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Research article

Microplastics in the Volta Lake: Occurrence, distribution, and human health implications

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ABSTRACT

Pollution of plastic waste in aquatic ecosystems in Ghana is of significant concern with potential adverse effects on food safety and ecosystem function. This study examined the abundance and distribution of microplastics (MPs) in freshwater biota samples namely: the African river prawn (*Macrobrachium vollenhovenii),* the Volta clam (*Galatea paradoxa*), Nile tilapia (*Oreochromis niloticus),* and sediment from the Volta Lake. Both biota and sediment samples were subjected to microscopic identification and FTIR analysis. In biota samples, the highest mean microplastic abundance of 4.7 ± 2.1 items per individual was found in the prawn, while the Nile tilapia recorded the least (2.8 ± 0.6 items per individual). A total of 398 microplastic particles were observed in sediment samples from the Volta Lake. Microfibers were the major plastic shapes identified in biota and sediment samples. We examined the relationship between microplastic abundance, biota size, and sediment properties. Despite the lack of statistical significance, microplastic shape, size, and polymer composition in assessed organisms mirrored those in the benthic sediment. Polyethylene, polypropylene, polyester, and polystyrene were the four dominant polymer types identified in the organisms and sediments. Although the estimated human exposure was relatively low compared with studies from other regions of the world, the presence of microplastics raises concern for the safety of fisheries products consumed by the general populace in the country. This research is essential for developing effective mitigation measures and tackling the wider effects of microplastic contamination on Ghana's freshwater ecosystems, particularly the Volta Lake.

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1. Introduction

The extensive use of plastic as a substitute to reduce deforestation and overexploitation of natural resources has led to the production of large quantities of plastic waste. There are concerns about a potential threat to natural ecosystem sustainability due to the considerable environmental degradation brought about by poor disposal and management of plastic waste [1]. Plastic waste could easily be disintegrated from larger plastics to smaller ones called microplastics under favourable conditions such as weathering, photo-degradation, oxidation, mechanical abrasion, and chemical reactions [2]. According to the ISO [3] definition, microplastics are plastic particles in the range of 1 μm–5 mm. Microplastics accumulated over time could pose as vectors of heavy metals and persistent organic pollutants through the aquatic food web [4]. This phenomenon has drawn increasing attention to the harmful effects on aquatic organisms and human health.

Microplastic pollution in the aquatic environment is a global catastrophe and is widely distributed across various aquatic habitats worldwide, from seawater [1,5,6,97], marine sediment [7–11], beach sand [12–17], freshwater [18–21] riverine sediments [22–25] and lakes [26–28].

Research on freshwater ecosystems is scarce as most studies focus on coastal and marine habitats. Meanwhile, microplastics are associated with areas of high anthropogenic activities and the proximity of freshwaters to anthropogenic activities may present such ecosystems with high microplastic pollution. Therefore, urban freshwater systems are both a potential repository for land-based microplastics and a source of marine microplastics that expose inhabiting organisms to the risk of microplastic toxicities [29].

Organisms living in aquatic ecosystems may ingest microplastics during feeding from the water column, sediment, or consumption of prey species, which may induce inflammatory responses, mortality, oxidative stress, neurotoxicity malfunction and hormonal [30,31]. The evidence of microplastics in edible fish products pose significant health challenges to humans since plastics may contain chemical additives or may absorb environmental contaminants, which could expose humans to environmental pollutants. The consumption of fish remains a key source of plastic exposure to humans [29]. Microplastics that remain in human guts may be excreted through the intestine. However, recent studies have shown that microplastics smaller than 150 μm could cross digestive barriers and translocate to other sensitive organs [32].

Most developing countries, including Ghana, are struggling to manage their plastic waste. According to the Ghana National Plastic Partnership [100] report the amount of plastic waste generated in Ghana will triple by 2040. The use of personal protective equipment during the COVID-19 pandemic is likely to aggravate this prediction. Over the years, Ghana has become a sub-regional dumping ground for imported used clothing. The United Kingdom alone accounts for more than 40% of used clothing imports to Ghana, with a market value of more than $70 million per year [96]. Due to poor quality and texture composition, over 40% of these clothes are not useable and are often burned or disposed of in nearby water bodies and dumpsites. As cited by majority of research publications, fiber strands from laundry and textile materials may account for a significant number of microplastics in the aquatic environment as they are considered stable and durable [26,33,34]. The packaging of drinking water in single-use plastic materials has further exacerbated Ghana's plastic pollution menace.

Although some studies have reported the occurrence and distribution of microplastics in the marine ecosystems in Ghana, from oysters [35], sediment cores [36], seawater [1], and fish [34,37], few research works have been done to ascertain microplastic pollution status of freshwater ecosystems. This study therefore determines the occurrence and abundance of microplastic in the African river prawn, the Volta clam, Nile tilapia and sediment from the Volta Lake and estimates any human health implications associated with the consumption. The study further hypothesized that the distribution of microplastics in both biota and sediment is influenced by a variety of environmental and intrinsic biological factors, including proximity to urban areas, patterns of water flow, and the unique characteristics of the freshwater organism studied. Our findings will significantly contribute to pushing the frontiers of microplastic occurrence in sediment as well as understanding the ingestion of microplastics by freshwater species. The findings are useful in the development of protection and mitigation measures to manage aquatic pollution caused by microplastics.

