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Studies on the Impact of Microplastics in Freshwater Systems: Biota Could Be Vital Indicators in Delta State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Microplastics have impacted freshwater system globally. Despite the global concern about microplastic pollution, only a little is evidenced in research on the occurrence and intensity of pollution in research. This study determined the effects of microplastics on aquatic water bodies was determined using plants as bio-indicator. The study was conducted bimonthly (June- August) to examine the occurrence of microplastics. Physicochemical parameters and biochemical

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parameters of plants were analyzed using standard methods. Hydrogen ion concentrations of the water sources were mildly acidic (5.6±0.15 and 5.49±0.19), and turbidity levels were notably high (71.00±4.20 NTU and 92.70 ±4.32 NTU) in lotic and lentic water bodies respectively. Dissolved oxygen and biological oxygen demand were significantly compared within aquatic systems ($p<0.05$). Water hyacinth- Pontederia crassipes Mart (former Eichhornia crassipes) exhibited higher levels of soluble sugar at 110.34±3.32 mg/L in lotic water body compared to water leaf- Talinum triangulare (Jacq.) Willd, 70.44±4.78 mg/L in lentic water. Total chlorophyll levels and water retention capacity were lower in lotic water at 37.90±2.35 and 2.08±0.21 respectively. Ascorbic acid levels were higher in lotic water (308.00±12.34 mg/100g). Chironomus sp. and Nais sp. were commonly encountered. The vital role of Chironomus sp. and Nais sp. should not be underestimated as bioindicators in freshwater systems. Hence, they should be further investigated in different freshwater ecosystems.

Keywords: Aquatic insects; bio-indicator; fresh water; plant; plastic pollution; human well-being; aquatic ecosystems.

1. INTRODUCTION

Plastic pollution in aquatic ecosystems has gained global attention in recent years due to its detrimental effects on biodiversity, ecosystem health, and human well-being [1]. Plastics are synthetic polymers that have revolutionized various industries due to their durability, versatility, and low cost. However, their extensive use and improper disposal practices have led to their accumulation in aquatic environments, posing severe ecological and environmental challenges [2]. Most plastics will form plastic debris with a small particle size. Microplastics in the environment can be further degraded/fragmented to produce microplastic less than 5mm in size or nanoplastics (1–100 nm), which, when compared to other forms of plastic litter, have largely unknown fates and toxicological properties (da Costa et al*.*, 2016), [3]. Microplastics can be classified as primary or secondary, depending on how they are produced. Primary MPs are plastic particles released directly into the environment via domestic and industrial effluents, spills and sewage discharge or indirectly via run-off). The range of primary MP particle types includes fragments, fibers, pellets, film and spheres [4]. Secondary MPs are formed as a result of gradual degradation/fragmentation of larger plastic particles already present in the environment, due to e.g. UV radiation (photo-oxidation), mechanical transformation (e.g. waves abrasion) and biological degradation by microorganisms [5]. The microplastics can accumulate harmful pollutants from the surroundings thereby acting as transport vectors, causing harm and entanglement to aquatic organisms, leading to injuries, impaired mobility, and even death [6].

The physical presence of microplastics can cause harm, plastic debris in aquatic ecosystems comprises various types of polymers, each with different physical and chemical properties. Common types of plastics found in aquatic environments include polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS) [7]. The composition of plastic debris can vary depending on the sources and degradation processes. Furthermore, plastics contain a variety of chemical additives, including plasticizers, flame retardants, and UV stabilizers, which can leach into the surrounding environment and potentially affect organisms [8]. These additives may have toxic effects, causing cellular damage, immune system suppression, and disruptions in hormonal balance [8]. Long-term exposure to chemicals can have wide-ranging effects on organism health and may have a severe impact on aquatic insects particularly on immature aquatic insects [9,10]. Maximum impact on floral communities is however observed in form of microplastics. Wright et al., [11] emphasized the important role of microplastics as they are easily ingestible by small organisms such as plankton species and form a pathway for contaminants to enter the food web. Microplastics can be transported over long distances by ocean currents and wind. Invasive species attached to these plastics can be carried far from their native ranges, leading to the introduction of potentially harmful organisms into new ecosystems [12]. Remote and isolated regions, such as islands, can be particularly vulnerable to invasive species introductions as well. Microplastics washed ashore on these islands can transport invasive organisms, impacting native biodiversity and ecosystem functioning [13]. Microplastics accumulate biofouling communities composed of various organisms, including invasive species. These bio-fouled plastics can serve as mobile ecosystems, providing shelter and sustenance for invasive species during their transit across water bodies [14].

