Microplastic Presence in Sediment and Water of a Lagoon Bordering the Urban Agglomeration of Lagos, Southwest Nigeria

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Abstract

Microplastics are a fast emerging group of contaminants. Their worldwide occurrence in water, sediment, and aquatic fauna raises questions and concerns as to their probable effects on aquatic life and ecology. This study investigates for the first time presence, abundance, and types of microplastics in water and sediment from a lagoon bordering the large urban agglomeration of Lagos in Nigeria, and renders additional information about grain size and sediment composition. Water and sediment samples were collected from four locations in the Lagos lagoon and a tributary. The abundance and distribution of microplastics in four range classes were determined for the sampled locations. Plastic particles were counted using digital microscopy, and identified with FTIR and pyrolysis GC-MS. The abundance of microplastics ranged from 310-2319 microplastic particles/kg in sediment, and 139-303 particles/m^3 in water. The large discrepancy in the sediments can be explained by sediment characteristics as more microplastics were detected in the fine-grained sediments of Makoko. Fibres were the predominant shape found in all samples followed by fragments and few films whereas spheres were missing. Fibres were more abundant in water (92.6 %) than in sediments (32.5 %) while more fragments and foils occurred in sediments. The most commonly used polymers polypropylene and polyethylene were also the most detected ones in both matrices. Compared to other studies in Nigeria, our findings especially in the coarser sediments were lower while the fine-grained site revealed similar results.

Keywords: Lagos lagoon, plastics, FTIR, pyrolysis GC-MS, sedimentology

1 Introduction

Plastic pollution of the world's oceans and inland waters has become a matter of global concern [1, 2]. The plastic production has exponentially risen from 1.5 Mt in 1950 to 359 Mt in 2018 [3]. Millions of single-use bottles are purchased daily, and the use of plastic bags is even more pervasive with approximately trillions per year [4]. Improper waste management leads to littering in the environment and to a rising occurrence of plastics in freshwater and marine environments. Macroplastics degrade to microplastics (MPs) (<5 mm) which were first described in the 1970s [5, 6]. They enter fresh- and marine waters when not properly disposed. Thus, most of the world's plastic reaches the oceans by rivers and other inland waters [7-9]. Moreover, large amounts of such debris affects the aquatic fauna posing risks of fouling/entanglement, injury, and ingestion [10, 11].

However, basic information about the occurrence of MPs in Africa's oceans, lakes, and estuaries is lacking [12]. MPs in water have been investigated in Lake Naivasha, Kenya [13] and in sediments in seven tributaries of the Bizerte Lagoon in Tunisia [14]. For Nigeria, one study about MP ingestion of gastropods in the river Osun, Nigeria (a tributary of the Lagos Lagoon), and another about MP ingestion of aquatic insect larvae has recently been published [15]. MPs in fish in the River Nile, Egypt [16], in pelagic and demersal fish [17] and two local fish species [18] in the marine waters of Ghana were also investigated.

The city of Lagos is a densely populated area with a proliferation of overcrowded slums and neighborhoods that are home to millions of the city's population [19]. These densely populated locations next to the bordering Lagos Lagoon are significant contributors to the loading of plastic waste into this water body. In the city of Lagos, large amounts of waste are generated daily, with plastics contributing a significant proportion [20]. Missing or improper management leads to a high amount of waste in the environment.

The goal of this study is to present first data about the presence, abundance and types of MPs in water and sediment of the Lagos Lagoon abutting the large urban agglomeration of Lagos in Nigeria and to compare these results with sedimentological characteristics of the sediments.

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2. Materials and methods

2.1 Study area

The study area is located at the Gulf of Guinea in the State of Lagos, Nigeria. The city Lagos is a west African megacity [21] with a large and strongly growing population estimated at 17 million inhabitants [22] and projected to reach 88.3 million by 2100 [23]. The lagoon of Lagos borders the city of Lagos. With an estimated length of 50 km, width of 3-13 km, and a total size of 6354.7 km² [24], the lagoon is the fourth largest lagoonal system of the Gulf of Guinea. The two larger rivers Ogun and Osun discharge into the lagoon. Several channels and the Badagry creek connect the lagoon with Cotonou, Benin in the west, and with the Lekki lagoon to the east. A 2-16 km wide beach barrier separates Lagos Lagoon off the Gulf of Guinea. Badagry creek has its confluence with the lagoon in its southwestern part where they discharge into the Gulf of Guinea (Figure 1).