2. Materials and methods

2.1. Study area

Crustaceans, shellfish, and finfish used for microplastic determination were collected from Lake Volta. Lake Volta is a man-made lake in Ghana. The lake was created by the construction of the Akosombo Dam, which generates over 912 MW and meets most of Ghana's energy requirements. Lake Volta extends over 250 miles (400 km) and spans 3283 miles (8502 km^2) covering over 3.6 percent of Ghana's total surface area. Lake Volta provides a route for cargo boats and ferries, making it a significant means of transport. The large population and intensive economic activities within the lake boundaries have led to severe environmental pollution including accumulation of plastic waste in the lower Volta. Ghana's inability to meet the high fish consumption rate has necessitated rapid growth in commercial fish production on the lake. The cage system accounts for more than 80% of fish production., of which 90% are located on the lower Volta Lake, where the study was conducted. The predominant aquaculture activities could serve as a primary source of plastic pollution on the lake. The depressed topography of the lower Volta makes it susceptible to plastic pollution from runoff, spills, and overflow from landfills situated near its banks. Textile industries within the Akosombo municipality according to Karikari et al. [38], discharge their effluents into drains that flow to the Volta Lake.

2.2. Sample collection

African river prawn (*Macrobrachium vollenhovenii*), Volta clam (*Galatea paradoxa*) and Nile tilapia (*Oreochromis niloticus*) were sampled for microplastic analysis. Prawns (N = 50) were collected using a dragnet at a depth of 3.2 m with the assistance of local fishermen. Sample collection was done in compliance with the Fisheries Commission Regulation Act. Clams (N = 50) and Nile tilapia (N = 30) were purchased at the fish landing site using randomized sampling techniques. Samples were washed with filtered tap water (0.7 μm) and placed in a metal case. The samples were transported on ice to the laboratory and kept at - 20 °C until further analysis. Samples of benthic sediments were taken at depths ranging from 7.8 to 18.9 m. An Ekman Grab was deployed to collect benthic sediment samples for microplastics, total organic matter, and particle size analysis. Sediment samples for microplastics were taken from the topmost 5 cm layer into decontaminated glass jars with metal lids. Sediments were taken from upstream (FG1-FG4) Midstream (FG5-FG7) and downstream (FG8-FG10) (Fig. 1). Sediment samples were collected at 3 stations from all the fishing grounds at 1-km intervals. Two replicate sub-samples were taken from each grab/sampling station ($n = 60$). Furthermore, a single sample for granulometric analysis and organic matter was collected from each station.

2.3. Microplastic extraction in biota

Fish samples were allowed to thaw at room temperature, and their meristic and morphometric features were determined to estimate their condition factor. The sex, weight, and total length of prawns (from the apex of the rostrum to the distal extreme of the telson) were measured to determine the condition factor using an electric fish measuring board. For microplastic analysis, the abdominal muscle, including the gastrointestinal tract of prawns, the entire muscle weight of clams and the wet gut of Nile tilapia were dissected separately with scissors and a scalpel and placed into a clean glass beaker covered with aluminium foil. Digestion of the tissues was carried out using a 10% potassium hydroxide (KOH) at 40 °C for 72 h, as recommended by Hara et al. [39]. The digestate was filtered through a 1.2 μm glass membrane filter (CHMLAB–GF3) using a vacuum filtration pump (GS885DX). The filters were placed into a clean glass Petri dish and dried in an oven at 40 °C for 30 min, and later examined for microplastics.