The arrival of invasive species via microplastics can have detrimental effects on native ecosystems. Competition for resources, predation on native species, and alteration of ecosystem dynamics are among the potential consequences, which may result in ecosystem disruption and biodiversity loss [15] Aquatic insects have been copiously used in biomonitoring since most groups are sessile and their lifespan is long enough for assessment of specific ecological conditions [16].

Various studies have provided evidence of microplastic ingestion by freshwater aquatic insects. The study of Hurley et al*.* [17] reported MP in oligochaetes, Nel et al*.* [9] in Diptera/chironomids, Akindele et al*.* [18] in gastropods and Windsor et al*.* [19] in Ephemeroptera and Trichoptera. This is possible given the fact that freshwater aquatic insects have a wide range of feeding guilds (e.g. grazers, shredders, collectors-filterers, collector gatherers and predators) and ecological niches [16], they could be suitable indicators for assessing microplastics pollution, both in the water column and in the benthic zone of freshwater systems. A high rate of microplastic ingestion by aquatic organisms in some United Kingdom rivers was reported by Windsor et al., [19], with approximately 50% of all sampled insects ingesting microplastics, and they were recorded in three insect families such as Heptageniidae, Baetidae and Hydropsychidae. This study provides further insight into the presence and chemical nature (polymers) of microplastics in two freshwater habitats; the lotic and lentic waters in Delta State, Nigeria. The impact of microplastics on water quality was determined, using surrounding plants (Water hyacinth- *Pontederia crassipes*, Water leaf - *Talinum triangulare*) and aquatic insects as bioindicators.

2. MATERIALS AND METHODS

Study area: This study was conducted in Delta State, Nigeria. Two freshwater bodies were selected. Lotic water located along the Warri River- Burutu section in Burutu local Government Area, Delta State (Station 2) and a lentic water body located at Abraka in Ethipoe East Local Government Area, Delta State (Station 2) (Figs. 1 and 2). Water hyacinth *Pontederia crassipes* was the plant used for bioassessment in the lotic water while water leaf (*Talinum triangulare*) was the plant for bioassessment in lentic water. Station 1 is the MP-free station comprised of two stations; one lentic and one lotic site without MP impacts.