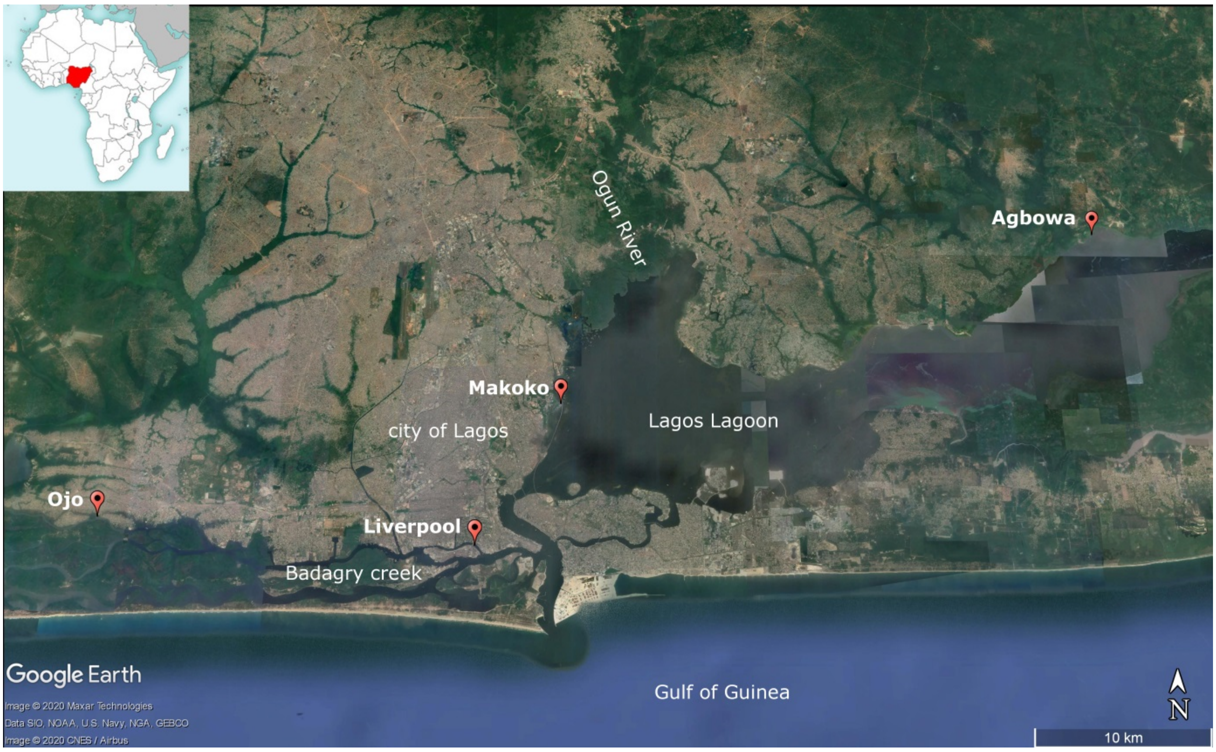

Figure 1: Location of the study area. Sampling sites in the Lagos Lagoon and the Badagry creek (source: Google Earth pro 2020).

Four different sites were sampled along the Lagos Lagoon (Agbowa and Makoko) and further west (Ojo and Liverpool) (Figure 1). The sampling sites Makoko and Agbowa are located inside the Lagos Lagoon. Makoko [25] on the western side is characterised by stilt houses. Ojo lies upstream of Badagry creek 37 km to the west of Lagos city and Liverpool/Apapa with the main harbour of the agglomeration of Lagos further downstream. Badagry creek was sampled upstream and at the site Liverpool, close to the embouchure into Lagos Lagoon.

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2.2 Sampling

The samples were taken approximately 1 m from the shore. Four water samples (one per sampling site) of 700 mL were taken with a pre-cleaned jar directly below the water surface. The four sediment samples (one per sampling site; ~110-190 g) were retrieved with a Van-Veen-grabber at a depth of approximately 80 cm.

2.3 MP extraction from water and sediment samples

Water samples were filtered using glass fibre filters paper (Whatman™ 1823-047 Grade GF/D, diameter: 4.7 cm, pore size: 2.7 µm). Sediments were oven-dried and sent to the Federal Institute of Hydrology (Koblenz, Germany). The wet and dry weight of sediment samples were noted. Depending on the amount of organic matter, the samples were digested with 35–145 mL of hydrogen peroxide (Sigma-Aldrich 34.5-36.5 %) and agitated for 5–6 days. MP particles were separated from the remaining inorganic material in a separation funnel with a saturated aqueous potassium formate solution (density: 1.6 g mL^{-1}). After 3–4 days, the lowest water phase with inorganic material was separated and the remaining water with MPs pressure-filtrated on nanopore inorganic membrane (anodisc) filters (Whatman, diameter: 47 mm, pore size: 0.2 µm). The filters were covered to prevent contamination, air-dried at 50°C, and stored in an aluminum bowl.

2.4 Identification of MP in water and sediment samples

2.4.1 Visual identification

For visual identification, a digital microscope with an attached camera (Keyence VHX2000) was used. Standard criteria for visual identification of tentative MP particles were chosen after Norén [26]. Colour (black, blue, grey, green, purple, red, transparent, turquoise, white, yellow), size (longest particle diameter), and shape (fragment, sphere, fibre, film) were considered. Moreover, the absence of organic structures, equal thickness e.g. for fibres and homogenous coloration of the particle were taken into account. For the water samples, total particle abundance was calculated based on the filtered water volume and stated as MP per m^3. MP of sediment samples are given as MP per kg dry sediment .

