MICROPLASTIC POLLUTION OF THE AMANSEA AXIS OF EZU RIVER WITH EMPHASIS ON ITS SPATIAL CONCENTRATIONS WITHIN THE AQUATIC ECOSYSTEM

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ABSTRACT

Microplastic pollution is adversely impacting the Amansea section of Ezu River in Anambra State, adversely affecting local aquatic life. This study examined microplastic pollution in the Amansea section of Ezu River, Anambra State. Water and fish samples (Xenomystus nigri, Malapterurus electricus, and Pelteobagrus fulvidraco) were collected from three sections of the river: upstream, midstream, and downstream. The physicochemical parameters of water: temperature, pH, TDS, EC, DO, alkalinity, and TSS, were measured using standard water analysis techniques, while microplastics were extracted and identified using Fourier transform infrared spectroscopy (FTIR). Statistical analysis revealed the highest microplastic levels at the upstream section of Ezu River (0.23 ± 0.12), with lower levels at the midstream and downstream sections (0.14 ± 0.16). The fish X. nigri had the highest microplastic load in gills (0.53 ± 0.08) and tissues (0.7 ± 0.04). Different microplastic types prevailed across locations and fish species: upstream water and M. electricus gills contained mostly polyvinyl alcohol, X. nigri gills predominantly had alginic acid sodium salt powder, and P. fulvidraco gills and fish tissues featured polyvinyl alcohol and polyacrylamide carboxyl, respectively. Neoprene was notably present in X. nigri tissues. Fish samples (0.41 ± 0.19) were more polluted than water samples (0.17 ± 0.15). These findings highlight the presence of microplastic pollutants in the Ezu River and its potential impact on aquatic organisms. Hence, implementing strict regulations on plastic waste management, raising public awareness, and promoting sustainable practices, continued monitoring and research are recommended as essential and effective mitigation measures.

Keywords: Microplastic pollution, Ezu River, Fish gills and tissues, Physicochemical parameters, Fourier transform infrared spectroscope

INTRODUCTION

The accumulation of plastic waste in the environment has become a growing concern for planetary health (Engler, 2012). Microplastics are synthetic pieces of plastic that measure less than 5 mm in size and include fragments, fibres, and films. Microplastic pollution has become a major global environmental issue due to its abundance and widespread distribution in aquatic environments (Cole *et al.,* 2011). This issue is of growing concern due to the increasing production and disposal of plastic products worldwide (Wright *et al.,* 2013). Microplastics can enter the aquatic environment through a variety of sources, such as the breakdown of larger plastic debris, microbeads in personal care products, and plastic fibres released during the washing of synthetic clothes (Galloway and Lewis, 2016).

Once in the water, microplastics can be ingested by aquatic organisms such as fish, crustaceans, and zooplankton, which can lead to physical and chemical effects, such as reduced feeding rates, digestive problems, and decreased growth and reproduction (Cole *et al.,* 2011). Moreover, microplastics can adsorb and accumulate persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) from the water, which can increase their bioavailability and toxicity to aquatic organisms (Boucher and Friot*,* 2017). Unnikrishnan *et al.* (2023) also reported that microplastics have been released into the environment from a variety of sources, such as wastewater treatment plants (WWTPs), direct input from personal care products, textile manufacturing effluent, urban run-off, and tyre abrasion. The increasing prevalence of microplastics is believed to be responsible for numerous adverse impacts on aquatic ecosystems (Kabir *et al.,* 2023).

Microplastics can be ingested by humans and animals. They have been reported in seafood, drinking water, and even in the air we breathe. It is not yet clear how much of a health risk they pose, but some studies have suggested that ingesting microplastics could lead to inflammation, oxidative stress, DNA damage, metabolic disorder, organ dysfunction, neurotoxicity, immune response, as well as reproductive and developmental toxicity (Qiao *et al.,* 2019; Campanale *et al*., 2020; Li *et al*., 2023). Du *et al.* (2021) also reported that microplastics can absorb and concentrate toxins from the environment. For example, if a microplastic particle absorbs a toxic chemical like a pesticide or flame retardant, it can release that chemical into the body of an animal or human that ingests it. This may potentially lead to toxic effects such as cancer or reproductive problems. Furthermore, the accumulation of microplastics in aquatic ecosystems can also have cascading effects on food webs and ecosystem processes. The ingestion of microplastics by zooplankton consumption can lead to decreased grazing rates and altered energy transfer to higher trophic levels (Cole *et al.,* 2011). Additionally, microplastics can affect the physicochemical properties of aquatic sediments, such as oxygen diffusion and nutrient cycling, leading to altered microbial communities and reduced ecosystem productivity (Lambert *et al.,* 2017).

The impact of microplastics on the aquatic environment has become an area of intense research due to their ubiquitous presence in marine, freshwater, and estuarine ecosystems (Priscilla *et al.,* 2019). These particles have been shown to negatively impact various aquatic organisms, including plankton, fish, and marine mammals (Raju *et al.,* 2022). Nigeria, like many other countries, is facing a significant challenge with microplastic pollution, with potential implications for both the environment and human health (Dumbili and Henderson, 2020). The sources of microplastics in Nigeria are diverse and complex. According to a study by Ibeto *et al.* (2023), the major sources of microplastics in Nigeria are plastic waste, domestic wastewater, and industrial effluent. Plastic waste is the most significant contributor, as a significant amount of plastic waste generated in Nigeria is either poorly disposed of or ends up in the aquatic ecosystem. Domestic wastewater and industrial effluent also contribute to the problem, as they contain microplastics from personal care products, cleaning agents, and industrial processes (Dumbili and Henderson, 2020).

Several studies (Ilechukwu *et al.,* 2019; Nwonumara *et al.,* 2021; Fardami *et al.,* 2023) have been conducted to assess the levels of microplastics in various environments in Nigeria. A study by Ilechukwu *et al.* (2019) analysed the levels of microplastics in sediments from three different locations in Lagos, Nigeria, and reported that all the sediments contained microplastics, with the highest concentration reported in the sediments from the Lagos Lagoon. The microplastics were reported to have negative impacts on the marine ecosystem, including bioaccumulation in fish and other marine organisms (Ilechukwu *et al.,* 2019). Another study by Nwonumara *et al.* (2021) analysed the levels of microplastics in different segments of Ndibe, Cross River, Nigeria. The study reported that microplastics were present in all the water samples. The impacts of microplastics in Nigeria are significant, both for the environment and human health. Microplastics have been reported to have negative impacts on the aquatic ecosystem, including bioaccumulation in fish and other aquatic organisms. This can have far-reaching consequences, as these organisms are an essential source of food for humans. In addition, microplastics can release toxic chemicals and absorb pollutants, which can be harmful to human health when consumed. Microplastics in drinking water and food have been linked to health problems, such as inflammation, oxidative stress, and cell damage (Fardami *et al.,* 2023).

The decomposition rate of plastics in aquatic environments depends largely on the type or chemistry but generally persists for tens if not hundreds of years releasing monomers, oligomers [micro], and even nanoplastic material which impact the endocrine systems of organisms given their similar molecular structure compared with hormones inside living organisms which often leads to fatal physiological disorders, adding another layer of complexity given prolonged timeframes (Altunışık, 2023). Hence, the impact of microplastics on the aquatic environment is significant and requires urgent action. This study therefore evaluated the levels of microplastics in water and fish samples from the Amansea section of Ezu River, Anambra State, Nigeria. Specifically, the study determined the physicochemical properties, the level of microplastics, the types of microplastics, and the microplastic load in the gills and tissues of fish species from the Amansea section of Ezu River, in Anambra State and compared the microplastics in water and fish samples.