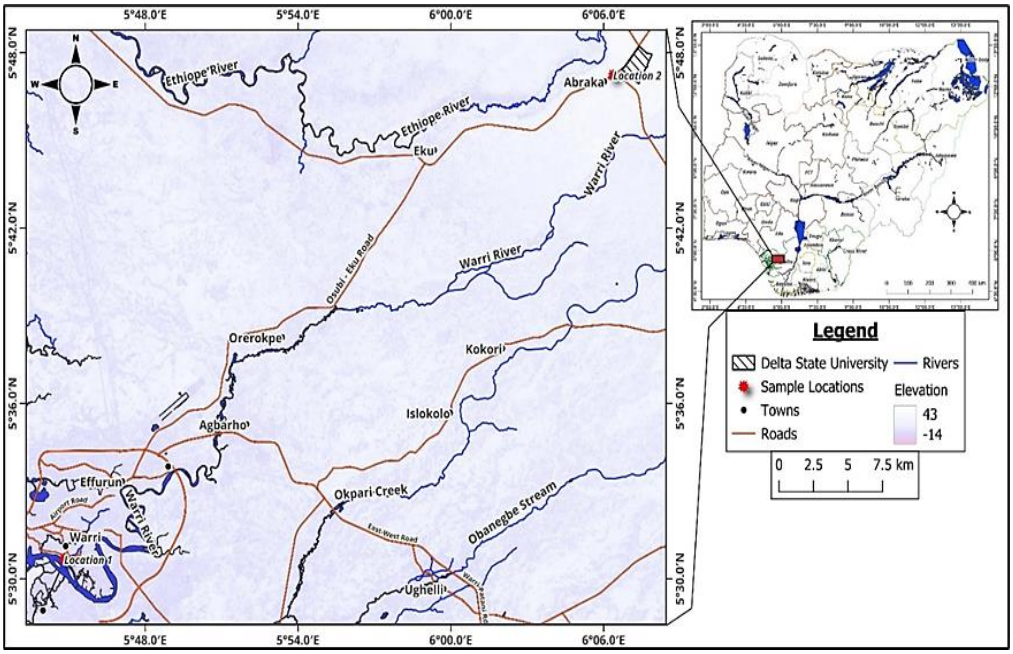


Fig. 1. Map showing the study areas

Station 1. Plastics polluted **Station 2. Plastic polluted**

Fig. 2. Stations selected for the study

Collection of aquatic insects: Aquatic insects were collected bi-monthly from June to August. This was done using an Ekman grab, which was sorted and then preserved in 10% formalin. Aquatic insects were sorted and viewed under a binocular dissecting microscope. Identification of specimen was done following available manuals and keys by Tachet et al. [20].

Collection of water samples and plants: Water samples for the various analyses were collected using one-liter and transparent reagent bottles. Dissolved oxygen and BOD_5 were determined in Department of Chemistry, Delta State University, Abraka. Plant species were collected and identified in the Department of Botany, Delta State University, Abraka. The plants were stored in herbarium and assigned voucher numbers in cases where they were absent DELSUH-115 and DELSUH-275 for *Pontederia crassipes* and *Talinum triangulare* respectively.

Physicochemical analysis of water and plants: Hydrogen ion concentration (pH) was obtained using a buffered electronic pH meter (Kent, 7020). Electrical conductivity and total solids were measured with an Extech, meter (Model Exstik, Ec 400) and standard methods of AOAC (2019) and ASTM (2008) as recommended by Clesceri et al. [21]. Biological oxygen demand and dissolved oxygen were determined using winker's method (APHA, 2005). Total Chlorophyll was determined using spectrophotometric analysis, total sugar was determined by polarimetric and chromatographic methods, ascorbic acid was determined using HPLC methods and water retention capacity determination were analysed by conventional and centrifuge methods following the method of Limantara et al*.* [22].

Data analysis: All data analysis was done using SPSS statistical package. Descriptive statistics, such as means, standard deviations, and percentages, were used to summarize the field observations and laboratory measurements. Analysis of variance test (ANOVA) was done to determine significant differences between control and treatment groups.

3. RESULTS

Physicochemical parameters and effects of lotic habitat: Acidity, electrical conductivity and biological oxygen demand were higher in MP-polluted water. Turbidity, pH, and dissolved oxygen were higher in MP-free water (Table 1). The differences between electrical conductivity, dissolved oxygen and biological oxygen demand were significant ($p<0.05$). Soluble sugar, ascorbic acid, and water retention were higher in MP-polluted water compared to MP-free water (Table 2). The differences between soluble sugar, total chlorophyll and water retention were significant ($p<0.05$).

Physicochemical parameters and effects of lentic habitat: Electrical conductivity, and turbidity were higher in the MP-polluted water body compared to the other (Table 3). The difference was significant ($p<0.05$). Likewise, total chlorophyll, soluble sugar, and water retention were higher in MP-polluted water bodies (Table 4). The difference was significant ($p<0.05$).