2.4.2 ATR-FTIR and µFTIR analysis

All tentative MP >2 mm were measured with a Vertex 70 ATR-FTIR (Bruker, Ettlingen, Germany). Subsamples <2 mm of tentative MP of both water and sediment samples were further isolated and analysed using µFTIR analysis (Hyperion 2000, Bruker, Ettlingen, Germany) to determine particle polymer composition. The FTIR measurements with the Vertex 70 were conducted in attenuated total reflectance mode (ATR) in a wavenumber range of 4000-600 cm^{-1} with 8 co-added scans and a spectral resolution of 4 cm^{-1}. The µFTIR measurements were conducted in transmission mode (wavenumber range 3800-1250 cm^{-1}) and ATR (wavenumber range 4000-600 cm^{-1}) mode with 32 co-added scans and a spectral resolution of 4 cm^{-1}. Particle spectra were compared to a plastic polymer data bank with reference spectra for the most common polymer types using the software OPUS 7.5 (Bruker) [27] and considered as MP with a hit quality >700 [28, 29]. Natural fibres were also identified.

2.4.3 Pyrolysis GC-MS analysis

For pyrolysis GC-MS, selected particles and fibres from water and sediment samples were measured in metal cups (Eco-Cup LF, Frontier Laboratories, Saikon, Japan) and flash pyrolyzed at 600°C [30]. Measurements were done with a Multi-Shot Pyrolyzer EGA/PY-3030D (Frontier Laboratories, Saikon, Japan) and an Auto-Shot Sampler AS-1020E (Frontier Laboratories, Saikon, Japan). An Agilent 7890B gas chromatograph (Santa Clara, CA, USA) with a separation column DB-5ms (Agilent, Santa Clara, CA, USA) of the dimensions 30 m length, 0.25 mm inner diameter, 0.25 µm film thickness was used. Injection was performed in split mode with a split ratio 1:25 for particles and 1:10 for fibres. Chromatographic separation was performed by the temperature program: hold at 40 °C for 2 min, increase at 20°C min^{-1} to 320°C and hold for 13 min. An Agilent MSD 5977B (Santa Clara, CA, USA) in full scan mode (m/z 40-500) was used for detection. For identification, the resulting pyrograms were compared to the NIST 14 MS database and the F-Search 3.4 database (Frontier Laboratories, Saikon, Japan).

2.5 Quality control

Quality controls for the samples were conducted during the extraction process and visual sorting. For the extraction process, two processing blanks were run by digesting and filtrating 10 mL of distilled water in the same way as the water and sediment samples. For the quantification of atmospheric fallout, aluminum oxide filters (sorting blanks) were exposed next to the digital microscope for a duration equalling the time needed for visual analysis for filtrates of one sampling site. MPs on the processing and sorting filters were characterized visually and some representative particles analysed with the µFTIR.

2.6 Granulometry and C/N ratio

For grain size analysis, the sediment samples were dried and sieved (<2 mm). Samples were treated with hydrogen peroxide (15% H_2O_2) for destruction of the organic content and with sodium pyrophosphate (Na4P2O7, 46 g/l) for dispersion. A laser diffraction particle size analyzer (Beckman Coulter, LS‐13320) was used for measuring the grain size. Statistical

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analysis was done with the Gradistat software [31]. For measuring the C/N ratio, all sediments were homogenized and weighed three times in tin boats. Measurements were conducted with a Vario Macro CNS (Elementar). Total carbon (TC) and nitrogen (N) were determined, followed by the total organic carbon (TOC).

3. Results

3.1 Abundance, shape and size

After visual analysis, all water and sediment samples from the four locations (Figure 2) Agbowa, Makoko, Ojo and Liverpool contained tentative MPs with sizes >100 µm. For sediments, Makoko revealed the highest quantity of MPs (2319 MPs/kg) followed by Ojo (410 MPs/kg), Liverpool (345 MPs/kg) and Agbowa (310 MPs/kg) (Figure 2) The water samples revealed concentrations with a max. in the Liverpool sample (303 MPs/m³) and a min. in the Agbowa sample (139 MPs/m³). In Makoko and Ojo samples, ca. 200 MPs/m³ were counted (204 MPs/m³ and 184 MPs/m³ respectively).