MATERIALS AND METHODS

Study Area: The study area was Amansea, a section of the Ezu River which is located in Awka North LGA, Anambra State, Nigeria. Amansea is situated within the Awka capital territory and is bounded by Awka Town to the south, Mamu Rivers and Ebenebe Town to the north, Mgbakwu to the west, and Ezinato/Ubibia stream to the east (Ezeonyejiaku *et al.,* 2023). It is within the rainforest area of Nigeria and experiences an annual rainfall of 1000 – 1500 mm. Amansea has a latitude of 6°21'40" N and a longitude of 6°51'38" E. The areas have typical semi-tropical rainforest vegetation, characterized by freshwater swamps. They have a humid climate with a temperature of about 30.6 °C (87 °F) and a rainfall between 152 and 203 cm annually. The area has two distinct seasons: a wet season from April to October and a dry season from November to March (Nzoiwu *et al.*, 2017). Amansea has experienced urbanisation which has led to a population increase. The increase in population is due to the influx of people to Awka capital territory after the creation of Anambra State in 1991 and the proximity of the town to Awka, the seat of the government, the location of Nnamdi Azikiwe University, around the town also contributes to the increase in its population. Amansea consists of five villages Orebe, Amaowelle, Umuokpala, Ebeagu, and Okeukwa (Ezeonyejiaku *et al.,* 2023). All the plastic waste, domestic wastewater, and industrial effluent generated in this area may end up in the Ezu River. The occupations of the people are mainly fishing, farming, crafting, itinerant trading, and civil servants (Okoye *et al.*, 2023).

Ezu River is a significant water body located in Anambra State, Nigeria. It is a tributary of the larger Anambra River, which plays a crucial role in the hydrology and ecology of the region (Figure 1).

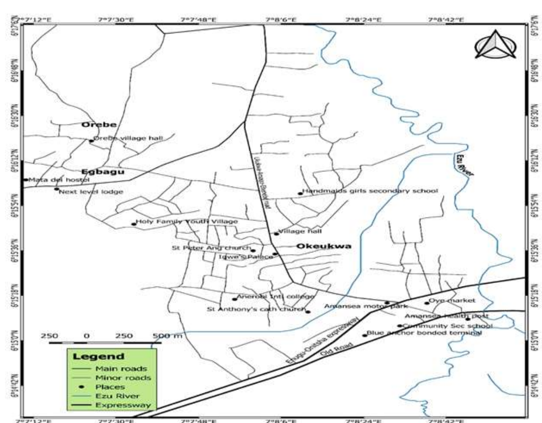

Figure 1: Map of Amansea showing Ezu River. (Source: NAU, 2023)

Ezu River spans a length of approximately 120 kilometres, flowing through several communities in Anambra State. The river serves as a vital water resource for local communities, supporting various socio-economic activities such as fishing, agriculture, and transportation. It provides water for irrigation, domestic use, and livestock farming. The river also holds cultural and recreational value, as it is often used for traditional ceremonies and leisure activities (Ogbuagu *et al.,* 2021). The area was chosen as it represents a section of the Ezu River with distinct geographical features and potential sources of pollution.

Research Ethics: The study adhered to ethical guidelines for the ethical treatment of animals during capture, handling, and sample collection. Necessary permits were obtained from the Animal Research Committee of Nnamdi Azikiwe University, Awka.

Experimental Design: A cross-sectional ecological survey was adapted for the study. The research data was gathered from a population or a representative subset at a specific point in time (Setia, 2016). This type of observational study is particularly effective for determining prevalence and association at a single moment, rather than over some time (Levin, 2006). Adopting a cross-sectional approach for examining the presence of microplastics in the Ezu River is beneficial, as it allows for the assessment of the level of contamination through sample collection and data analysis concurrently (Shelton and Capel, 1994). This snapshot can provide valuable insights into the environmental impact and potential health risks associated with microplastics in the river's ecosystem (Andrady, 2011), supporting the design's relevance to addressing the study's aims within the context of current environmental concerns.

Sample Collection: The water samples were collected at each sampling point to ensure representativeness and account for spatial variability according to the method of Nwonumara *et al.* (2021). The fishermen were engaged to help in the collection of the fish samples. The fish were *Xenomystus nigri,* commonly known as African brown knife fish, *Malapterurus electricus,* commonly known as the electric eel, and *Pelteobagrus fulvidraco,* the yellow catfish.

Laboratory Analysis: The physiochemical properties (temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), alkalinity, and total suspended solids (TSS)) were analysed using standard methods according to APHA (2005) and Lusher *et al.* (2017) methods of analyses. The microplastic analysis of polyvinyl alcohol, neoprene, alginic acid sodium salt, and polyacrylamide carboxyl from the samples water and fish was done using a Fourier Transform Infrared Spectroscope (FTIR), equipped with a counting chamber on top of the object glass to identify and classify microplastic particles. The spectra of the samples were recorded using an ATR-FTIR spectrometer (Agilent Cary 630 FTIR Spectrometer) equipped with a single bounce diamond crystal and a deuterated triglycine sulphate detector (Hidalgo-Ruz *et al.*, 2012; Löder and Gerdts, 2015; Fan *et al.*, 2021).

Quality Control and Validation: Quality control measures were implemented by analysing triplicate samples and reference standards to assess the precision and accuracy of the FTIR imaging results. Care was taken to ensure that spectral interpretation aligns with established polymer identification standards.

Statistical Analysis: The data obtained from the analysis of physiochemical parameters and microplastic concentrations were subjected to statistical analysis. Descriptive statistics (means, and standard deviations) were used to summarize the data. Student's t-test and Analysis of Variance (ANOVA), were performed to evaluate significant differences in microplastic concentrations between, wet and dry seasons, and sections, where there was a significant difference, the Duncan Multiple Range Test was used to separate the means at $p<0.05$. The results were presented in tables, and figures to facilitate data interpretation. All statistical analyses were conducted using Statistical Package for Social Sciences (SPSS) version 25.

RESULTS

Physicochemical Parameters of the Amansea section of Ezu River, Anambra State: The physicochemical parameters of the Amansea section of the Ezu River, Anambra State are presented in Table 1. The table shows the analysed data for the downstream, midstream, and upstream. The data were analysed to ascertain patterns and variations among temperature, pH, TDS, EC, DO, alkalinity, and TSS.

Temperature: The highest temperature value was recorded in the midstream section of the Amansea section of Ezu River (30.05 ± 0.64 ^{0}C), while the lowest temperature value was observed in the downstream section (29.37 ± 1.46 ^{0}C). The measured temperature values in the Amansea section of Ezu River fell within the United States Environmental Protection Agency (USEPA) acceptable range. However, there were no significant differences ($p>0.05$) between the temperature value records in the three sections of the river (Table 1).

pH: The highest pH value was recorded in the downstream section of the Amansea section of Ezu River, with a measurement of 6.94 ± 0.01. On the other hand, the lowest pH value was observed in the Midstream section (6.47 ± 0.01) (Table 1). The measured pH values in the Amansea section of Ezu River fell within the USEPA acceptable range. There were significant differences ($p<0.05$) between the pH values recorded in the three sections of the river (Table 1).

Total dissolved solids (TDS): The result of the TDS content showed that the highest concentration was reported downstream (43.00 ± 1.41 mg/L), while the lowest was measured in the midstream section (15.50 ± 0.71 mg/L). The recorded TDS concentrations in the Amansea section of the Ezu River fell well below USEPA-recommended limits. There were significant differences ($p<0.05$) between the TDS content recorded in the three sections of the river (Table 1).