Table 1. Physicochemical parameters of water from microplastic-free and microplastic polluted parts of Warri River, Delta State (Lotic water body)

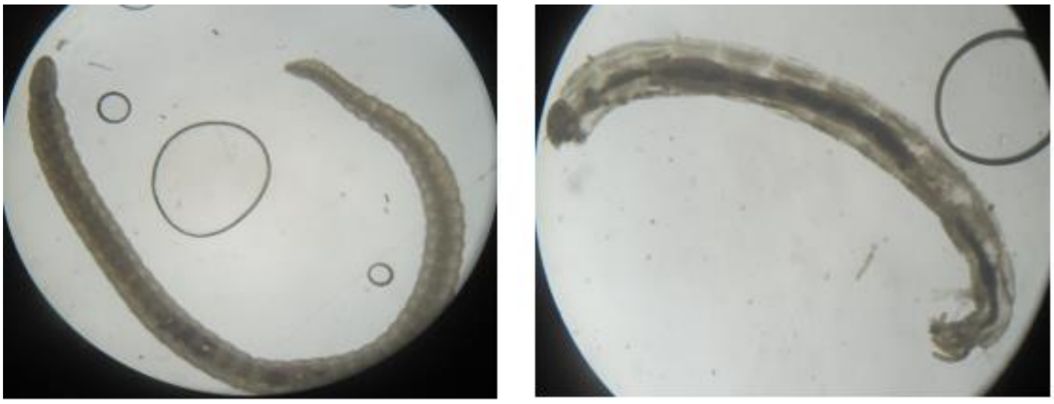
Parameters	Control Station (Microplastics free)	Impacted Station (microplastic polluted)	p-value
P^H	5.98±0.21	5.67±0.15	0.06
Acidity (mg/L)	1.92±0.07	2.10±0.03	0.07
Electrical conductivity (µs/cm)	43.42±2.32	35.88±2.65	0.03*
Turbidity (NTU)	76.00±3.78	71.00±4.20	0.08
Dissolved Oxygen (mg/L)	4.69±0.03	3.08±0.04	0.02*
Biological Oxygen Demand (BOD) (mg/L)	1.71±0.34	1.94±2.56	0.04*

* *signifies that there is significant difference between rows*

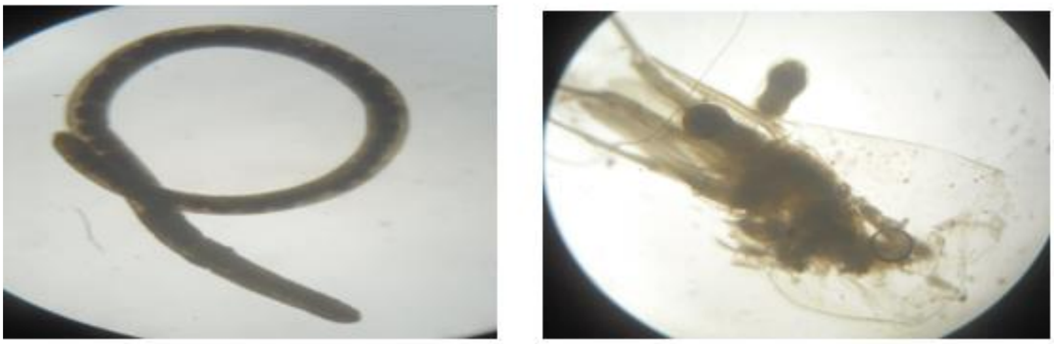
Table 2. The effect of microplastics on water hyacinth (*Pontederia crassipes*) in Burutu section of Warri river (Lotic water body)

Parameters	Control station (Microplastics free)	Impacted station (Microplastics polluted)	p-value
Soluble sugar (mg/L)	81.34±4.25	110.34±5.32	0.00*
Total Chlorophyll	56.66±3.21	37.90±2.35	0.01*
Ascorbic Acid (mg/100g)	294.00±18.43	308.00±12.34	0.12
Water retention capacity	2.03±0.04	2.08±0.21	0.00*

* *signifies that there is significant difference between rows*



A. Nais simplex B. Nais communis



C. *Chironomus fractilobus* D. *Desmocaris bilineata*

Plate 1. Representatives of microplastics in the freshwater aquatic insects in the two sampled stations in Delta State

Table 3. Physicochemical analysis of water from microplastics-free and microplastics polluted gutter in Abraka Market (Lentic water body)

