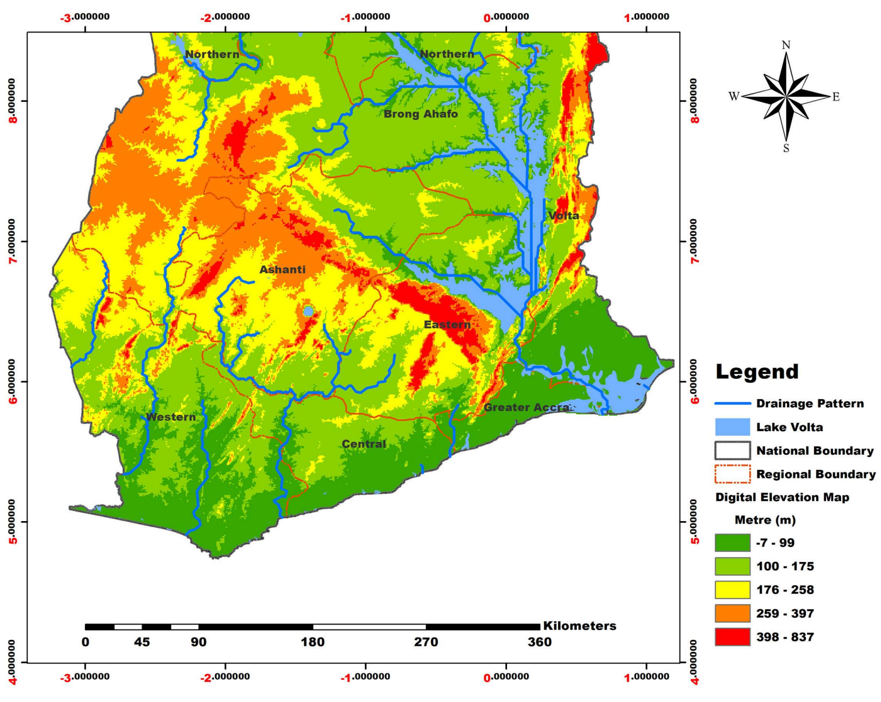

Figure 2. Map showing Southern Ghana main lagoons and rivers.

may trigger the marine ecosystem to collapse, impacting the ability of the coast to effectively provide for the plants, animals, and people that rely on it and each other to thrive.

3. Sources and Fates of Microplastics in the Freshwater Environment

3.1. Sources of Microplastics

Plastics can reach freshwater ecosystems through different pathways, from different sources. However, waste management methods in various areas of the world often vary, and this may be a more significant factor compared to another in one geographical area (Lambert et al., 2014). Microplastics are found in marine ecosystems worldwide, from deep ocean sediments to coastal habitats and in areas as remote as the poles (Obbard et al., 2014). Plastic waste originates from sources on land, as well as fishing and shipping industries, which contribute markedly to the release and redistribution of microplastics. Microplastic litter consists of plastics manufactured to be of a microscopic size (primary sources), for example, cosmetic exfoliates and pre-production pellets (Napper et al., 2015), and fragments derivational of the degradation process of greater plastic debris (secondary sources).

More recently, (Napper et al., 2015) examined the washing of clothes made of synthetic materials, such as; polyester, a polyester-cotton blend, and acrylics as an important origin of microscopic fibres emancipating into the environment. Their results concluded that a 6 kg wash cycle of such fabrics released up to 728,789 microscopic fibres, making it a considerable contributor. Plastics still experience physical and environmental deterioration in freshwater systems, reflecting smaller physical influences than aquatic ones (Andrady, 2011). Many environmental factors in freshwater may have a greater impact, for example (Free et al., 2014) found that plastic debris can be subjected to fairly extreme weathering due to high UV penetration in poorly managed lakes (Free et al., 2014). Major sources of microplastic contamination include the discharge of wastewater plants for treatment (Browne et al., 2015), weathering and degradation of plastic waste in the bodies of water (Eerkes-Medrano et al., 2015), and soil erosion or runoff terrestrial inputs (Horton et al., 2017). Microplastics can also flow by surface runoff and atmospheric accumulation into the lakes and rivers (Dris et al, 2018). Cleaning up of industrial materials like garments (clear water) is a significant contributor to the sources of microplastics entering wastewater (Browne, 2015; Peng et al., 2017). Once in the laboratory; the cleaning cycle was replicated in a household washing machine, the washing machine's drains contained a significant quantity of fibre-like microplastics (Hernandez et al., 2017). The number of microplastics in the drainage of the washer was significantly greater by using detergent than cleaning without detergent.