Electrical conductivity (EC): The result of the EC showed that the highest value was recorded in the midstream section (22.65 ± 0.21 μS/cm). Meanwhile, the lowest EC value was observed in the upstream section (15.15 ± 0.07 μS/cm) (Table 1). The measured EC values in the Amansea section of Ezu River fell within the USEPA acceptable limit. However, there were significant differences ($p<0.05$) between the EC values recorded in the three sections of the river (Table 1).

Dissolved oxygen (DO): The DO content exhibited its highest value in the downstream section (9.40 ± 0.14 mg/L). Conversely, the lowest DO concentration was recorded in the upstream section (7.10 ± 0.14 mg/L) (Table 1). The recorded DO concentrations in the Amansea section of Ezu River fell within the USEPA acceptable range. However, there were significant differences between the DO contents recorded in the three sections of the river (Table 1).

Alkalinity: The alkalinity levels were highest in the downstream section (50.00 ± 0.00 mg/L), whereas the lowest alkalinity was reported in the midstream section (43.00 ± 0.71 mg/L).

Total suspended solids (TSS): The result in Table 1 showed that the TSS content was highest in the upstream section, measuring 3.74 ± 0.07 mg/L. The lowest TSS concentration was observed in the downstream section (2.83 ± 0.09 mg/L). Grand Valley State University (2023) reported a value of less than 20 mg/L as an acceptable limit. The measured TSS concentrations in the Amansea section of Ezu River fell within acceptable limits, indicating relatively low levels of suspended solids in the water. However, there were significant differences between the TSS contents recorded in the three sections of the river (Table 1).

Level of Microplastics in Water from the Amansea section of Ezu River: The result of microplastics in water from the Amansea section of Ezu River showed that the highest microplastic pollution occurred upstream (0.23 ± 0.12 particles/g), while the lowest was recorded in the

Table 1: Physicochemical parameters of Amansea section of Ezu River, Anambra State

Parameters	Sections			USEPA, 1963; WHO, 2017
	Downstream	Midstream	Upstream	
Temperature (˚C)	29.37 ± 1.457^{a}	30.05 ± 0.636^{a}	29.55 ± 0.919^{a}	20 – 35
pH	6.94 ± 0.014^{c}	6.47 ± 0.014^{a}	6.76 ± 0.00^{b}	6.5-8.5
TDS (mg/L)	43 ± 1.414^{b}	15.5 ± 0.707^{a}	16.5 ± 0.707^{a}	<500/1,000
EC (Usm/cm)	17.25 ± 0.212^{b}	22.65 ± 0.212^{c}	15.15 ± 0.071^{a}	<1,200/
DO (mg/L)	9.4 ± 0.141^{c}	8.1 ± 0.141^{b}	7.1 ± 0.141^{a}	>5
Alkalinity (mg/L)	50 ± 0.000^{b}	43 ± 0.707^{a}	48.75 ± 1.768^{b}	100-200
TSS (mg/L)	2.83 ± 0.088^{a}	2.89 ± 0.013^{a}	3.74 ± 0.066^{b}	<20

Row sharing different superscripts are significantly different at p<0.05

midstream and downstream (0.14 ± 0.16 particles/g) respectively (Figure 2). However, there were significant differences (p<0.05) in the microplastic levels recorded in the three sections of the river.

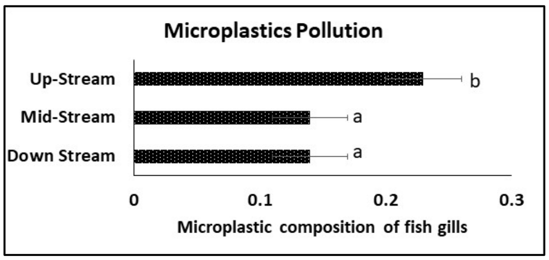

Figure 2: The level of microplastics in water from the Amansea section of the Ezu River. The error bars represent ± SE of triplicate data obtained from the matching co-efficient of microplastic analysis from 200 samples in Agilent Cary 630 FTIR Spectrometer. ***Key:*** *The bars having different letters are significantly different at p<0.05.*

Types of Microplastics in Water from the Amansea section of Ezu River: The types of microplastics present in the water from the Amansea section of the Ezu River are presented in Figures 3 – 5. The types of microplastic were identified using the highest matching coefficient from 200 spectra lines microplastics stored in Agilent Cary 630 FTIR Spectrometer.

Microplastic in the upstream: Microplastic in the upstream section of Ezu-river showed that polyvinyl alcohol was prominent with a matching co-efficient of 0.70 (Figure 3).

Microplastic in the midstream: Furthermore, the microplastic in the midstream section of Ezu River showed that polyvinyl alcohol was prominent with a matching co-efficient of 0.80 (Figure 4).

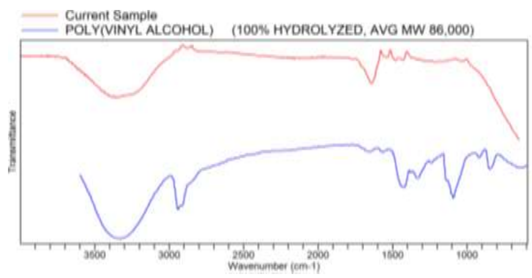

Figure 3: Microplastic reported upstream in the Amansea section of Ezu River, Anambra State

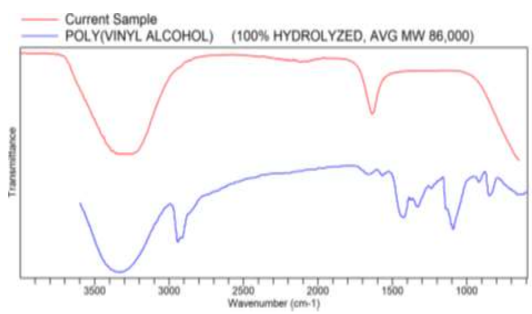

Figure 4: Microplastic reported midstream of the Amansea section of Ezu River, Anambra State

Microplastic in the down-stream: The microplastic in the down-stream section of Ezu River showed that polyvinyl alcohol was prominent with a matching co-efficient of 0.80 (Figure 5).

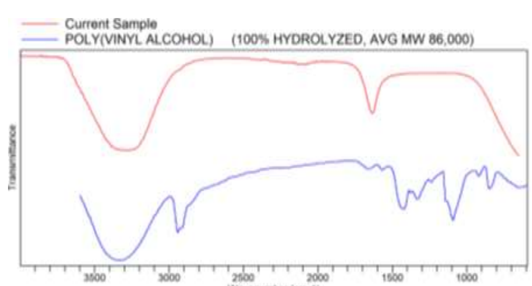

Figure 5: Microplastic reported downstream of the Amansea section of Ezu River, Anambra State

Microplastic load in the gills and tissues of *Xenomystus nigri, Malapterurus electricus* and *Pelteobagrus fulvidraco* from the Amansea section of Ezu River: The result of the microplastic load in the gills and tissues of *X. nigri, M. electricus,* and *P. fulvidraco* from the Amansea section of Ezu River showed that the highest load of microplastics in the gills of the fish species occurred in *X. nigri* (0.53 ± 0.08 particles/g), followed by *M. electricus* (0.35 ± 0.14 particles/g), while the lowest was obtained from *P. fulvidraco* (0.31 ± 0.15 particles/g) (Figure 6). There were significant differences ($p<0.05$) among the fish species.