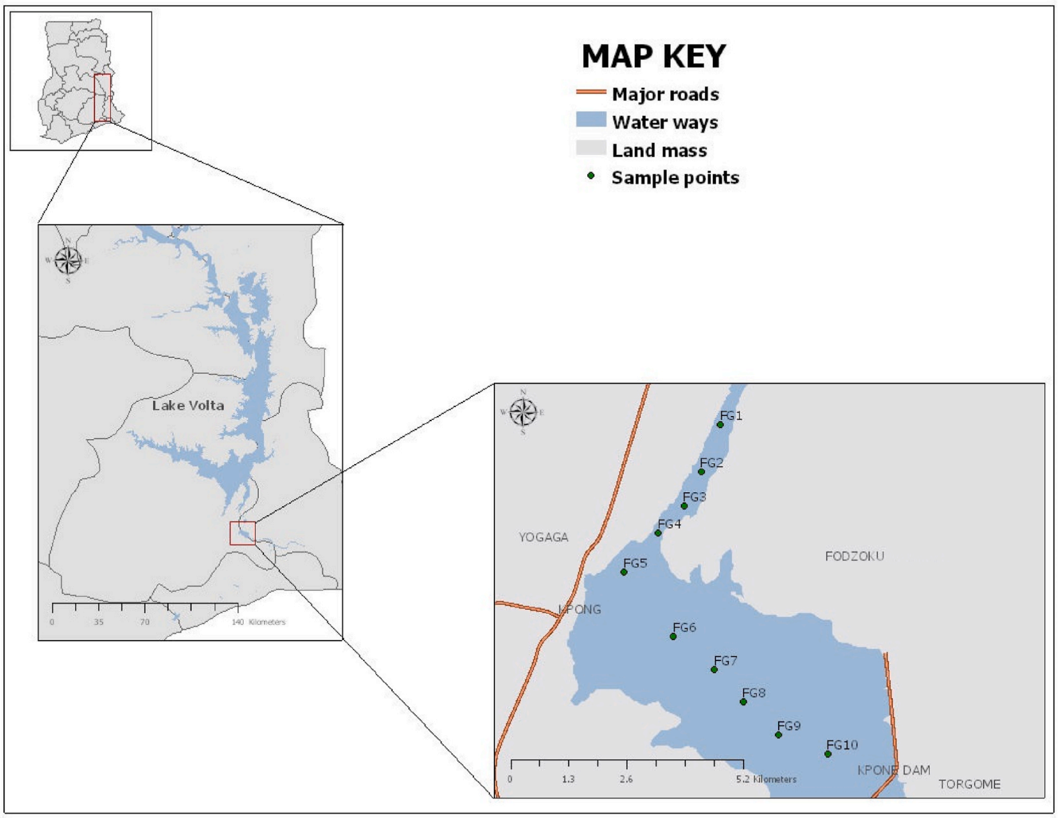

Fig. 1. Study location of the Volta Lake indicating sampling sites for sediment and biota.

2.4. Sediment analysis

2.4.1. Granulometry

Grain size analysis was done by the dry sieving method recommended by Pagter et al. [40] with slight modifications. Approximately, 50 g of dried (120 °C for 24 h) and homogenate sediment was treated with 100 ml of 6% hydrogen peroxide at room temperature for 12 h in a fume hood to digest organic matter. The excess hydrogen peroxide was washed out through a 63 μm sieve, and the sample retained in the sieve was washed back into the glass beaker. Approximately. 10 ml of 10% sodium hexametaphosphate was added to enhance sediment disaggregation for 12 h. The mixture was dried at 90 °C for 24 h after initial washing of the sample to remove surplus sodium hexametaphosphate. Sediment separation was done using a column shaker (Endocotts Octagon Digital Sieve Shaker) with a range of graduated sieves (1 mm–63 μm). The amount of sediment retained in each sieve was recorded using an analytical balance to the nearest 0.001 g. Sediment composition was determined using Gradistat® software version 9.1 based on the weight of sediment retained in each sieve.

2.4.2. Total organic matter

The total organic matter composition in the sediment was determined by the mass loss on the ignition method described by Pagter et al. [40]. Approximately 5 g of dried and homogenized sediment was burned at 450 °C using a muffle furnace for 6 h. The sample was reweighed and the difference between the initial weight was recorded.

2.4.3. Microplastic extraction in sediment

Sediment for MPs analysis was oven-dried at 50 °C for 3 days, and moisture content was determined. Approximately 50 g of the dried and homogenized sediment was weighed into a decontaminated glass beaker. The samples were treated with 40 ml of 30% hydrogen peroxide and heated at 70 °C for 45 min to digest organic materials [41]. Excess peroxide was washed through a 20 μm metal sieve and the retentate was washed back into the beaker with filter distilled water (0.7 μm). The density separation method recommended by Rodrigue et al. [42] was used to extract microplastics from the treated sediment samples with the addition of 150 ml of saturated zinc chloride solution (1.6 g/cm^{-3}). The mixture was agitated for 10 min with a mechanical shaker and allowed to settle overnight. Using a vacuum pump, the floating plastic supernatant was filtered through a 1.5 μm glass membrane filter (CHMLAB GF-6). The density separation procedure was repeated three times to ensure maximum recovery of MPs in sediment samples. The filters were kept in desiccators and later examined for MPs.

2.5. Microplastic examination and polymer identification analysis

Filters were examined for MPs under a bright field using a stereomicroscope (Motic SMZ-171) incorporated with a digital camera (Moticam A-16). The filter papers were examined under 40 x magnification in a zig-zag pattern to avoid overestimation of the count, as stated by Teng et al. [43]. MPs were counted, photographed, and their sizes and shapes were determined as fibers (long and elongated), fragments (irregular and angular pieces mainly from the degradation of large plastic materials), pellets (spherical shape) and films (clear and transparent). The size of MPs was grouped as > 100 μm, 100–500 μm, 501–1000 μm, 1001–3000 μm, and 3001–5000 μm [44].

PerkinElmer spotlight 200i FT–IR microscopy system with temperature stabilize DTGS (deuterated triglycine sulfate) detector was used for polymer identification on isolated MPs. Sample spectra were collected in transmission mode in 128 scans (minimum), with a spectral resolution of 4 cm^{-1}, in a wavenumber range of 4000–400 cm^{-1}. Scanning of MPs was preceded by measurements of background spectra. OMNIC Specta Software (Thermo Scientific) was used for polymer identification.

2.6. Contamination control

As a precaution to reduce the risk of cross-contamination, only cotton lab coats and nitrile gloves were always used. Laboratory glassware was decontaminated with 10% nitric acid for 24 h, rinsed several times with filtered distilled water (0.45 μm), and covered immediately with aluminium foil to prevent air particle accumulation. Air controls were used at every stage of the procedure. To monitor potential contamination from the extraction solution, procedural blanks were performed on hydrogen peroxide, zinc chloride, and potassium hydroxide solutions. Commercial polymers of different sizes were purchased for matrix spike to evaluate the efficiency of the analytical method. The percentage recovery was 99% for polyethylene, 100% for polypropylene and 96% for polystyrene. However, method recovery was only performed in sediment samples. The detection limit for the minimum size count was 48 μm.