3.2. Primary and Secondary Microplastics

The primary microplastics are directly placed into the environment through spills, sewage, or industrial and domestic means as well as indirect means such as runoff water. Primary microplastic in Ghana also includes pellets, fibres, fragments, film, and spheres, spheres are more commonly known as particles found in cosmetics and certain pharmaceuticals.

Primary microplastics are plastic components formed in the range of sizes below 5 millimetres (Kershaw & Rochman, 2015). They involve: 1) plastic pellets, typically 3 - 5 millimetres long, used for the primary material in plastics production; 2) beads applied in cosmetics; and also 3) abrasive surface blasting beads.

Main microplastics pathway to reach the atmosphere would rely on the system or framework: particulate matter from the personal care items usually enters wastewater; abrasive microplastics enters the atmosphere and sewage, while microplastics of primary raw material can enter the environment by accident or lost during distribution and transhipment, or by discharge from processing facilities. If sewage treatment systems are too small to sustain, primary microplastics can be transported directly to oceans or transferred into freshwater water sources to enter the aquatic ecosystem afterward.

Secondary microplastics are also by-of deterioration of the atmosphere and dampening of large plastics materials (Caspers, 1987). Secondary microplastics in Ghana may be produced through the use of plastic goods (e.g., fabrics, tyres, and paints) or in the environment before plastics are discarded off. There are many mechanisms with the input of secondary microplastics into the atmosphere, including: 1) substances from fabrics that enter through sewage after cleaning or during drying by air (Napper et al., 2015; Underwood et al., 2017); 2) the dampening of plastics used for Agric purposes may introduce surface runoff from the soil into the environment; 3) the tyres abrasion during use produces microplastics that enter the environment using air and runoff; 4) the deterioration and dampening of landfill products by ultraviolet radiation which would release microplastics into the environment, oceans and rivers, or by wind or surface runoff, and 5) the dampening of plastic debris in coastal areas and shores which may persist inshore sediments or be deposited further seaside.

Secondary microplastics in comparison come from much larger plastic objects or fragments and come from the further fragmentation and or degrading of said plastics in the environment due to physical effects such as waves eroding them, chemical effects such as UV rays degrading them, and even biological effects from microorganisms tearing them apart and when these microplastics end up in the environment under these effects they tend to easily turn into Nano-plastics which are within 1 - 100 nm and have a much lesser-known effect due to their small size. Ultraviolet light penetration, temperature, and abrasion are the major environmental factors associated with secondary microplastic production. Areas with decreased Ultraviolet exposure and low temperature (such as the deep ocean) in aquatic environments can slow down the second generation of microplastic (Andrady, 2015).

3.3. Environmental Fates of Microplastics

Studies of freshwater in the large reservoirs (Eriksen et al., 2013; Free et al., 2014; Imhof et al., 2013) indicate that dispersal for MPs is responsible for specific physical forces as those in aquatic environment studies. Microplastics dispersal in marine environments focuses on microplastics' physical and chemical structure, the physical forces that cause them to travel, the interactions within biota and particles, and the connections among them (Eriksen et al., 2013; Free et al., 2014; Hoellein et al., 2014).

The main losses of smaller substances on the surface of freshwater were assessed by calculating the size distribution of MPs at various locations around the universe (Cózar et al., 2014; Eriksen et al., 2014). Kukulka et al, 2012, concluded that this conventional calculation greatly underestimates the overall plastic content in the ocean. They noticed that vertical mix, the size distributions of floating plastics on the water will be affected, as small plastics are more likely to be transported upright. Aside from the deposition of deep-sea sediments in oceanic basins and freshwater sediments, they are a potential drain for MPs, indicating the incomplete proportion. Woodall et al., 2014, discovered that fabrics are as many as four times high in sedimentation in magnitude (for volume per unit) than seawater at surface in the Pacific, Indian and Mediterranean Oceans.

Hetero-aggregation and the creation of biofilms also play a major role in influencing the aqueous microplastics fate (Rummel et al., 2017; Woodall et al., 2014). Biofilm-hetero production will lead to an increase in a microplastic decrease in buoyancy and density (Lagarde et al., 2016); and small microplastics appear to achieve more rapidly significant densities of rainfall (Chubarenko et al., 2016). Since the sinking rate represents particle size and weight, sedimentation indicates a greater density than surface water (Long et al., 2015). While the formation of biofilms can make MP sticky due to the matrix of the extracellular polymeric materials, thereby facilitating hetero-aggregate formation.