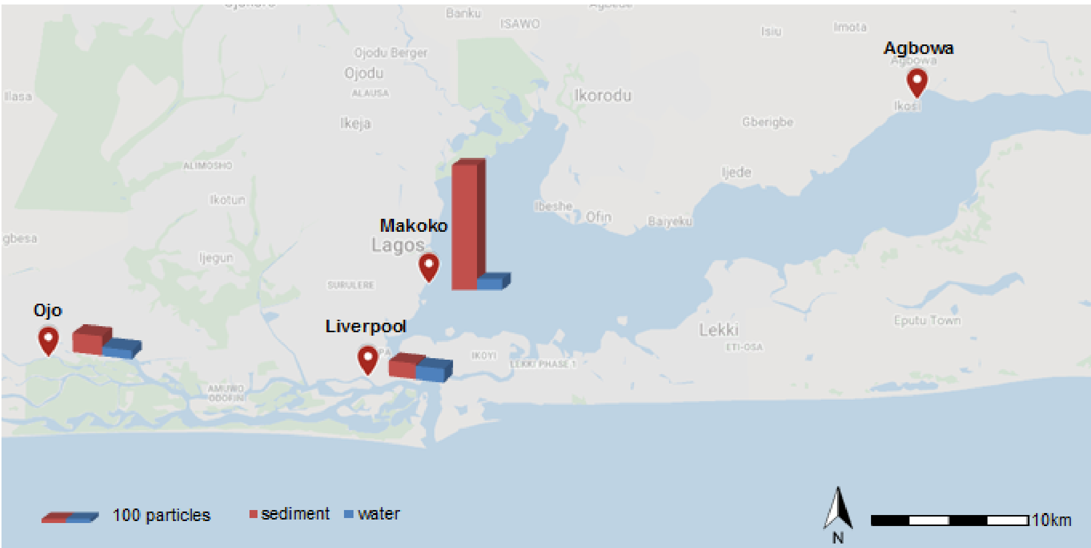

Figure 2: Abundance of MPs in sediment and water at the four sampling sites (source: Google Maps, 2020)

The three shapes fibres, fragments and foils were differentiated. The majority of tentative MPs were fibres. In the water samples 87-95 % fibres were counted, in sediments 24-50 %. Some fragments (2-11 %), mostly in Liverpool and Agbowa, and few foils (0-4 %) were detected in the water phase. The shape differed within one site in the different compartments as the number of fragments was considerably higher in sediments (31-73 %; min. Ojo, max. Liverpool) than in the water phase (1-12 %). Only Ojo revealed more fibres than fragments in the sediments. Moreover, the number of foils was higher in the sediments from Makoko and Ojo (both 18/19 %) than in the other two samples (Liverpool 2 %, Abgowa 7 %) (Figure 3).