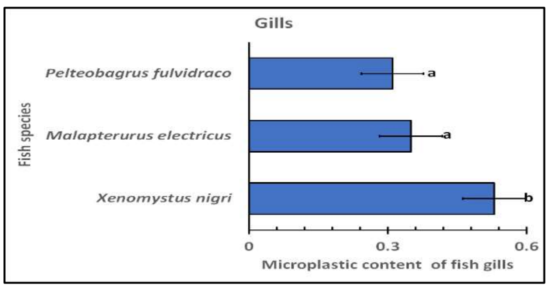

Figure 6: Microplastic load in the gills of *X. nigri, M. electricus,* and *P. fulvidraco* from the Amansea section of Ezu River, Anambra State. The error bars represent ± SE of triplicate data obtained from the matching co-efficient of microplastic analysis from 200 samples in Agilent Cary 630 FTIR Spectrometer. ***Key:*** *The bars having different letters are significantly different at p<0.05.*

Microplastics in the Gills of Fish: The type of microplastics identified in the gills and tissues of the fish samples were further presented in Figures 7 – 9.

Microplastics in the gills of *Xenomystus nigri:* The microplastics recorded in the gills of *X. nigri* showed that Alginic acid sodium salt powder was predominant, with a matching co-efficient of 0.88 (Figure 7).

Microplastics in the gills of *Malapterurus electricus*: The microplastics recorded in the gills of *M. electricus* showed that polyvinyl alcohol was predominant with a matching co-efficient of 0.85 (Figure 8).

Microplastics in the gills of *Pelteobagrus fulvidraco*: The microplastics recorded in the gills of *P. fulvidraco* showed that polyvinyl alcohol was prominent with a matching co-efficient of 0.83 (Figure 9).

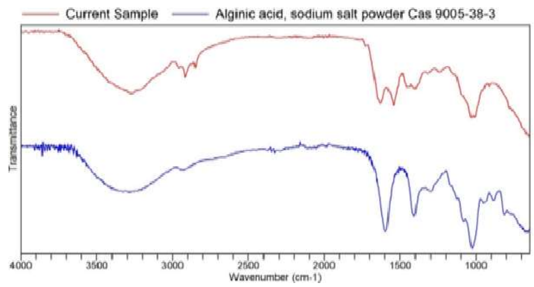

Figure 7: Microplastics reported in the gills of *Xenomystus nigri* from the Amansea section of Ezu River, Anambra State

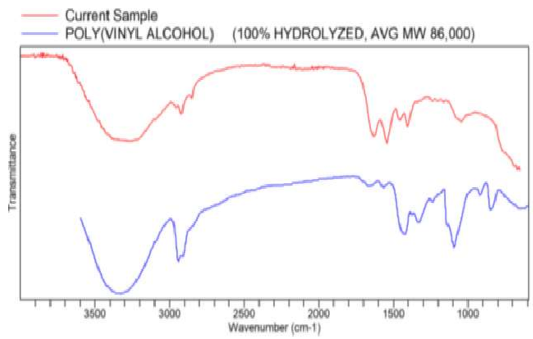

Figure 8: Microplastics reported in the gills of *Malapterurus electricus* from the Amansea section of Ezu River, Anambra State

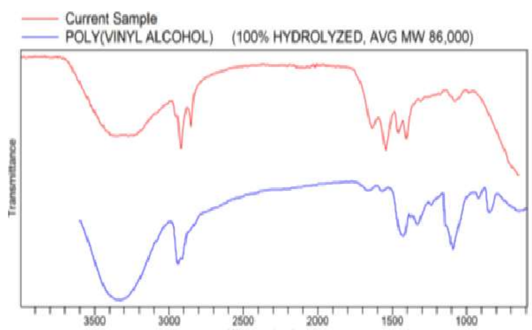

Figure 9: Microplastics reported in the gills of *Pelteobagrus fulvidraco* from the Amansea section of Ezu River, Anambra State

Microplastics in the Tissues of Fish: The result of the study showed that the highest load of microplastics in the tissues of the fish species from the Amansea section of Ezu River occurred in *X. nigri* (0.7 ± 0.04 particles/g), followed by *P. fulvidraco* (0.37 ± 0.14 particles/g), while the lowest was obtained from *M. electricus* (0.21 ± 0.16 particles/g) (Figure 10). There were significant differences among the fish species ($p<0.05$).

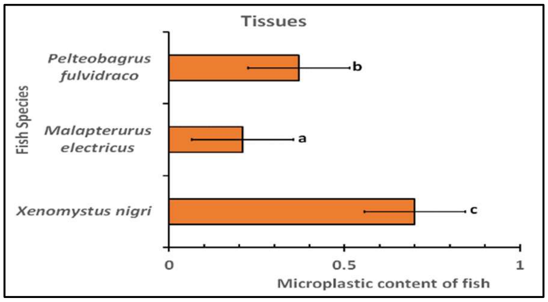

Figure 10: Microplastic load in the tissues of *X. nigri, M. electricus,* and *P. fulvidraco* from the Amansea section of Ezu River, Anambra State. The error bars represent ± SE of triplicate data obtained from the matching co-efficient of microplastic analysis from 200 samples in Agilent Cary 630 FTIR Spectrometer. ***Key:*** *The bars having different letters are significantly different at p<0.05*

The type of microplastics identified in the tissues of the fish samples were further presented in Figures 11 – 13.

Microplastics in the tissues of *Xenomystus nigri:* The microplastics from the tissues of *X. nigri* showed that neoprene was prominent with a matching coefficient of 0.81 (Figure 11).

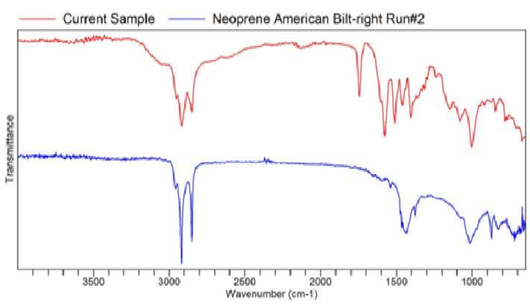

Figure 11: Microplastics reported in the tissues of *Xenomystus nigri* from the Amansea section of Ezu River, Anambra State

Microplastics in the tissues of *Malapterurus electricus*: Polyvinyl alcohol was identified as the prominent type of microplastic detected in the tissues of *M. electricus*. The matching coefficient for polyvinyl alcohol was 0.81 (Figure 12).

Microplastics in the tissues of *Pelteobagrus fulvidraco*: Polyacrylamide carboxyl was identified as the prominent type of microplastic in the tissues of *P. fulvidraco*. The matching coefficient for this particular microplastic was 0.80 (Figure 13).