Additionally, the downhill movement of MPs can be encouraged by the discharge of zooplankton faecal pellets (Cole et al., 2016; Gorokhova, 2015). It is vital to keep an eye on MPs' current and new sinks. The potential sinks of microplastics include deposition, decay, sedimentation on the shore and intake of organisms (Law et al., 2010). Weathering mechanisms such as photooxidation, oxidant, hydrolytic degradation, and biodegradation mechanisms may have a major effect on the plastic fate waste in the marine world.

Many microplastics are lighter than seawater and floatable at sea level, and their concentration of large tropical ocean basins, where confluent ocean surface flows collect and also retain waste over long periods, is the most detailed spatial pattern of MPs (Eriksen et al., 2014; Goldstein et al., 2012; Wilber, 1987). Due to lower weight and smaller size in contrast with natural sediments, MPs influenced by wave action, bioturbation, or tides and any other disruptions can be resuspended from the bottom sediments more readily than larger plastic fragments (Kershaw & Rochman, 2015).

4. Implications and Effects of Exposure to Microplastics in Ghana

The consequences of plastic waste in our freshwaters are numerous, with many of these difficult to tackle. The most predominant of these in Ghana originates from land-based sources, contributing to 80 percent of overall plastic waste in our oceans. Such waste is transported to the freshwater by natural factors including storm, water runoff, natural disasters such as tsunamis, and the transport of trash by the wind into rivers or streams. It also involves anthropogenic practices such as groundwater leakage as a result of inadequate management, and intentional plastic disposal, which contributes to less than 10 percent of aquatic plastic emissions. The excess comes from freshwater operations, including discarded fishing equipment from boats including nets, plastic bottles, trap boxes, and ropes falling overboard. Accidental consumption of plastic pellets, plastic caps, and small toys overlooked for food has serious implications. This affects the wellbeing and protection of penguins, dolphins, seals, crustaceans, whales, marine reptiles, seabirds, fish, and turtles in the freshwater systems of Ghana. It causes reduced food intake, which affects absorption, impaired mobility, blockages of the digestive tract, ulcers, malnutrition, and weakening. Another important factor is the rise in world population size and the unsustainable preferences of consumers, evident as plastic production exceeded 300 million tonnes in 2013 from 0.5 million tonnes in 1960, as illustrated in **Figure 3**. As 50 percent of the population resides within proximity of up to 80 km of the ocean, coastal areas are especially vulnerable.

Of the 557 species known in our garbage, at least 203 (Kühn et al., 2015) also consume microplastic in the wild, some of which are fish (Lusher et al., 2016) and other vertebrate species (Anastasopoulou et al., 2013; De Stephanis et al., 2013).

4.1. Implications of Microplastics Exposure

There is increasing concern about implications for animals including fish diseases (Rochman et al, 2013) and lower fecundity and shorter life expectancy of

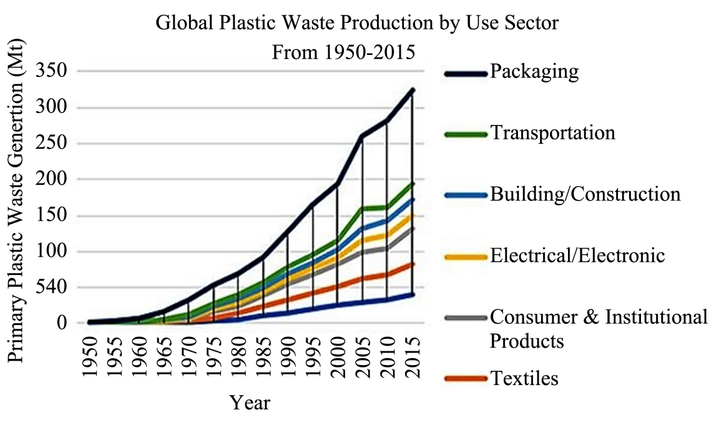

Figure 3. Global plastic waste output by use sector from 1950-2015 (Geyer et al., 2017).