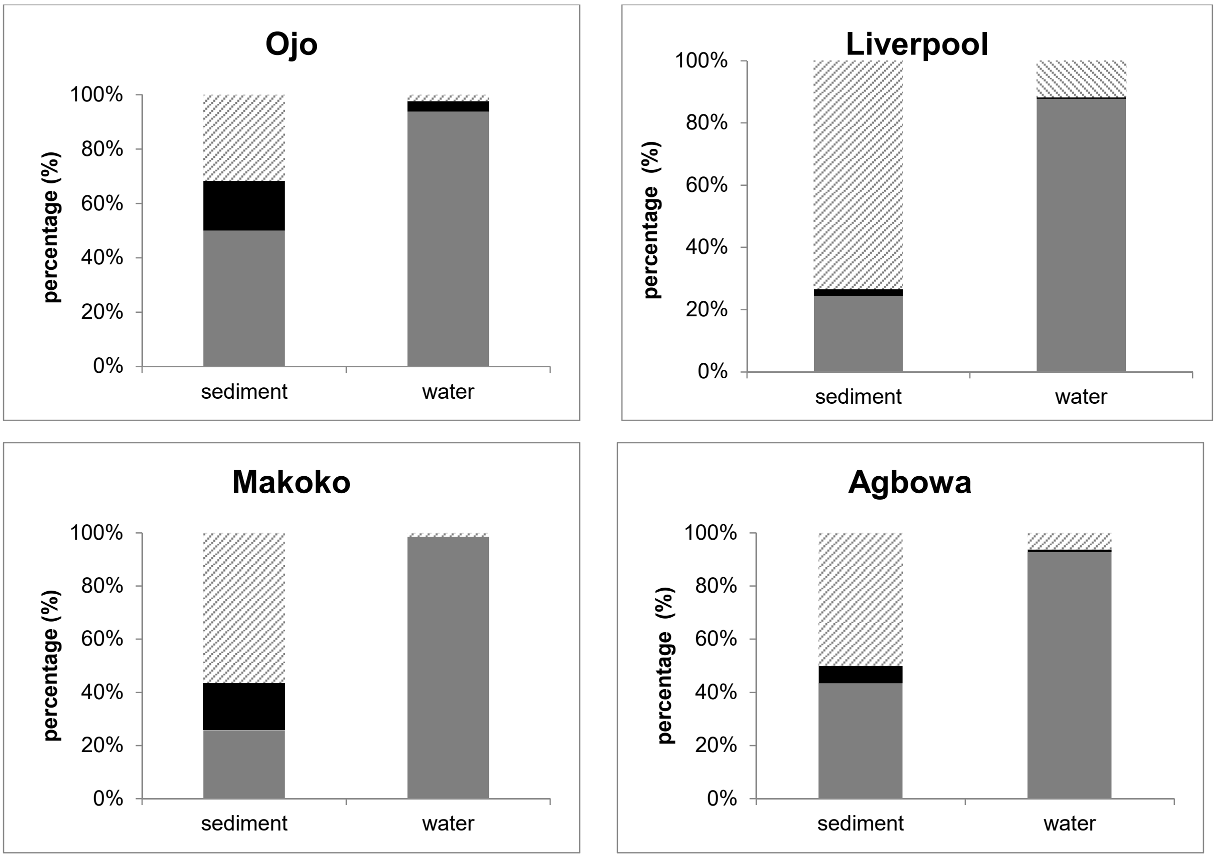

Figure 3: Form of microplastics in water and sediment samples (grey: fibre, black: foil, dashed line: fragment).

MPs were diffentiated into three size classes 100-500 µm, 500-1000 µm and >1000 µm. The size of the tentative MP reveals contradictory results in the two compartments: more particles with a larger size were counted in the water phase (Figure 4). With the exception of Agbowa, more particles with a smaller size were present in the sediments.

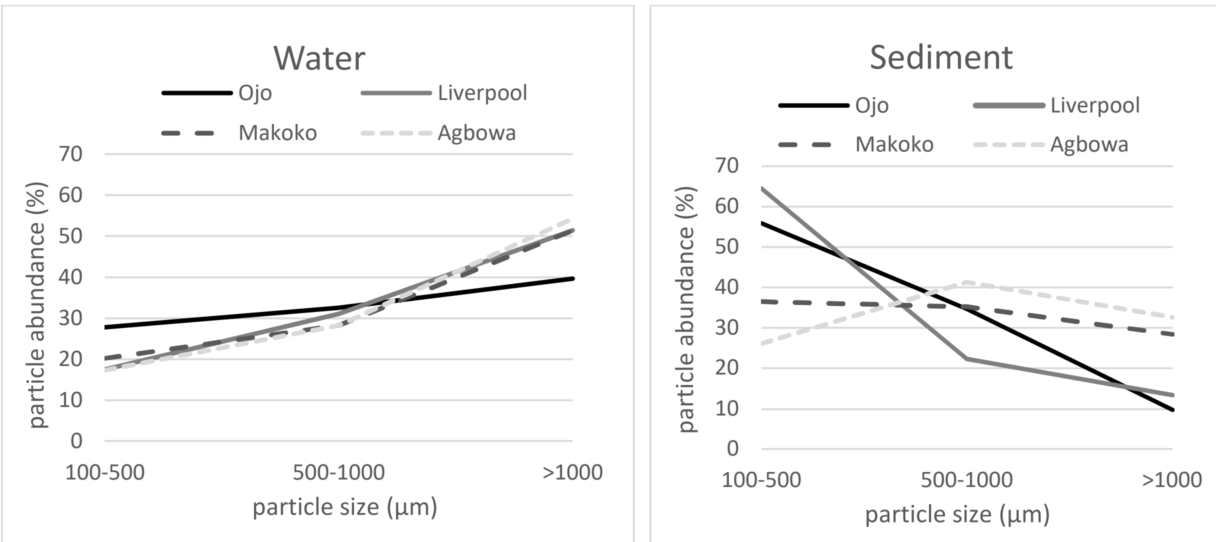

Figure 4: Size distribution of tentative MP particles (visual analysis) in the water and sediment samples of the four sampling sites.

MPs of ten different colours were identified in the samples: black, blue, grey, green, purple, red, transparent, turquoise, white and yellow. The most common colours of tentative MPs were transparent (41 %) and black (30 %) for sediments and black (40 %), blue (23 %), and transparent (22 %) for the water samples.

3.2 Control samples

On the blanks, only fibres were detected. On processing blanks, 13 fibres were counted for water samples and 58 for sediments. Sorting blanks revealed 1-4 fibres per sampling site. Representative fibres (two blue, one red, one transparent) were measured using µFTIR. The results revealed that all measured fibres were of natural origin, most probably cotton.

3.3 Grain size and C/N

The sediments of Ojo, Liverpool, and Agbowa are composed of coarse-grained sand (mean 450-608 µm). Makoko in contrast is dominated by clayey silt with a mean of 18.5 µm (Table 1).

Table 1: Grain size distribution (%).

Grain size distribution	Ojo	Liverpool	Makoko	Agbowa
sand (%)	99.5 %	99.7 %	32.7 %	98.7 %
silt (%)	0.20 %	0.10 %	52.80 %	0.90 %
clay (%)	0.3 %	0.2 %	14.5 %	0.4 %
mean (µm)	606.9	608.8	18.46	453.6
sorting (µm)	1.89	1.7	7.9	2.31

The C/N ratio and TOC (total organic content) was determined for all sediment samples. Ojo has a C/N ratio of 15 % and a TOC of 0.3 %.,Liverpool a C/N of 30 % and a TOC of 0.6 %, Makoko a C/N of 20.22 % and the highest TOC (4.65 %). The lowest C/N ratio was measured ar Agbowa (12.5 %, TOC: 0.25 %).