2.7. Data analysis

GraphPad Prism version 9.5 was used to analyze the data obtained. MPs was reported as an item per individual or as an item per gram of tissue (wet weight). Non-parametric statistical analysis was performed based on the outcome of the descriptive normality test. Analysis of variance (Kruskal Wills test) was performed to test the statistical difference between the abundance of MPs in fish and sediment, followed by Dunn's test for multiple comparisons. Sample T-test was used to determine the significant difference in MPs abundance and sex among fish species. A correlation analysis (Spearman correlation) was performed to determine the relationship between MPs abundance and fish size as well as the relationship between sediment characteristics (grain size and total organic matter) and MPs abundance in sediment. The level of significance was set at $P = 0.05$.

2.8. Human health exposure assessment

Human exposure to microplastic from the consumption of the contaminated species was computed by multiplying the mean MP abundance (items/gram tissue) by the shellfish and consumption in Ghana. The estimated annual intake (EAI) equation by Piyawardhana et al. [101] was used for the exposure assessment.

$$EAI = C \times FIR$$

where C = mean microplastic abundance 0.19 ± 0.10 item/gram/tissue (*Macrobrachium vollenhovenii*) and 0.30 ± 0.18 item/gram/tissue (*Galatea paradoxa*). FIR is the Shellfish ingestion rate for Ghana (2600 $gperson^{-1}year^{-1}$) [45].

3. Results

3.1. Microplastic abundance in biota

Microplastics were found in air control samples despite measures to prevent contamination. These were fibers with a mean size of 654 μm. Polymer identification analysis showed that the contamination was natural fibers mainly from cotton, which could come from wearing cotton laboratory coats during extraction. Microplastic contamination of blank samples was minimal (0.46 ± 0.51 particles) hence no deductions were made from the results. The average condition factor (CF) of biota samples was highest for Nile tilapia (1.8 ± 0.5) and lowest (1.6 ± 0.2) for the prawn (Table 1).

A total of 447 items of MPs were found in biota samples comprising of 237 for prawns (*M. vollenhovenii),* 126 for clams (*G paradox)* and 84 for Nile tilapia (*O. niloticus)*. Out of the 130 individuals examined, 112 individuals (86%) have ingested at least one microplastic. The frequency of occurrences was 92% for prawns*,* 84% for clams*,* and 80% for Nile tilapia. The abundance ranged from 1 to 9 items per individual with an average of 3.7 ± 1.6 (items per individual) Prawns had the highest microplastic abundance (4.7 ± 2.1 items per individual), followed by clams (3.0 ± 1.3 items per individual) and tilapia (2.8 ± 0.6 items per individual) (Fig. 2). ANOVA revealed statistically significant differences in MP abundance between species (Kruskal-Wallis's test, $P = 0.0001$). According to the Dunns test, there was a significant difference between prawns and clams ($P = 0.0001$) and prawns and tilapias ($P = 0.0001$). Females had a higher MP abundance ($n = 250$) than males ($n = 197$), with an average of 4.10 ± 1.92 items per individual and males 3.22 ± 1.83 items per individual. Paired T-test analysis showed a significant difference in MP abundance between males and females ($P = 0.0052$). The relationship between MPs and body size varies among fish species. An individual correlation between species and size, including zero values, indicated a positive correlation (Spearman's correlation; $r = 0.5390$, $P = 0.0002$) for prawns and Nile tilapia (Spearman's correlation; $r = 0.3084$, $P = 0.1008$). However, an inverse correlation ($r = -0.0852$, $P = 0.6159$) was observed for clams.

3.2. Microplastic characteristics in biota

Analysis of shape is crucial for MP studies since it can determine microplastic's toxicity to aquatic life. We observed three (3) shapes/types of MPs namely, microfibers, fragments, and films). Of these, microfibers dominated all the counts in the studied organisms (Fig. 3). Microfibers accounted for 74% ($n = 331$) of the total particles extracted. Prawns had the highest (88%) microfiber composition. This was followed by clams with a 78% abundance and Nile tilapia with a 72% microfiber composition. Fragments and films were present in small quantities (20% and 8% respectively) for Nile tilapia, and (16% and 6% respectively) for clams. However, no film was found in prawns (Fig. 3).

The different microplastics analyzed for all biota samples were classified into five classes depending on their size (Fig. 4). The size of the microplastic ranged from 48 μm to 4957 μm with a mean length of 785 μm. Microfiber less than 1000 μm size was the dominant and prevalent size class observed across all three (3) biota samples examined. A very small percentage of microfibers had size classes greater than 3000 μm. The dominant size class for fragments was 1001–3000 μm for Nile tilapia and clams. Like microfibers, a size class of less than 1000 μm was the most prevalent for prawn fragments. Sixty-nine of the 447 microplastic particles found in biota were less than 100 μm in size. This represents 15% of the identified particle size class.

3.3. Polymer composition

Polymer identification analysis confirmed that 96% ($n = 90$, 30 per species) were synthetic polymers. The common polymer types identified were polyethene (PE), polypropylene (PP), polyester (PES), polyamide (PA), polystyrene (PS) and polycarbonate (PC) (Fig. 5). PE, PP, PES, and PS occurred in microplastics isolated in all three biota samples whereas PC was present only in Nile tilapia.

Table 1
Morphometrics data and condition factor for the studied organisms.