water worms (Wright et al., 2013). Some research also exposes implications for laboratory populations: one oyster study found that there is "evidence that micro-PS (polystyrene) cause feeding modifications and reproductive disruption with significant impacts on offspring" (Sussarellu et al., 2016). Although some study suggests plastic may be a conduit or point of entry, others do not want such toxicants to penetrate the food chains. Some research on microplastic consumption showed absolute egestion, as in Idotea emarginata, a freshwater isopod (Hämer et al., 2014), or mud snail Potampoyrgus antipodarum ingestion of non-buoyant microplastics, which demonstrated no deleterious developmental consequences in the complete larval stage (Imhof and Laforsch, 2016). A detailed study found that bioaccumulated negatively charged chemicals from natural predators outweigh the flow of ingested microplastics to most ecosystems, suggesting microplastics are unlikely to increase exposure in the ecosystem (Koelmans et al., 2016).

As a consequence, microplastics transfer to the aquatic and eventually marine surroundings (primary or secondary by admission throughout the form of extra items that ultimately contribute to microplastics) exists in the chain production, example, in the case of loss of pellet, reckless or waste debris treatment (**Figure 4**). Also, in **Figure 4**, shows a model which items are produced by the usage of modern, mostly oil-based resources. Most of the value of the product is destroyed throughout the lifespan due to contamination across the distribution channel (red arrows), includes littering, pellet loss, combined drainage system contamination, transport loss, and unsuitable waste storage, and badly manufactured goods which are quickly lost to the atmosphere and impossible to retrieve (tiny wrapper, microbeads, broken packing angles). It contributes to the pollution of the ecosystem that affects both ecology and people's well-being. A small amount used for remanufacturing (green arrow) and the remainder is used for recovery of the oil.

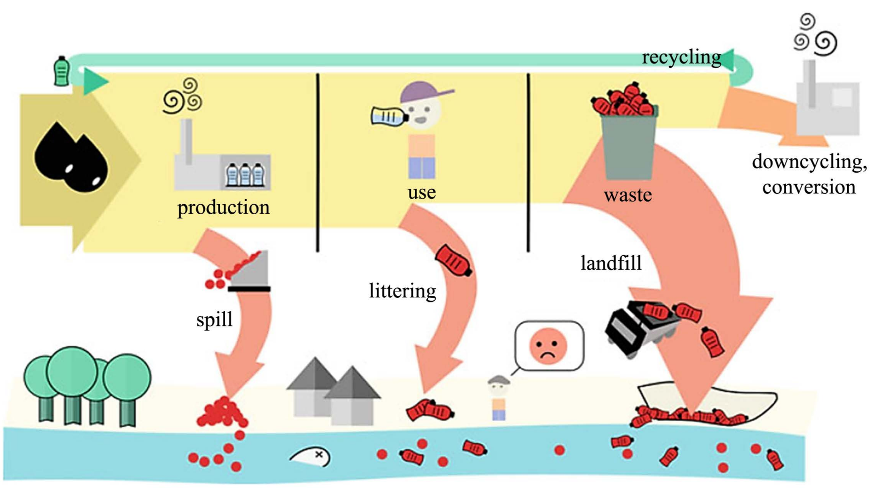

Figure 4. (Eriksen et al., 2018), A linear economy design for plastics items and discharge and packaging.

4.2. Effects of Microplastics Exposure

The impacts associated with freshwater MPs exposure have been studied across different levels of biological organization: from gene to population level. The variety of microplastic products and impact measures used makes it difficult to properly assess toxicity results. Research also indicates that microplastic exposure can influence reproduction. A research studying the impact of polystyrene microbeads (2 and 6 μm at 32 $\mu g \cdot L^{-1}$) reported after a 2-month treatment, mussels had reduced reproductive ability (Sussarellu et al., 2016). Microplastic morphological features (shape, texture and size) can affect toxicological results, such as the management of tissue translocation, blockage of the digestive system or tissue irritation or laceration, result in abnormalities or increased exposure to infectious disorders. The effect of a contaminant on the marine food chain can have knock-on consequences on the functionality of the trophic structure and environment. Microplastics may cause inflammatory symptoms, resulting from the ability of their structure to interact with the tissues, under situations of extreme concentrations or high personal exposure. Growing exposure to environmental pollutants, like microplastics, could also be associated with a growing occurrence of neurodegenerative disorders, immune conditions and tumors. That being said, there is insufficient awareness of the impact on human health of environmental exposure to microplastics, resulting in high uncertainty which should not be transformed into hysteria, even though the preventative principle is applied.