3.4 Microplastic identification

45 representative particles out of 889 (5.1 %) were chosen for FTIR and pyrolysis GC-MS analysis. 18 particles could be identified as polymers. In the water phase, PP, PE and polyester were identified while sediments revealed a more diverse polymer distribution (PP, PE, polyester, PS and polyacrylic). The most abundant polymer type was PP (23 % in sediments, 17 % in water), followed by polyester for water (13 %) and PE for sediments (9 %) (Figures 5, 6).

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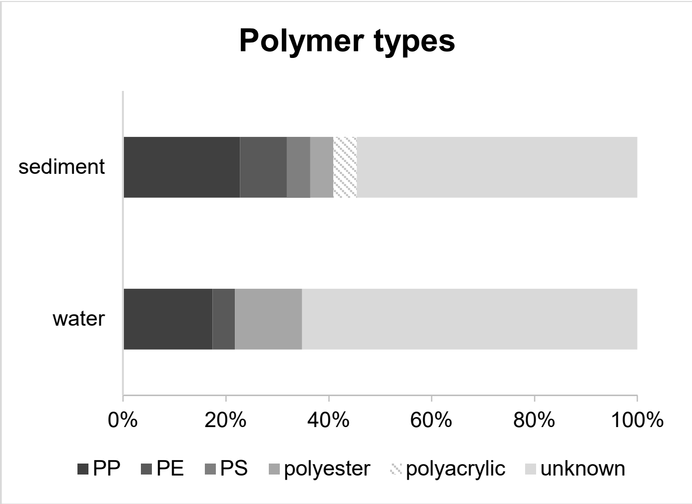

Figure 5: Polymer abundances in percentage in water and sediment.

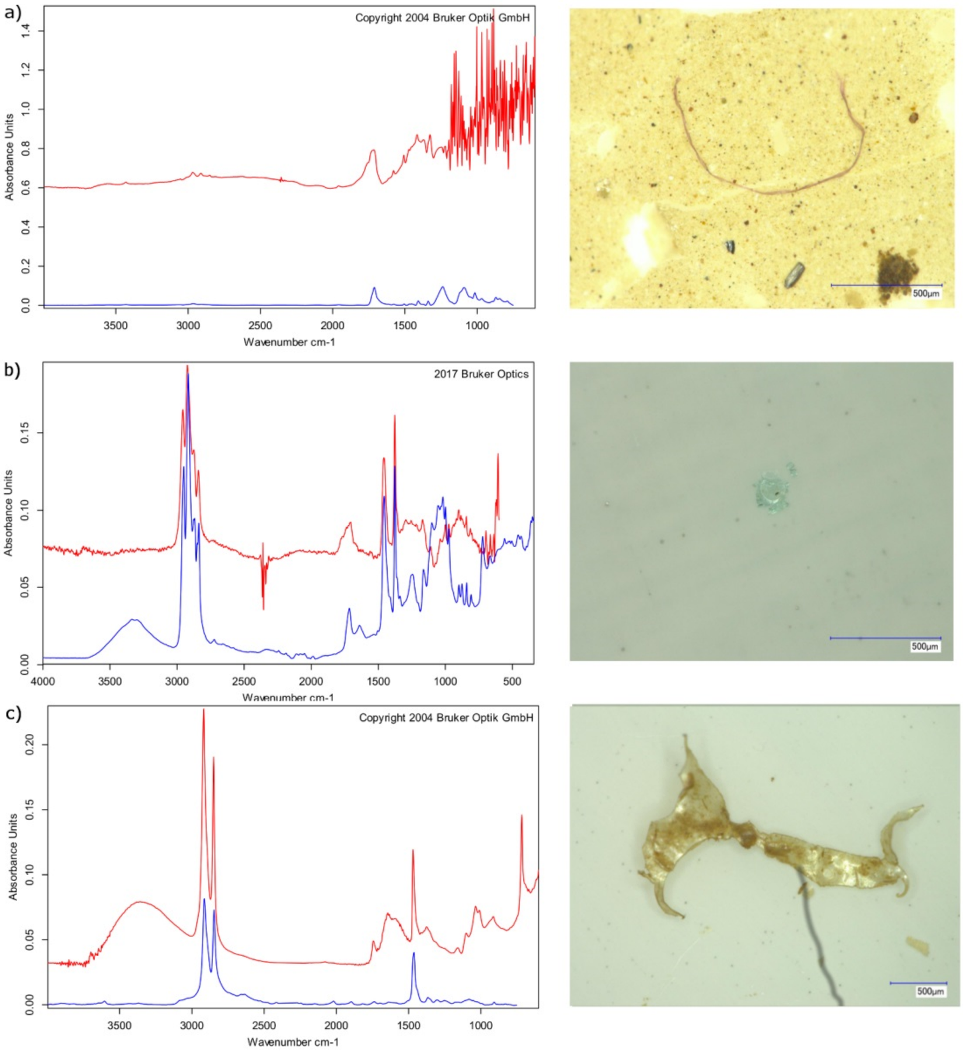

Figure 6: µFTIR spectra (red: measured spectrum, blue: reference spectrum from the Bruker spectral database) of analysed microplastics: a) red polyester fibre, b)green polypropylene fragment , c) transparent polyethylene foil.