Species	Total Length (cm)	Weight (g)	Condition Factor	Feeding Habit
Prawn	12.4 ± 1.4	30.0 ± 10.2	1.6 ± 0.2	Omnivorous
Clam	6.4 ± 0.4	10.4 ± 2.8	N/A	Filter feeder
Nile tilapia	21.7 ± 2.1	247 ± 25.4	1.8 ± 0.5	Omnivorous

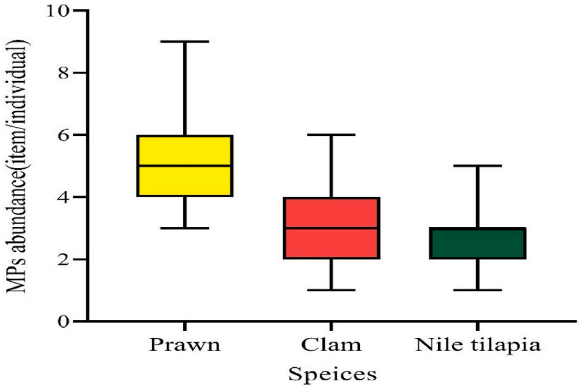

Fig. 2. Average numbers of microplastics isolated in tissues of Prawns (*M. vollenhovenii),* Clams (*G. paradoxa)* and Nile tilapia (*O. niloticus)* from Lake Volta in Ghana.

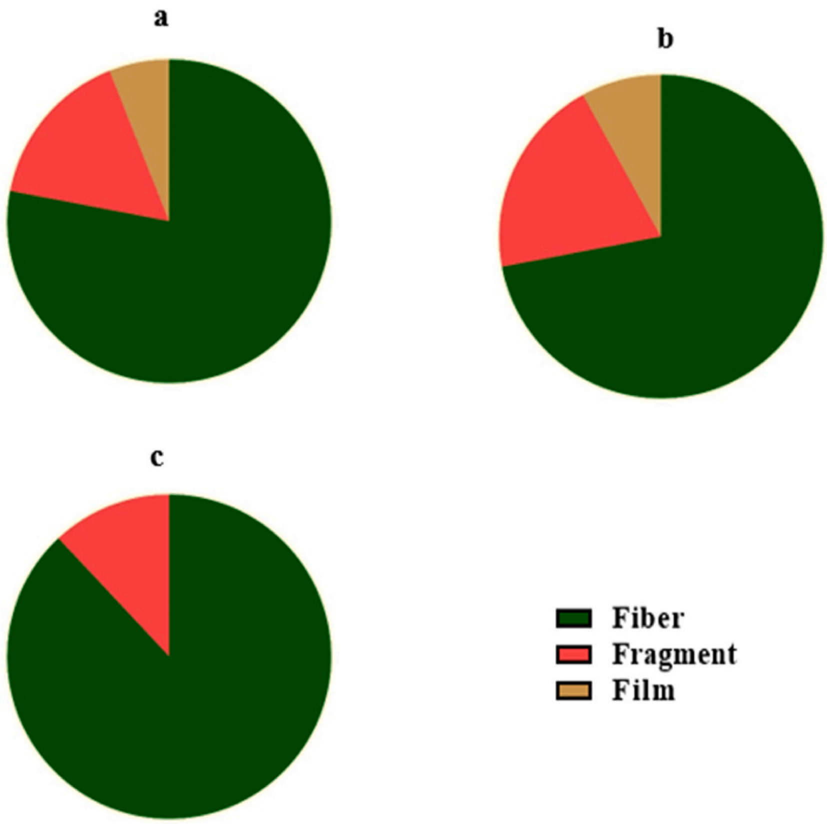

Fig. 3. Abundance and distribution of microplastic types/shapes in biota samples from Lake Volta: [a] Nile tilapia, [b] Clam, and [c] Prawn.

The percentage composition of the synthetic polymers was ranked as follows: PP (26%), PP (22%), PES (20%), PS (17%), PA (8), cellophane (5%), and PC (3%).

3.4. Microplastic exposure assessment

Microplastic exposure assessment from the consumption studied biota was computed for only prawns and clams. The omission of tilapia species was based on evidence from the literature that over 90% of microplastic ingested in finfish is retained in the gastro-intestinal intestinal tract, which is often removed before consumption [46], hence, its inclusion may lead to over-estimation of the exposure. Based on the fish consumption rate for Ghana (1800 g/person/year for crustaceans and 2600 g/person/year for molluscs) the estimated weekly intake was 10.38 and 9.30 MPs items per week for clams and prawns, whereas the yearly intake was 539.6 and