Due to the widespread occurrence and persistence of these physical entities (i.e., MPs) in the environment, they are hypothesized to physically alter biogeochemical cycling, change the dynamics of aquatic food webs, and have an impact on large-scale ecosystem processes (Geyer et al., 2017). For example, the accumulation of buoyant particulates in surface waters likely reduces light penetration, whereas sedimentation of plastic debris on the seafloor could impede the gas exchange between surface water and the interstitial water of sediments, potentially causing hypoxia (Wang et al., 2018). These consequences are more likely to be attributed to larger plastic debris that, due to its bulky size, has a greater potential to influence and cause physical damage in natural environments.

To better predict potential implications and effects of freshwater MPs on higher levels of biological complexity, the refinement of data concerning concentrations and fate of MPs in the environment and impacts in the organism from numerous trophic levels in the field is needed.

5. Conclusion, Knowledge Gaps and Research Needs

In summary, we reviewed that microplastic study in Ghana is a fairly new field of scientific interest that is continuing to grow. Although marine MPs research is more progressed, there are huge gaps in knowledge, particularly in Ghana regarding freshwater MPs. MPs research is practically absent in Ghana's freshwater ecosystems. At the same time, appropriate sources and environmental fate remain to be examined. Many recent seminars, organized conferences, and review papers also sought to identify differences in information and possible research objectives (e.g., Arthur et al., 2009; Zarfl et al., 2011). This paper adds to the debate about finding knowledge gaps that could direct potentially research on microplastics in Ghana's marine ecosystems.

Firstly, information on the occurrence of microplastics in freshwater environments in Ghana is quite minimal and the majority of information stems mainly from European countries. It is obvious that particles (>150 μm) are also not consumed and thus, research projects must focus heavily on measuring microplastics < 150 μm, which is not yet usual practice. As this review points out, the biggest gaps in existing knowledge are in our knowing of microplastic pollution in freshwater ecosystems that focus primarily on Ghana, particularly environmental quantities, sources, and environmental impacts. Due to the lack of quantitative data, it is difficult to quantify the exact scope of the microplastic potential danger in these systems and how the implications of microplastic existence in these ecosystems will occur themselves.

However, this is relevant to microplastics study as a whole, in which the long-term effects of microplastics are still uncertain relative to better research chemical contaminants. To advance the area of research, it is of the utmost concern, firstly, to identify "microplastics" obviously as an ecological pollutant and, subsequently, to develop standardized methods for accumulating, storing, and evaluating environmental samples. This standardization can reduce uncertainty and thus, enable direct comparison between research to understand sources and modes of transportation.

More data is required on the significance of primary and secondary microplastics sources worldwide and from Ghana's perspective, and even patterns in excess across various physical and socio areas. Much better awareness of the factors of abiotic and biotic that influences the distribution and absorption of such substances may help to establish effective strategies to avoid their discharge into the freshwater world. Although ingestion of microplastics has indeed been shown in quite several marine lives, the issue of what are the consequences of ingestion, or which species are most susceptible to effects, has not been addressed unequivocally. Trophic movements of microplastics (i.e., concentrations, levels, processes) including long-term effects of such substances are not well known in aquatic or freshwater ecosystems.

Compared with aquatic ecosystems, microplastics in freshwater have never been properly understood and thus, the existence and consequences of microplastics in freshwater habitats remain unidentified. In Ghana, there were only several studies that described the existence of microplastics in debris in water bodies and freshwater. Rivers and lakes were critical water sources for detecting microplastics and will continue to be so. Assuming rivers will play a major role in carrying poorly managed plastic waste from land into the ocean, river microplastic litter measures are urgently needed. Similarly, dissolved microplastics that float along the river bed should also be measured to prevent undervaluation.

Globally, substantial advances have been made in identifying the role and likely impacts of microplastics in the aquatic environment, especially in the last five years. However, our knowledge of these pollutants in Ghanaian water sources and their related pollutants, especially freshwater, is comparatively limited and poses possibilities for further study. In Europe, most plastic emission studies were performed in freshwaters. However, the research initiatives in Africa, particularly in low-middle-income countries, need to be broadened. Rising population rates, growing economy, and rapid urbanization have significantly increased the pace of plastic waste production, while care, recycling solutions, recovery channels, and final disposal in many third world countries in such regions are still a shortfall.

Regarding the limitations or gaps described above, it is proposed that future research would try to develop the sampling methods and tools, and find persistent exposures despite the intransigent existence of such substances.

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Conflicts of Interest

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

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