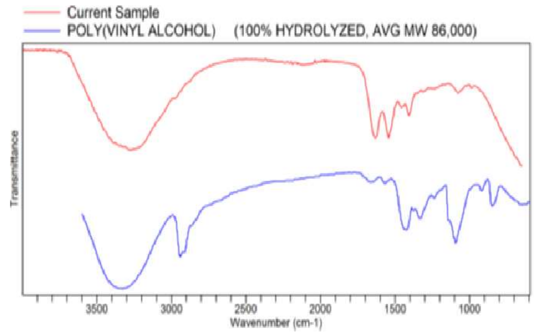

Figure 12: Microplastics reported in the tissues of *Malapterurus electricus* from the Amansea section of Ezu River, Anambra State

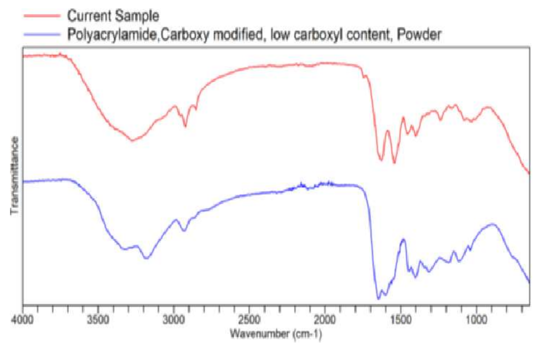

Figure 13: Microplastics reported in the tissues of *Pelteobagrus fulvidraco* from the Amansea section of Ezu River, Anambra State

Comparing Microplastic Concentrations in Water and Fish Samples from the Amansea section of the Ezu River, Anambra State

Microplastics reported in the gills and tissues of fish: The graphical representation demonstrates that *X. nigri* exhibited higher microplastic loads in its tissues (0.70 ± 0.04 particles/g) compared to the gills. On the other hand, *M. electricus* showed higher concentrations of microplastics in the gills (0.35 ± 0.145 particles/g) compared to the tissues (0.21 ± 0.16 particles/g). Furthermore, *P. fulvidraco* had a higher concentration of microplastics in its tissues (0.37 ± 0.14 particles/g) than in the gills (0.31 ± 0.15 particles/g) (Figure 14). However, there were significant differences (p<0.05) in the microplastic loads in the gills and tissues of the fish species in the Amansea section of the Ezu River.

Microplastics in water and fish: The graphical representation of the data demonstrated significantly higher microplastic loads in fish

(0.41 ± 0.19 particles/g) compared to water (0.17 ± 0.15 particles/litre) from the Ezu River (Figure 15). There were statistically significant differences ($p<0.05$) between the microplastics in water and fish species.

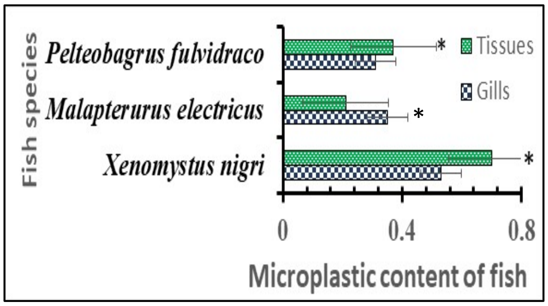

Figure 14: Graphical representation of microplastic loads in the tissues and gills of fish species. ***Key:*** **Significant mean at p<0.05 using t-test pairwise comparison*

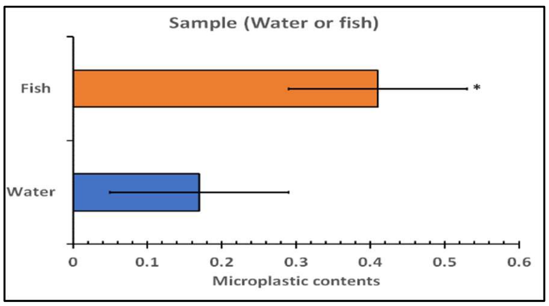

Figure 15: Graphical representation of microplastic in water and fish. ***Key:*** **Significant mean at p<0.05 using t-test pairwise comparison*

DISCUSSION

The study examined the physicochemical parameters of the Amansea section of the Ezu River in Anambra State. The findings of the study showed that there were temperature variations in the Amansea section of the Ezu River. Variations in river temperatures are not uncommon in tropical aquatic freshwater ecosystems. Several studies have explored the temperature profiles of rivers and their impact on aquatic ecosystems. Syvitski *et al.* (2019) studied the temperature regimes in various river systems and reported that temperature variations within a river can be attributed to factors such as weather conditions, flow rate, and geographic location. The observed temperature differences between the midstream and downstream sections of the Amansea section of the Ezu River may be due to local environmental factors and human activities along the riverbanks. The area is an active transportation route and is inhabited by humans on both sides of the riverbank. Furthermore, the measured temperature values in the Amansea section of the Ezu River fell within the acceptable range defined by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) (FAO, 2020; Iwar *et al.*, 2021) This suggests that the temperature of the river is conducive for various aquatic organisms and activities such as fishing. Iwar *et al.* (2021) emphasized the importance of maintaining temperature conditions within acceptable limits for sustaining healthy aquatic ecosystems. They highlighted that deviations from these ranges can have adverse effects on fish populations and water quality. The fact that the Amansea section of Ezu River falls within the USEPA acceptable range is a positive sign for the maintenance of the ecological health of the river. Despite the observed differences in temperature between the sections, there were no significant differences among the temperature values recorded in the three sections of the river. This result suggests that although temperature variations were present, they did not deviate significantly from one another.

The pH value in the Amansea section of the Ezu River exhibited significant variations between the three sections. The downstream section recorded the highest pH value, while the midstream section had the lowest value. These findings indicate differences in the acidity or alkalinity levels in different sections of the river. pH is a crucial parameter for assessing water quality as it affects the solubility of minerals, nutrient availability, and the survival of aquatic organisms (Omer, 2019). The USEPA recommends that pH levels for freshwater should be within the range of 6.5 – 8.5 to ensure the optimal function of biological processes (USEPA, 1983). The measured pH values in the Amansea section of Ezu River fell within this acceptable range, indicating that the water was suitable for a variety of uses such as irrigation and drinking water supply.

The TDS content in the Amansea section of the Ezu River exhibited significant differences among the three sections. The downstream section had the highest TDS concentration, whereas the midstream section had the lowest concentration. The variation in different TDS may be a result of the inflow of particles from the upstream of the river which leads to the accumulation of these particles. TDS refers to the total concentration of inorganic substances dissolved in water, including minerals, salts, and trace elements (Bhardwaj and Boora, 2023). The FAO suggests that TDS concentrations should be below 500 mg/L for agricultural purposes to ensure the absence of adverse effects on crops and soil (FAO, 2020). The WHO guideline for drinking water sets the acceptable limit for TDS at 1,000 mg/L (WHO, 2017). The recorded TDS concentrations in the Amansea section of the Ezu River fell well below these recommended limits, indicating that the water is suitable for various uses, including irrigation and consumption.

The EC values in the Amansea section of the Ezu River show significant variations between the three sections. The Midstream section recorded the highest EC value, while the upstream section had the lowest value. EC is an important parameter used to estimate the total dissolved solids and salinity levels in the water. According to FAO, the EC of freshwater bodies should be less than 1,200 µS/cm to prevent adverse effects on fish and other aquatic organisms or crops and vegetation when used for irrigation in the mainland (FAO, 2020). However, the measured EC values in the Amansea section of the Ezu River fell within the acceptable limit, indicating that the water is suitable for agricultural purposes. These findings are consistent with the study conducted by Iwar *et al*. (2021), which reported similar EC values in rivers of the region known for their agricultural importance.

The DO content in the Amansea section of the Ezu River exhibited significant variations among the three sections. The downstream section recorded the highest DO concentration, while the upstream section had the lowest concentration. DO is a critical parameter for assessing the health of aquatic ecosystems and the survival of aquatic organisms (Omer, 2019). The FAO recommends a minimum DO concentration of 5 mg/L for an optimal aquatic environment and to avoid oxygen deprivation in fish and other organisms (FAO, 2020). The recorded DO concentrations in the Amansea section of Ezu River fell within the acceptable range, indicating that the water provides a suitable habitat for aquatic life. This finding agreed with the report of Anyanwu *et al*. (2023) on the Anambra River, which reported similar DO levels that support diverse aquatic species.