Parameters	Control station (microplastics free)	Impacted Station (microplastics polluted)	p-value
P^H	5.95±0.26	5.49±0.19	0.08
Acidity mg/L	2.11±0.03	2.03±0.04	0.23
Electrical conductivity µs/cm	57.46±3.26	60.53±3.98	0.03*
Turbidity (NTU)	84.10±7.35	92.70±4.32	0.03*
Dissolved Oxygen (mg/L)	3.11±0.32	2.84±2.67	0.08
Biological Oxygen Demand (mg/L)	1.18±0.03	0.99±0.012	0.08

** signifies that there is a significant difference between rows*

Table 4. The effects of microplastics on water leaf (*Talinum triangulare*) obtained from gutter (Abraka market) (Lentic water body)

Parameters	Control station (microplastics free)	Impacted Station (microplastics polluted)	*p-value*
Soluble sugar (mg/L)	62.67±4.23	70.44±4.78	0.03*
Total Chlorophyll	79.56±5.93	96.21±8.65	0.04*
Ascorbic Acid (mg/100g)	259±32.13	250.40±25.56	0.07
Water retention capacity	3.98±0.23	5.34±0.45	0.04*

** signifies that there is a significant difference between rows*

Table 5. Substance characterization in sampled environment and aquatic sampled insects

Polymer type	Aquatic insects from pooled individuals	Functional feeding Group	Station 1 Microplastics free	Station 2 Microplastics polluted	Examples of substances encountered
Low Density polyethylene	*Nais simplex*	Scrapers	2	12	Carrier bag, bin liners and packaging films
Polyethylene Terephthalate	*Chironomus fractilobus*	Collector-gatherers	7	30	Water bottles, fizzy drinks
High density Polyethylene	*Nais communis*	Scrapers	-	17	Toothpaste, hypo bleach cleaners, shampoo bottles and milk bottles
Propylene/styrene	*Chironomus fractilobus*	Collector gatherers	8	22	tyro tubes films, protective packs from electrical goods
vinyl chloride	*Desmocaris bilineata*	Collector gatherers	1	9	Pipes fitting, automotive part from boat and canon
Styrene	*Desmocaris bilineata*	Collector gatherers	3	5	Plastic cutlery, toy

Species encountered: Some species encountered in this study include *Nais simplex*, *Nais communis*, *Chironomus fractilobus* and *Desmocaris bilineata*. There was more polyethylene terephthalate in the organisms sampled from the MP poluted sitesfollowed by propylene/styrene. Styrene was reportedly low. In MP-free station, high-density polyethylene was absent in the samples collected (Table 5).

4. DISCUSSION

The effect of microplastics on aquatic life is a pressing environmental concern that has garnered considerable attention in recent years. This study was designed to evaluate the effects of microplastics on aquatic life specifically water quality index and aquatic plant parameters. The physiochemical parameters of water polluted with microplastics collected from lotic (Burutu River, Warri) and lentic (stagnant) water (Abraka) sources were examined. The parameters assessed included pH, acidity, electrical conductivity, turbidity, Dissolved Oxygen (DO), and Biological Oxygen Demand (BOD). Also, aquatic plants were evaluated for soluble sugar, total chlorophyll, ascorbic acid and water retention capacity. Notably, thermoplastic was the predominant type of polymer found in the study area.

The results obtained from analyzed physiochemical parameter from the Warri River (Burutu Section) showed that pH, electrical conductivity, turbidity, and dissolved oxygen recorded a lower mean value while acidity and biological oxygen demand had higher mean values compared to the control (Table 1). These values suggested a mildly acidic environment in both water sources. Moreover, the levels of acidity, measured in milligrams per liter (mg/L), are marginally higher in the impacted station water (2.10±0.03mg/L) compared to the control water (1.95±0.07 mg/L). Although this difference is not substantial, it suggests that stagnant water bodies may have a slightly higher acid content, which could be attributed to the reduced flow and accumulation of pollutants, including microplastics. This aligns with the studies of García-Falcón et al., [23] that reported microplastics can alter the pH and acidity of aquatic ecosystems through several mechanisms, including the release of chemicals from plastics. Also, Dantas et al., [24] from their study affirmed that plastic debris may serve as surfaces for the adsorption of acids or bases, thereby affecting the surrounding water's pH. Additionally, the breakdown of plastics over time can release acidic compounds, contributing to changes in acidity levels in the water.