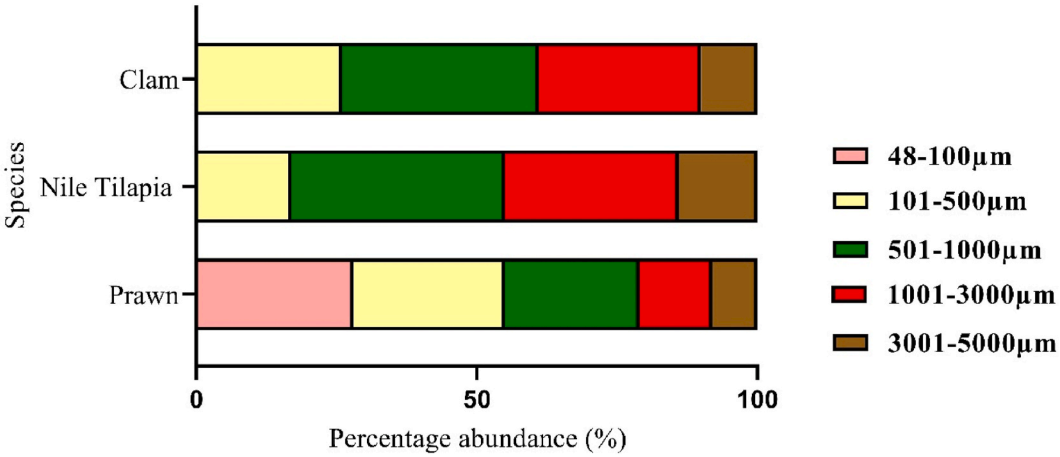

Fig. 4. Size distribution of MPs ingested by biota sampled from the Volta Lake.

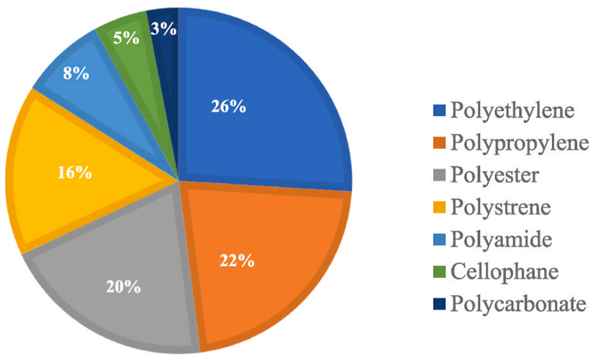

Fig. 5. Identification of plastic polymers ingested by biota sampled from the Volta Lake.

484.03 MPs items per year respectively.

3.5. Microplastic in sediment

The study area was segmented into upstream (FG1–FG4), midstream (FG5–FG7), and Downstream (FG8–FG10) to understand the spatial distribution and transport of microplastics in the Lake Volta. A total of 398 microplastic particles were extracted from 1.5 kg of dry sediment. The abundance of MPs ranges from 3 to 28 MP particles per 50 g of dried sediment, with a mean value of 13.3 MPs particles per 50 g of dried sediment. The highest microplastic abundance was observed from midstream (19.9 $\pm$ 3.8 MP particles per 50 g of sediment), whereas upstream recorded the lowest abundance (8.7 $\pm$ 3.8 MP per 50 g of sediment) (Fig. 6). An analysis of variance showed a significant difference in the distribution of microplastics in the sediment samples (Kruskal-Willis Test, $P = 0.0001$).

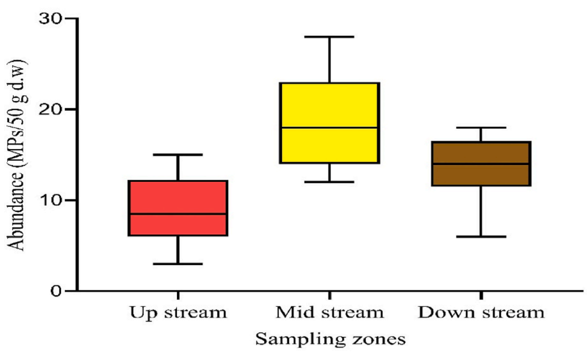

Fig. 6. Microplastic abundance in sediment sampled from Volta Lake.

Microfibers, fragments, pellets, and films were the four types of microplastics found in sediment. Of these, microfibers dominated the sediment from all three zones. Microfiber accounted for 39% (n = 155), followed by fragment 36% (n = 143), pellet 20% (n = 80), and clear film 5% (n = 20). Most of the pellets found in sediments came from the midstream samples. Microplastic between the 1001–3000 μm size class was the dominant and prevalent size class observed across all three (3) zones. This was followed by 3001–5000 μm, 501–1000 μm, and 100–500 μm. Twelve microfiber particles found in sediment had lengths above 5000 μm making them fall outside of the size definition of microplastics [3]. However, they were included because they had a width of <20 μm. Out of the 100 microplastic particles isolated from sediment for polymer identification, 22% were confirmed as PE, 20% as PP, 20% were PA, 15% were PES, 13% were polyvinyl chloride (PVC) and 10% were PS.

3.6. Microplastic abundance and sediment properties

The granulometry analysis revealed two sediment textural groups: fine sand and muddy sand. Even though muddy sand has a higher MP abundance than fine sand, the textural composition has no significant relationship with microplastic abundance. (T-test, P = 0.215). Total Organic Matter (TOC) percentage ranged from 5.8% to 17.5%, with an average of 11.7%. TOC and MP abundance did not have a significant relationship (T-test, P = 0.547).

4. Discussion

4.1. Microplastic abundance and polymer type in biota

The abundance of MPs from the largest lake in Ghana was studied. The results indicate that MP abundance was slightly higher (86%) than previously reported for wild fish from the Lijiang River (81%) in south China [47]. Similarly, Cordova et al. [48] recorded a 71% occurrence of MPs in estuarine species from the Ciliwung River in Indonesia. A higher MP occurrence (95%) was reported by Heshmati et al. [49] from the Qarasu River in Iran. In contrast, Park et al. [50] reported a 100% prevalence in freshwater species from the River Han in South Korea. Another study on the Parana River in Argentina by Blettler et al. [51] also recorded a 100% prevalence.