The analysis of alkalinity levels in the Amansea section of the Ezu River revealed significant variations between the three sections. The downstream section recorded the highest alkalinity level, while the midstream section had the lowest level. Alkalinity plays a crucial role in maintaining stable pH conditions in aquatic systems and supporting various biological processes (FAO, 2020). The measured alkalinity levels in the Amansea section of Ezu River fell within acceptable limits, suggesting that the water provided a suitable environment for aquatic life. Stable alkalinity levels contribute to the buffering capacity of water and support the survival of aquatic organisms. These findings align with studies conducted by Nwanna *et al*. (2022) and Anyanwu *et al*. (2023), which emphasize the importance of maintaining suitable alkalinity levels for the overall health and sustainability of aquatic ecosystems.

The analysis of TSS content in the Amansea section of the Ezu River exhibited significant variations among the three sections. The upstream section recorded the highest TSS concentration, while the downstream section had the lowest concentration. The higher value may be a result of the direct acceptance of particles from runoff arising from nearby farmlands, and industrial and household effluents. TSS refers to particles or solids that are in suspension or floating in water. The measured TSS concentrations in the Amansea section of Ezu River fell within acceptable limits, indicating relatively low levels of suspended solids in the water. Low TSS concentrations are desirable as they can reduce the potential adverse effects on aquatic organisms, maintain water clarity, and minimise potential threats to the health of aquatic organisms (Vasistha and Ganguly, 2020). The findings of this study supported the findings of a study conducted by Anyanwu *et al*. (2023), which reported similar TSS concentrations in the Anambra River, located within the same region.

The levels of microplastics in the water from the Amansea section of the Ezu River indicated varying levels of microplastic pollutants in different sections of the river. Specifically, the highest concentration was observed in the upstream section, while both the midstream and downstream sections exhibited lower concentrations. This discrepancy in microplastic levels among the sections of the river suggests differences in potential input sources or transport mechanisms that warrant further investigation. This finding aligned with previous studies that have also reported variations in microplastic concentrations in different water bodies (Rowley *et al*. 2020; Talbot *et al*., 2022; Devereux, 2023). The study by Devereux *et al*. (2022) reported similar trends in microplastic pollution in various sections of the Thames River, with higher concentrations in upstream areas compared to downstream locations. This pattern can be attributed to factors such as proximity to urban centres, industrial activities, and prevailing water flow dynamics (Xu *et al*., 2021).

Furthermore, the study identified distinct types of microplastics present in the water samples from the Amansea section of the Ezu River. This characterization was achieved by determining the sample with the highest matching coefficient. In the upstream section, the prevalent microplastic was polyvinyl alcohol, with a matching coefficient of 0.70. This specific identification of microplastic types is crucial for the understanding of their sources, potential environmental impacts, and effective mitigation strategies. The presence of polyvinyl alcohol in the upstream section of the Ezu River raises questions about its potential sources, implications, and impact on the ecosystem. Previous studies have identified polyvinyl alcohol as a common component in various consumer products, including textiles, adhesives, and packaging materials (Andrady, 2011). Therefore, its presence in the river water may be indicative of anthropogenic activities in the surrounding area, possibly linked to agricultural, industrial and (or) domestic sources.

In the midstream section of Ezu River, the microplastic analysis revealed that polyvinyl alcohol was the predominant type, with a matching coefficient of 0.80. This finding suggests that polyvinyl alcohol is a significant component of the microplastic composition in this particular section of the river. This observation is consistent with previous studies that have also identified polyvinyl alcohol as a prevalent type of microplastic in aquatic environments. Enyoh *et al*. (2023) conducted a risk assessment of microplastics and potentially toxic elements (PTEs) in garri (cassava flake), a common staple food consumed in West Africa and reported the presence of polyvinyl alcohol as a major component of microplastics. Lim *et al*. (2022) suggested that this may be attributed to the widespread use of polyvinyl alcohol in various consumer products, which can ultimately lead to its release into the aquatic ecosystem.

Similarly, in the downstream section of Ezu River, the microplastic analysis indicated that polyvinyl alcohol was the dominant type, with a matching coefficient of 0.80. The consistency of findings in both the midstream and downstream sections highlights the significance of polyvinyl alcohol as a prevalent microplastic in these areas (Lim *et al*., 2022; Enyoh *et al*., 2023). The presence of polyvinyl alcohol in both upstream, midstream and downstream sections raises important questions about potential sources and pathways of introduction into the river ecosystem.

The presence of microplastic concentrations in the gills and tissues of *X. nigri, M. electricus*, and *P. fulvidraco* from the section of the Ezu River has been earlier reported that aquatic organisms ingest microplastics when present in their habitats (Lusher *et al*., 2013; Rochman, 2015). The range of microplastics reported in the fish species in this study, particularly in the gills, signifies potential health risks for these fish species, as well as their predators, which include humans (Rochman *et al*., 2015). The prevalence of Alginic acid sodium salt in the gills of *X. nigri* shares similarities with studies by Miranda-Peña and colleagues, who documented the occurrence of this type of microplastic in fish species from Tocagua Lake, Colombia (Miranda-Peña *et al*., 2023). Notably, alginic acid sodium salt is commonly used in the production of biodegradable materials, cosmetics, food and drink products, and pharmaceuticals (Hassabo and Mohamed, 2023).

Their presence may be indicative of their inflow from agricultural, domestic and industrial waste sources along the Ezu River.

The prominent occurrence of polyvinyl alcohol in *M. electricus* and *P. fulvidraco* corroborates with earlier studies by Li *et al*. (2018) and Enyoh *et al*. (2023). Polyvinyl alcohol is commonly reported in a broad range of products, including paper coatings, textile finishing, and adhesive manufacturing (O'Brien *et al*., 2021). The detection of polyvinyl alcohol in the gills of these fish species possibly indicates an abundance of this pollutant in the environment. The differences in the types of microplastic pollutants reported among the fish species reflect variances in their feeding habits, habitats, and life strategies, as reported by Avio *et al*. (2015). The presence of these microplastics provides evidence of the overall pollution of the Ezu River, potentially originating from specific types of waste such as household, industrial, and perhaps even medical.

Furthermore, the examination of the microplastic in the tissues of the fish species *X. nigri*, *M. electricus*, and *P. fulvidraco* from the Amansea section of Ezu River showed that the highest concentration was reported in *X. nigri,* compared to *M. electricus* and *P. fulvidraco*. This agrees with research by Lusher (2015) and Vandermeersch *et al*. (2015) who reported the presence of microplastics in various body tissues of fish species irrespective of their habitats or ecological roles. The identification of neoprene in the tissues of *X. nigri* was significant. Neoprene is a synthetic rubber produced by polymerization of chloroprene, commonly used in diverse applications such as automotive parts and wetsuits (Busvold, 2023). This detection may suggest a broad range of contamination from automobile repair centres in and around the Ezu River. Also, a continued indicator of polyvinyl alcohol presence, as reported in the tissues of *M. electricus*, supports the earlier reports of it being a cosmopolitan pollutant within the aquatic environment (Savoca *et al*., 2020; Ogbuagu *et al*., 2021). Polyvinyl alcohol is abundant in various commercial products and is released into the environment as waste (O'Brien *et al*., 2021), supporting its detection in *M. electricus*. The detection of polyacrylamide carboxyl modified in the tissues of *P. fulvidraco*, aligned with previous findings by Hermabessiere *et al*. (2017). Polyacrylamide carboxyl is a common plastic ingredient, often employed in water treatment systems, which subsequently releases such pollutants into the natural water bodies. Hence, the contamination may be indicative of improper waste management or treatment practices (Saravanan *et al*., 2022). The findings from the analysis of the fish tissues reaffirmed that distinct microplastic pollutants are linked with specific types of waste, reflecting the ecological and environmental realities of the Ezu River (Avio *et al*., 2015).