Electrical conductivity values are generally lower in impacted water (35.88±2.26µs/cm) than in the control water (43.42±2.23 µs/cm). This finding suggested that the presence of microplastics may influence electrical conductivity to some extent. In a similar study, Koelmans et al., [25] reported electrical conductivity in water is influenced by the presence of dissolved ions, and macro-plastics can potentially release ions and contaminants as they degrade, this leads to changes in electrical conductivity levels, affecting the overall water quality. Also, turbidity levels are notably reduced in microplastics-impacted water (71.00±4.20) compared to the control (76.00±3.78), indicating reduced water clarity in polluted areas. The higher turbidity in the polluted water may be due to the stagnant nature of the waterbody, allowing for the accumulation of microplastics and other suspended particles. This study result agrees with those of Wright et al., [11] that reported microplastics can increase water turbidity by trapping suspended particles and organic matter on their surfaces which can reduce water clarity and light penetration, potentially impacting aquatic ecosystems and organisms that rely on clear water conditions.

In addition, lower DO levels can be attributed to reduced gas exchange and increased microbial decomposition of organic matter associated with microplastics. This disagrees with the study of Erhenhi and Omigberale, [26] on the assessment of water quality whose values were 5.50± 0.13 - 5.67± 0.12 in the Ethiope River. In this study, BOD values revealed a substantial difference between the control and the impacted water. The higher BOD observed for impacted water, indicated a higher load of organic matter and potentially greater microbial activity. This could be linked to the enhanced breakdown of organic materials trapped among macro-plastics in flowing waters. Löhr et al., [27] reported that the presence of microplastics can also contribute to increased biological oxygen demand in aquatic ecosystems. As plastics break down, microorganisms metabolize the organic matter adhering to the plastic surfaces, consuming oxygen in the process. This can result in higher BOD levels, potentially harming aquatic life.

The physiochemical parameter used for this study showed that microplastics had an impact on the impacted station (roadside drainage in

Abraka market) for pH, acidity, dissolved oxygen and biological oxygen demand which recorded a lower mean value while electrical conductivity, turbidity showed higher mean which is an indication of impacted biological activities (Table 3). This contradicts the trend in Burutu River as observed in acidity which was lower, higher conductivity, reduced turbidity, and reduced BOD for Abraka roadside drainage water.

This study also evaluated the various parameters related to aquatic plants using water hyacinth *Pontederia crassipes* from microplastic polluted water. Soluble sugar in the impacted station was higher than the control station, whose mean values were 81.34±4.25 and 110.34±5.32, an indication of the effect of microplastics on the aquatic habitat. This trend suggested that plants in impacted water may have developed mechanisms to produce more soluble sugars, possibly as a response to stress induced by microplastic pollution. This finding aligns with the results of a study by Smith et al*.,* (2020), which reported increased soluble sugar levels in aquatic plants exposed to plastic pollution in river ecosystems. In addition, water retention capacity in the studied plants were less in the control (2.03±0.04), compared to impacted stations were higher (2.08±0.21).

The total chlorophyll recorded mean values of (56.66±3.21) showed a higher value in the control station than the test station whose mean value is 37.90±2.35 (Table 2). This result may suggest that microplastic pollution has a more pronounced negative impact on photosynthetic pigments. This finding contradicts the study by Green et al*.,* [28], which reported a decrease in total chlorophyll content in stagnant water plants exposed to plastic pollution. This disparity of result could also be due to the use of different plant species.

Moreover, this study revealed that aquatic plants from impacted station had higher levels of ascorbic acid (308.00±12.34 mg/100g) compared to those from the control (294.00±0.04mg/100g). This result suggests that plants in polluted water may have an enhanced antioxidant response to counteract the oxidative stress induced by microplastic contamination. This finding aligns with the observations made by Mozart and Brown [29] in their study on antioxidant responses in aquatic plants exposed to plastic debris.