The abundance of microplastics varied significantly among the different samples studied. For instance, prawns which are omnivorous and benthic organisms recorded a higher mean microplastic abundance (4.7 ± 2.1 item/individual) (Fig. 2). MP ingestion rates in bottom dwelling organisms are usually reported to be higher than pelagic ones [7,34,52,53]. Bottom dwellers inhabit and feed on the fauna associated with the substrate, which might be in direct contact with contaminated sediment and serve as a prime route to plastic exposure. However, other factors such as size and maturity state influence microplastic ingestion by aquatic organisms. According to Vital et al. [54], microplastic particles attached to algae are usually consumed by organisms more often than free-floating particles.

Additionally, several studies have found high abundances of microplastics in primary producers, mostly phytoplankton [55–59], and zooplankton [6,60–63]. Primary producers ingest and accumulate microplastics during feeding in the water column. This contributes to the transfer of microplastics through the aquatic food chain. Prawns are non-selective opportunistic feeders and feed mainly on algae, plankton, snails, and other smaller fish species. Hence, the continuous ingestion of contaminated prey from the aquatic food chain could account for the higher microplastic abundance recorded. This finding is consistent with that of Lusher et al. [64], who reported a higher abundance of microplastics in omnivorous species from the English Channel and attributed their presence to the ingestion of invertebrates and planktivorous species.

Microfiber pollution threatens seafood safety due to its high abundance and bioavailability. Microfibers have been reported as the most prevalent plastic type in aquatic ecosystems. Severe studies have reported high fiber abundance in organisms [29,65–67]. The predominant fiber abundance in biota samples reported in this study could be due to municipal and industrial waste discharges, runoff from landfills near the riverbanks, or fragmentation of aquaculture cages within the Volta Lake enclave.

The dominant size category identified in the study species was microplastics smaller than 1000 μm, which accounted for more than 75% of the total estimated size class. This finding agrees with previous works by Cho et al. [31]; Digka et al. [68]; and Phuong et al. [69], who also recorded plastics smaller than 1000 μm as the commonest size range. These findings, compared with previous studies, suggest that smaller microplastic particles are preferred and more easily ingested by aquatic organisms than larger ones. Over 55% of the microplastic particles accumulated in prawns were less than 500 μm. The presence of the chitinous plate in the prawn stomach acts as a size bottleneck and retention for ingested MPs which further promotes fragmentation into smaller particles [70]. These findings are in agreement with that of Cau et al. [99] who reported a smaller size range between 70 μm and 1160 μm in crustaceans.

Polymer identification analysis revealed PE, PP, PA, PS, and PES as the dominant polymer compositions. PE and PP are primarily used as food packaging materials and have been reported as the predominant polymer types in the aquatic ecosystem (Plastic Europe. 2019). Synthetic polymers such as PES and PA accounted for nearly 60% of all world fiber production, which is used extensively in the clothing and textile industry [71]. Usually, the shredding of PES fibers from fabrics occurs during laundry and subsequent discharge into the environment [71]. In addition to laundry, used clothing disposed into the aquatic environment may shed PES fibers as they degrade [72]. As noted in the preceding sections, Ghana has become a global trade hub for second-hand clothing, most of which come in very deteriorated conditions that get disposed into the environment [73]. The association between microplastic concentrations in freshwater organisms and their surrounding environments remains unclear. Although few studies have reported a positive correlation between environmental concentration and accumulation [74], further research is essential to address the knowledge gaps. It should be noted that the major polymer composition identified in the organisms reflected what was found in the sediment samples. This observation provides evidence of the possible potential association between environmental concentration and microplastic ingestion by aquatic organisms.

4.2. Microplastic exposure and human health

Consumption of fishery products forms a significant portion of the Ghanaian diet and constitutes over 60% of annual protein intake [75]. Given Ghana's high fish and shellfish consumption, it was critical to assess the possibility of human exposure to microplastics through their consumption. Compared to the 11,000 microplastic particles that European shellfish consumers are exposed to annually, the projected yearly intake of microplastics 539 microplastic particles for clams and 484 microplastic particles for prawns is comparatively modest [76]. Another study by Addo et al. [35] reported a high annual intake (2600 MP particles per year) from the consumption of oysters (*Crassostrea tulip*) in the Gulf of Guinea. Despite some evidence that MPs in edible fish tissue negatively impact food safety, empirical evidence is lacking regarding potential relationships [61]. Although data on the toxic effects of MPs on human health is limited, chemical additives in plastics can leach into host tissues. For example, bisphenol A, a disruptive endocrine chemical, is a common additive used in plastic production that can lead to changes in the endocrine system, low birth rate, and the development of cancerous cells in humans [77]. In addition to chemical exposure, microplastics may serve as substrates for the growth of microbial communities known as 'plastisphere' in the aquatic environment. The presence of microbes on plastic surfaces may further promote the spread of pathogenic organisms such as *Vibrio* spp., *Bacillus cereus*, and *Escherichia coli*, some of which may be detrimental to human health. Despite the low exposure rate reported, microplastic toxicity and adsorption capacity are influenced by their size. Plastic particles less than 150 μm can pass through the human gut barrier [78]. Recent studies have reported microplastics <100 μm in human lymph nodes and portal veins [79]. Zhu et al. [80] reported MP size between 20 and 307 μm human placenta, while a size range of 7–16.8 μm was found in the human lungs [81]. Similarly, Huang et al. [82] reported microplastic particles in human sputum. It is disturbing to discover microplastics in these delicate parts of the body since they may have harmful effects on humans. However, a comprehensive approach is needed to establish the relationship between exposure and the fate of microplastics in humans after ingestion.