4. Discussion

4.1 Characterization and distribution of microplastics in Nigeria and the Lagos lagoon

The ubiquitous presence of MPs in the world's oceans has been described by different authors [32, 33]. Estimations show that millions of tons of plastic waste enter the world's oceans every year originating predominantly from land-based sources (e.g. as a result of poorly managed waste) [34-36] and transported via freshwater into the oceans [37] where it is present in marine litter aggregations [38]. At the same time, MPs are generated due to attritive processes including photolytic and thermal oxidation, hydrolysis, and microbial driven biodegradation [39]. This ultimately results in the degradation of larger marine plastic fragments in a prolonged and sustained manner considering the environmental resilience and persistence of fabricated plastic polymers. In contrast, only little information on presence, distribution, types and contribution of inland waters including estuaries, rivers and lagoons especially from inland Africa [40] is available [41].

The per capita consumption of plastics in Nigeria has grown consistently since 1997 and is estimated to reach 7.5 kg in 2020 [42]. Based on the latter projection and using Lagos as a microcosm of Nigeria, the city is set to generate a correspondingly large amount of non-degradable waste in 2020, mainly of single-use type plastics. Considering this against the backdrop of poor sewage disposal, usually without preliminary waste treatment, of liquid domestic and industrial waste streams, indiscriminate solid waste disposal and incineration on unprotected/poorly managed landfills [43], land-based contributions to plastic waste generation and contamination of water niches in the Lagos scenario can be rightly surmised to be significant.

The results of this study clearly revealed that more MPs were found in sediments than in the water phase. Moreover, between the study sites, differences were visible. Makoko had the highest amount of MPs with 2319 particles/kg, about eight times more than the other sites (310-410 particles/kg). The sediments of Makoko mainly contained silt and clay. A lower flow velocity and the deposition of more fine-grained particles are the consequence. Makoko is a community of largely stilt habitations situated offshore, and directly built into the lagoon. Movements between habitations and fishing activities (livelihood of a majority of inhabitants) are mainly done using paddle boats which serve as floating markets and service centers for residents. Waste (human, animal, solid) is directly disposed into the lagoon. The sediments of the other three sampling sites, in contrast, mainly consisted of sand (ca. 99 %) and considerably fewer numbers of MPs in water and sediments. This can be explained by a higher flow velocity of the creek and in the lagoon and thus by a deposition of fewer small particles. In the water phase, the highest amount of water-suspended fibres was counted in Liverpool (302 particles/m^3) whereas Makoko only revealed 204 particles/m^3. Liverpool also

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revealed the highest numbers of MPs >1000 µm in the water phase and the highest proportion of fragments in the sediments (73 %). A description of human activities at this location may help to explain the latter finding. This location is a major embarkation and berthing site for water transport boats, a landing site for one of the biggest daily fish markets in Lagos, and a site of significant levels of sand dredging. Liverpool is also located close to the main Lagos port and sea lanes. These activities serve to keep the waters in this location in a semi-permanent state of flux responsible for prolonged suspension and reduced settling of MPs. Alongside seasonal high water runoffs such as heavy rainfall events could help to accentuate the situation by remobilizing pools of larger sediment-bound MPs [44]. We surmise that MP distribution in all matrices and locations are governed by the local dynamics of their proximity to urban areas and human activities, as suggested by Frere et al. and Tata et al. [45, 46].

Fibres were the most common MP type in the water phase. A predominance of fibre presence in sediment and water have been reported in other studies in peri-urban water bodies [47-50]. These large percentages of fibres could be attributed to domestic wastewater streams, sewage overflows, in-situ washing of synthetic fabrics, seasonal rainy season inundations, terrestrial runoffs, and tidal hydrological interplay with the adjoining Atlantic ocean (fluvial dynamics).