Furthermore, aquatic plants from impacted water station exhibited higher water retention capacity (2.08±0.21) compared to those from the control water. This result implies that microplastic pollution in flowing water may disrupt the water uptake and retention capabilities of aquatic plants more severely. This finding contradicts the work of Chen et al*.,* [30], who reported reduced water retention capacity in water lilies exposed to plastic contamination in river systems.

The result in Table 4. showed that soluble sugar, total chlorophyll and ascorbic acid were high in the water leaf *Talinum triangulare* obtained from the impacted station except for water retention capacity whose mean values were lower in the control station. The result of the aquatic plant obtained from the both stations was slightly different for Total chlorophyll which was lower in Abraka gutter.

In this study, microplastics were recorded in four (4) orders of insects as well as different functional feeding groups, thus suggesting that aquatic insects of different taxonomic categories may be predisposed to microplastics pollutants. *Chironomus sp.* a significantly higher in station 2. Their presence may indicate environmental disturbances which may disrupt the natural balance of the ecosystem and impact negatively on sensitive species *Chironomus sp*. is a collector gatherer with the capacity to feed on deposited organic materials on stream or riverbeds and are more tolerant to pollution and become dominant in the water. The findings of Erhenhi and Arimoro [31] agree with this present study where *Chronomus sp* were preponderant organisms in the pool station in River Ethiope. Further studies by Voshell [16], and Wel et al. [32] agrees with the report of this present study.

Unlike the water column, this section of an aquatic system has a higher retention capacity and is regarded as the most important sink of pollutants in freshwater environments [33]. Primary or secondary MPs could end up in any of the following ways in river systems: (1) they could drift with the water mass into adjacent oceans or lakes; (2) like other suspended solids, they could settle on the riverbed when flow velocity is too low to keep them in suspension [16], The suitability of deposit feeders, particularly *Chironomus sp*., as MP bioindicator has also been reported by Nel et al. [9] in a South African river system. Deposit feeders may therefore be suitable as MP bioindicators in lotic freshwater systems since they are not only site-specific, but can also indicate impacts over some time.

Other evidences of low physiological fitness in aquatic insects on account of microplastics include reduced filtering or feeding capacity in *Desmocaris bilineata* and reduced reproductive output in species of haplolaxida (*Nais simplex),* similar findings were reported by Wegner et al. [34] and Cole et al. [35] in their study. Microplastics serve as vectors for the transfer of hydrophobic and persistent organic pollutants, hence pose a threat to the sustenance of aquatic organisms considering their physiological and ecotoxicological implications when ingested by aquatic animals. Microplastics polymers recorded in this study can also be related to prevalent plastic sources in Nigeria (Table 5). Microplastics could be linked to direct washing of clothes inside fresh water ecosystem which is a common practice by many locals in many parts of Nigeria and Africa, due to poor economies and lack of domestic water supply, especially in rural and semi-urban areas. In addition, evidence of worn-out tyres, boat parts, broken toys, water, bottles and fuzzy bottles was also sighted inside studied stations from which the *Chironomus sp*. was collected (Fig. 1). The heterogeneity of microplastics types recorded in these studied sites as well as the aquatic insects could reflect various applications of plastics in the respective river basins and the Environs that are finally deposited in the gutter after the rain or by humans. Going by the level of plastic deposits it is also most likely that these microplastics are mostly derived secondarily through fragmentation of larger plastic debris and factors such as wind, ultraviolet radiation and animal digestion [36-38]. In conclusion, collector-gatherers seemed to record more diverse polymers than scrapes in this study which concurs with the study of Emmanuel et al., (2020).

5. CONCLUSION

This study has shown the presence of MP in *Nais simplex*, *Chironmus fractilous, Nais communis* and *Desmocaris bilineata* obtained from polluted sediment. Indicator plants equally showed the occurrence of MP pollution. Point sources were from fragmentation of larger plastic debris probably broken down by ultraviolet radiation and drifted into water sources by wind. The absence of EPT group of macro-invertebrates (Ephemeroptera, Plecoptera, and Tricoptera) from the water sources predicts the high occurrence of MP pollution.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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