The results of the study conducted in the Amansea section of Ezu River, Anambra State, indicated significant differences in the microplastic loads reported in the gills and tissues of different fish species (*X. nigri*, *M. electricus*, and *P. fulvidraco*). In *X. nigri*, the concentration of microplastics was higher in the tissues compared to the gills. Conversely, *M. electricus* exhibited higher microplastic concentration in the gills compared to the tissues. Additionally, *P. fulvidraco* displayed higher microplastic concentration in the tissues compared to the gills. These variations in microplastic loads between the gills and tissues of different fish species can be attributed to several factors. One possible explanation is the differences in the physiological roles played by these organs. The gills are primarily responsible for respiratory functions in fish, facilitating the exchange of gases such as oxygen and carbon dioxide with the surrounding water (Foyle *et al*., 2020). It is plausible that the gills, being in direct contact with water, may have a greater likelihood of encountering and accumulating microplastics present in the aquatic environment. On the other hand, fish tissues serve various functions, including digestion, metabolism, and reproduction (Moraes and de Almeida, 2020). The differences in microplastic accumulation observed between the gills and tissues may be due to variations in the rate of microplastic ingestion, assimilation, and clearance among fish species. Factors such as feeding behaviour, gut morphology, and metabolic rates can influence the extent to which microplastics are absorbed and retained within the tissues (Collard and Ask, 2021). Also, variations in the surface properties of gills and tissues may contribute to the differences in microplastic concentrations observed. The structure of fish gills, with their extensive surface area and fine filaments, is well-suited for gas exchange but may also provide more surfaces for microplastic attachment (Au *et al*., 2019). In contrast, the composition and surface characteristics of fish tissues, including their higher lipid content, may not be conducive to microplastic adsorption (Sussarellu *et al*., 2016; Collard and Ask, 2021).

Furthermore, the feeding behaviour of these fish species is likely to have contributed to the different accumulation of microplastics between their gills and tissues. For example, if a fish species primarily feeds on plankton, it may ingest more microplastics than a fish species that feeds on larger prey (Volkoff and Peter, 2006). Additionally, the type of feeding behaviour also plays a role in microplastic accumulation. Fish with filter-feeding habits tend to retain microplastics in their gills for longer periods, leading to higher concentrations in their tissues. On the other hand, fish with more active feeding behaviours such as predators tend to expel microplastics from their digestive system more frequently, resulting in lower concentrations in their tissues (Avio *et al*., 2015). The fish *X. nigri*, commonly known as the black-lined pike cichlid, is an omnivore, but with a leaning towards carnivorous behaviours. They feed on a diet rich in crustaceans, insects, and small fishes (Volkoff and Peter, 2006). This would explain the elevated accumulation of microplastics In its tissues as compared to gills. The particles consumed likely reside in the tissues due to long digestion cycles, and the extensive processing of food, which can lead to higher accumulation in the tissues (Rochman *et al*., 2013).

M. electricus or electric eel, is predominantly a carnivore with a taste for invertebrates and small fishes (Albert and Crampton, 2009). Interestingly, the high concentration of microplastics in their gills compared to the tissues may be due to their ambush predatorial nature. The eels lurk in microplastic-polluted waters, breathing in water (and potentially microplastics) while waiting for prey, possibly leading to a higher pollution rate in their gills (Avio *et al*., 2015). *P. fulvidraco*, (yellowhead catfish), is a demersal omnivore, feeding on detritus, insects, and small fishes at the bottom of water bodies (Assan *et al*., 2021). Thus, the presence of higher concentrations of microplastics in the tissues compared to the gills can be a result of their feeding habits, as bottom dwellers are more likely to consume more microplastics. The feeding behaviour of *P. fulvidraco* exposes this species to a higher level of microplastics. Specifically, being bottom feeders, these fish possibly ingest settled microplastics along with their regular diet, causing a higher concentration of microplastics in their tissues (Lusher *et al*., 2013). Also, their feeding habit of sifting through sediments for food, where microplastics tend to accumulate, contributes to the inadvertent ingestion of these pollutants (Rochman, 2015). The higher accumulation of microplastics in tissues may be due to a longer retention time in the digestive tract where microplastics can be absorbed into their circulatory and lymphatic systems, hence ending up in body tissues.

The examination of the microplastics in the Ezu River in Anambra State revealed striking disparities in microplastic loads between water and fish samples. The data highlights a substantial difference, with fish exhibiting significantly higher microplastic loads compared to water samples. The study is in line with the study of Tien *et al*. (2020) who conducted a similar study on microplastics in fish from Fengshan River and reported elevated concentrations, emphasizing the ability of fish to accumulate microplastics from their environment. The study supports the notion that fish are susceptible to ingesting microplastics, potentially due to the ingestion of contaminated prey or direct exposure to microplastics in the water column (Tien *et al*., 2020). Moreover, the significantly higher microplastic loads in fish compared to water align with studies conducted by Rochman *et al*. (2015) in various marine environments. Rochman *et al*. (2015) demonstrated that microplastic concentrations in biota, including fish, are often higher than those in the surrounding water. This phenomenon is attributed to bioaccumulation and trophic transfer, where microplastics move up the food chain as predator-prey interactions occur (Rochman, 2015).

Conclusion: The findings of this study showed that the physicochemical parameters of the Ezu River in the Amansea section of Anambra State were below the recommended limits for USEPA and WHO on the physicochemical parameters of river/seawater. This showed that the water in this section of the Ezu River is conducive to supporting aquatic life and various activities such as fishing for domestic uses and irrigation. The analysis of microplastic pollution in the Amansea section of the Ezu River revealed variations in microplastic concentrations in different river sections. Polyvinyl alcohol was identified as the predominant type of microplastic, raising concerns about its sources and environmental implications. The presence of microplastics in fish gills and tissues indicates potential health risks for the fish species and their predators, including humans. The study also reported that fish species with different feeding habits exhibited different patterns of microplastic accumulation. Additionally, higher microplastic loads were observed in fish compared to water samples. This highlights the ability of fish to accumulate microplastics from their environment. These findings emphasize the need for effective waste management strategies to reduce microplastic pollution and protect the ecosystem of the Ezu River. Also, there is a need to encourage individuals to make sustainable choices and adopt eco-friendly alternatives to single-use plastics.

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REFERENCES

ALBERT, J. S. and CRAMPTON, W. G. (2009). A new species of electric knifefish, genus *Compsaraia* (Gymnotiformes: Apteronotidae) from the Amazon River, with extreme sexual dimorphism in snout and jaw length. *Systematics and Biodiversity*, 7(1): 81 – 92.

ALTUNIŞIK, A. (2023). Microplastic pollution and human risk assessment in Turkish bottled natural and mineral waters. *Environmental Science and Pollution Research*, 30(14): 39815 – 39825.

ANDRADY, A. L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin*, 62(8): 1596 – 1605.

ANYANWU, J. C., NWAFOR, D. M., EJIOGU, C. C., IWUJI, M. C., UYO, C. N., UCHE, C. C. and NWOBU, E. A. (2023). Assessment of physicochemical conditions and phytoplankton diversity of Anambra River in Anambra State, Nigeria. *International Journal of Multidisciplinary Research and Growth Evaluation,* 4(3): 677 – 683.

APHA (2005). *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association, Washington, D.C., USA.