The sediment composition may enhance retention at Makoko. A Canadian study [51] reported a higher number of MPs in water (max 220/m^3) than in sediment (max. 2400/kg DWT), but a similar preponderance of fibres. The authors posited that MP abundance in sediments was not significantly related to the mean particle size or the organic content of the sediment, suggesting that aggregated MPs (clumps) settle quicker due to mixing with other orgarnic and inorganic materials (foulers), giving greater density/less buoyancy and thus enhancing MP settling [51]. The authors suggest further investigations to ascertain these observations. Other studies in fresh- and marine waters showed that fibres have a low settling velocity. Moreover, water currents also prevent fibres from sinking and thus they do not accumulate in the sediments [52-54]. Foils and fragments were more common in the sediments than the water phase, probably due to the development of biofilms, the density of the polymers [55-57], or a lower surface to volume ratio [58]. Their particle size was also smaller (125-500 µm in sediments) whereas fibres with a size >1000 µm dominated the water phase. Thus, a direct connection between particle form and particle size can be made (see Fig. 4) [59].

The polymer content also reveals differences between the compartments. Polypropylene (PP), polyethylene (PE) and polyester were the most common polymers in the water samples. Sediments were characterised by a more diverse polymer distribution (PP, PE, polyester, PS, and polyacrylic). This has been confirmed by other studies [60-63]. The higher diversity in the sediments can be explained by many polymers with a density >1 g/cm³ as well as weathering, biofouling or, the formation of hetero-aggregates [55-57].

Abundance trends for water and sediment were fairly consistent with global trends of polymers (PE ≈ PP > PS > PVC > PET), indicating global [64] and local plastic demand [42] in Nigeria. Low-density polyethylene (LDPE) and PP are widely used in plastic packaging, PP especially for the packaging of water in sachets. This single-use applications of LDPE and PP have made indiscriminate post-usage disposal one of the most significant sources of non-degradable waste in Nigerian urban centers [65, 66], being responsible for the pollution of waterways, storm and sewage drains, and landfill mass in terms of sheer tonnage. Black plastic foil (>2 mm) as commonly found in the Makoko sediments probably originated from black plastic bags such as shown in the study by Akindele et al. [67].

4.2 Comparison to other studies

In this study, MP abundances ranged between 310-2319 MPs/kg and 139-303 MPs/m³ in sediment and water, respectively. Ilechukwu et al. [68] studied four beaches in the Lagos Lagoon and detected higher concentrations of MPs on beaches along the southern coastline (2420-3400 MPs/kg) than our findings in the western part of the lagoon. However, our results confirm the occurrence of the polymers PE, PP and PS which have been described by Ilechukwu et al. [68]. Martellini et al. [69] published a compilation of MP studies in coastal areas in the Mediterranean Sea. The results of studied sediments reveal that the most contaminated sites were the lagoon and estuaries. Sediments were predominantely studied. In Tunisia, two studies have been published about sediments of the Bizerte Lagoon and surrounding streams [70]. The results revealed higher counts than in this study with 2340-6920 MPs/kg for the streams and 3000-18,000 MPs/kg for the lagoon. Similar to this study, fibres and fragments dominated. In the Venice Lagoon, similar MP concentrations (672-2175 MPs/kg) as in Lagos Lagoon were observed [71].

The polymers in all studies were also similar to our study with a dominance of PP and PE. Results for the water phase were published for the freshwater Lake Naivasha, Kenya with very low concentrations of 1.5-5 MPs/m³ [13]. For rivers in contrast, many studies investigating the water phase report concentrations of 0.29 [48] to 340.000 MPs/m³ [72]. Thus, compared to rivers worldwide, the findings in the Lagos lagoon range in the lower limit of these results. A reason for this relatively low number especially at the sites Ojo, Liverpool and Agbowa could be the location of the study site as three of the four sites are dominated by sand.

Conclusion

One consequence of the exponential increase in plastic production worldwide is the presence of plastics in the marine environment. Rivers are responsible for the majority of the plastic input into the oceans. In order to draw conclusions about Nigeria's plastic input, this study was carried out to demonstrate the pollution caused by MPs in the Lagos Lagoon and the adjacent rivers. Plastic contamination of the water bodies could be determined by taking samples at different water bodies. In sediments, more MPs were counted than in the water phase (139-303 MPs/m^3). Within the sediments, comparatively more microplastics were found in the fine-grained sediments of Makoko (2319 MPs/kg) than in the sandy three other sites (310-410 MPs/kg). This clearly shows that MPs dominate the finer grain sizes. However, as only four samples were analysed in both sediment and water, a more detailed investigation with more samples is absolutely necessary for further studies.

The form also differed in the compartments: The water phase was dominated by larger MPs and fibres whereas more fragments and smaller MPs were present in the sediments. This is most probably due to a higher fragmentation in the sediments.

The most common polymers were PE and PP such as proven in many other studies.5 % of the potential MPs particles were identified by means of FTIR and pyrolysis GC-MS. However, the misidentification rate especially with the pyrolysis GC-MS was quite high. This was most probably caused by single measurements especially of fibres and a too low concentration of polymers within these fibres. Thus, future studies should also include more measurments of the potential MPs.

As the Lagos Lagoon is connected to the Gulf of Guinea, one part of the plastic will most probably be transported into the final sink the Atlantic Ocean. In the future, further studies will be needed to determine the exact concentrations, the increased sources of entry and the possible effects of microplastics.

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