4.3. Microplastics in sediment

Sediment is considered the final sink for most contaminants, including microplastics. Plastics accumulated on the sediment floor will be resuspended in the water column under certain limnological conditions, increasing their bioavailability. High microplastic sediment abundance was observed midstream (Fig. 6) of the Volta Lake, which can be attributed to the lake's large surface area, depressed topography and continuous flow, all of which promote the sedimentation of suspended particles. The accumulation pattern of microplastics in sediment is greatly influenced by waves, water currents, tides, and some physical properties such as total organic matter and particle size distribution [83]. Currently, there is no data on the abundance of microplastics in riverine sediment in the Volta Lake for comparison. Data obtained from this study could therefore serve as a baseline for plastic waste management in Ghana. The lack of a standardised unit for reporting microplastic abundance in sediment makes comparison difficult. In contrast to studies conducted in other regions of the world, the mean microplastic abundance (13.3 ± 2.3 particles per 50 g of dry sediment) found in this study was higher than that reported by He et al. [33] from Australia's Brisbane River and Vermiare et al. [25] from Canada. Nevertheless, higher microplastic abundance has been reported in the Beijiang River in China by Wang et al. [84], the Themes River in the UK by Horton et al. [20], and by Klein et al. [85] in the Rhine River Bay in Germany. The variations in microplastic abundance from the study site could be attributed to the water current. High flow velocity is expected to increase the mobilization of sediments and plastic particles [42], and when water flow velocity reduces, plastic particles are likely to settle out along with sediment particles [86]. Like biota samples, fiber was the most prevalent plastic shape identified in sediment samples. These findings agree with previous works by Gedik & Gozler [87]; Adams et al. [88]; Cashman et al. [89]); Athey et al. [90]; Huntington et al. [91]and Mu et al. [92]. Given that both the mid and downstream portions of the sampling region are active fishing grounds, the high fiber abundance may be the result of fishing activity within the area from lost fishing ropes, nets, cages, and lines. Other sources of fibrous pollution could come from the discharge of effluents into drains that lead to the lake from textile industries located in the area. In contrast to heavy metals and other environmental pollutants with effluent discharge guidelines, there are no standards for microplastics in effluents; thus, prominent policies to include microplastics limits in effluent before discharge and robust systems to remove microplastics in effluents are required to mitigate fibrous pollution load in the catchment areas of the lake where industries are located. The study also found a significant proportion of plastic pellets (20%) in sediment mainly from the midstream. Pellets are primary microplastics produced as the base material for plastic products of different shapes and sizes. The occurrence of pellets could be attributed to anthropogenic activities predominantly from industrial waste discharges in Volta Lake. There are also other sources of pellet pollution in aquatic environments, such as spills during transportation or discarded items such as dolls, toys, teddy bears, and weighted blankets that use pellets for stuffing [93]. The presence of pellets in aquatic ecosystems is of potential environmental and health concern as most pellets contain toxic chemicals either as absorb contaminants or additives during production [98]. According to the distribution of size fractions in the sediment, smaller microplastics have a higher tendency to sink than larger ones. This is in line with the findings of Fazey and Ryan [94], who reported that smaller microplastic particles lost buoyancy considerably quicker than bigger ones during a 12-week study period in False Bay, South Africa. However, the sinking of microplastics may not ultimately result in incorporation into the benthic sediments [95].

5. Conclusion

Plastic waste mismanagement remains a threat to ecosystem function and the sustainable utilization of aquatic resources, and further studies and legislation are necessary to protect vulnerable aquatic ecosystems. The study revealed the presence of microplastics in sediment, fish, crustaceans, and bivalves from the Volta Lake in Ghana. The significant prevalence of this emerging contaminant in the largest river in Ghana, which also hosts the largest commercial freshwater fisheries and provides household and industrial water to half of the population in the national capital, is cause for concern. This study further presents a baseline of information on microplastics in the biota and sediment from this water system as few studies can be found on microplastics in freshwater ecosystems of Ghana. It is imperative to take into account the possible harm that microplastics bring to the health of the freshwater ecosystem and hence regular monitoring is therefore recommended to identify hotspots to be able to address pollution sources more effectively.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Charles Mario Boateng: Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Samuel Addo:** Supervision, Resources, Project administration, Investigation, Formal analysis, Data curation. **Collins Prah Duodu:** Writing – original draft, Supervision, Methodology. **Harriet Danso-Abbeam:** Writing – original draft, Supervision, Conceptualization. **Prince Chapman Agyeman:** Validation, Supervision, Methodology. **Kofi Ferni Anyan:** Writing – review & editing, Validation, Investigation. **Eunice Konadu Asamoah:** Investigation, Formal analysis, Conceptualization. **Emmanuel Robert Blankson:** Writing – review & editing, Validation, Supervision. **Elvis Nyarko:** Writing – review & editing, Validation, Supervision, Data curation. **Atsushi Matsuoka:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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