ASSAN, D., HUANG, Y., MUSTAPHA, U. F., ADDAH, M. N., LI, G. and CHEN, H. (2021). Fish feed intake, feeding behavior, and the physiological response of apelin to fasting and refeeding. *Frontiers in Endocrinology*, 12: 798903. https://doi.org/10.3389/fendo.2021.798903

AU, S. Y., LEE, C. M., WEINSTEIN, J. E., VAN DEN HURK, P. and KLAINE, S. J. (2017). Trophic transfer of microplastics in aquatic ecosystems: identifying critical research needs. *Integrated Environmental Assessment and Management*, 13(3): 505 – 509.

AVIO, C. G., GORBI, S. and REGOLI, F. (2015). Experimental development of a new protocol for extraction and characterization of microplastics in fish tissues: first observations in commercial species from the Adriatic Sea. *Marine Environmental Research*, 111: 18 – 26.

BHARDWAJ, K. and BOORA, N. (2023). Water quality parameter. Pages 78 – 91. *In:* SHARMA, S. and SINGH, D. (Eds.). *Multidisciplinary Approach: Enhanced Agriculture Production in a Sustainable*

Way. Department of Agriculture Entomology, Shri Vaishnav Institute of Agriculture, Shri Vaishnav Vidyapeeth Vishwavidyalaya, Indore Gram-Baroli, Ujjain Road, Indore 453111 (M.P.), India.

BOUCHER, J. and FRIOT, D. (2017). *Primary Microplastics in the Oceans: A Global Evaluation of Sources.* International Union for Conservation of Nature and Natural Resources (IUCN), Gland, Switzerland. http://dx.doi.org/10.2305/IUCN.CH.2017.01.en

BUSVOLD, M. H. (2023). *Thermal Properties of Neoprene and Natural Rubber in Wetsuits.* Master's Thesis in Technology and Safety in the High North, UiT The Arctic University of Norway, Tromsø, Norway.

CAMPANALE, C., MASSARELLI, C., SAVINO, I., LOCAPUTO, V. and URICCHIO, V. F. (2020). A detailed review study on potential effects of microplastics and additives of concern on human health. *International Journal of Environmental Research and Public Health*, 17(4): 1212. https://doi.org/10.3390/ijerph17041212

COLE, M., LINDEQUE, P., HALSBAND, C. and GALLOWAY, T. S. (2011). Microplastics as contaminants in the marine environment: a review. *Marine Pollution Bulletin*, 62(12): 2588 – 2597.

COLLARD, F. and ASK, A. (2021). Plastic ingestion by Arctic fauna: a review. *Science of the Total Environment*, 786: 147462. https://doi.org/10.1016/j.scitotenv.2021.147462

DEVEREUX, R. (2023). *Microplastic Pollution in the Estuarine and River Environment of the River Thames, United Kingdom.* Doctoral Dissertation, University of East London, London, United Kingdom.

DEVEREUX, R., WESTHEAD, E. K., JAYARATNE, R. and NEWPORT, D. (2022). Microplastic abundance in the Thames River during the New Year period. *Marine Pollution Bulletin*, 177: 113534. https://doi.org/10.1016/j.marpolbul.2022.113534

DU, J., ZHOU, Q., LI, H., XU, S., WANG, C., FU, L. and TANG, J. (2021). Environmental distribution, transport and ecotoxicity of microplastics: a review. *Journal of Applied Toxicology*, 41(1): 52 – 64.

DUMBILI, E. and HENDERSON, L. (2020). The challenge of plastic pollution in Nigeria. Pages 569 – 583. *In: Plastic Waste and Recycling,* Academic Press.

ENGLER, R. E. (2012). The complex interaction between marine debris and toxic chemicals in the ocean. *Environmental Science* and *Technology*, 46(22): 12302 – 12315.

ENYOH, C. E., WANG, Q., RABIN, M. H., BAKARE, R. O., DADIEL, J. L., SHANGRONG, W., LU, S. and ILECHUKWU, I. (2023). Preliminary characterization and probabilistic risk assessment of microplastics and potentially toxic elements (PTEs) in garri (cassava flake), a common staple food consumed in West Africa. *Environmental Analysis, Health and Toxicology*, 38(1): e2023005. https://doi.org/10.5620%2Feaht.2023005

EZEONYEJIAKU, C. D., EZEONYEJIAKU, N. J., OFFORBUIKE, I. I. and ONYEJIKE, P. I. (2023). Toxic metal residues in gills and muscles of freshwater fishes: implications for chronic noncarcinogenic risk assessment. *Journal of Applied Sciences and Environmental Management*, 27(8): 1809 – 1815.

FAN, C., HUANG, Y. Z., LIN, J. N. and LI, J. (2021). Microplastic constituent identification from admixtures by Fourier-transform infrared (FTIR) spectroscopy: The use of polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC) and nylon (NY) as the model constituents. *Environmental Technology and Innovation*, 23: 101798. https://doi.org/10.1016/j.eti.2021.101798

FAO (2020). *The State of World Fisheries and Aquaculture 2020. Sustainability in Action*. Food and Agricultural Organization of the United Nations, Rome, Italy. http://www.fao.org/3/ca9229en/online/ca9229en.html

FARDAMI, A. Y., MAGAMI, I. M., YARIMA, A. A. and SABITU, M. (2023). Microbes associated with bioremediation of microplastic waste in Nigerian freshwater bodies: a review. *UMYU Scientifica*, 2(1): 140 – 150.

FOYLE, K. L., HESS, S., POWELL, M. D. and HERBERT, N. A. (2020). What is gill health and what is its role in marine finfish aquaculture in the face of a changing climate? *Frontiers in Marine Science*, 7: 400. https://doi.org/10.3389/fmars.2020.00400

GALLOWAY, T. S. and LEWIS, C. N. (2016). Marine microplastics spell big problems for future generations. *Proceedings of the National Academy of Sciences*, 113(9): 2331 – 2333.

GRAND VALLEY STATE UNIVERSITY (2023). *Appendix B. Stream and River Monitoring Data Sheets.* https://www.gvsu.edu/cms4/asset/7629BB08-CDA5-EDA9-B36CECEF76D8D026/appendixbstr_eam_river_monitoring.pdf Accessed December 23, 2023

HASSABO, A. G. and MOHAMED, A. L. (2023). Extraction, structural properties, and applications of alginic acid. Pages 619 – 646. *In:* AHMED, S. and ALI, A. (Eds.). *Natural Gums: Extraction, Properties, and Applications.* Elsevier. https://doi.org/10.1016/B978-0-323-99468-2.00023-1

HERMABESSIERE, L., DEHAUT, A., PAUL-PONT, I., LACROIX, C., JEZEQUEL, R., SOUDANT, P. and DUFLOS, G. (2017). Occurrence and effects of plastic additives on marine environments and organisms: a review. *Chemosphere*, 182: 781 – 793.

HIDALGO-RUZ, V., GUTOW, L., THOMPSON, R. C. and THIEL, M. (2012). Microplastics in the marine environment: a review of the methods used for identification and quantification. *Environmental Science and Technology*, 46(6): 3060 – 3075.

IBETO, C. N., ENYOH, C. E., OFOMATAH, A. C., OGUEJIOFOR, L. A., OKAFOCHA, T. and OKANYA, V. (2023). Microplastics pollution indices of bottled water from South Eastern Nigeria. *International Journal of Environmental Analytical Chemistry*, 103(19): 8176 – 8195.

ILECHUKWU, I., NDUKWE, G. I., MGBEMENA, N. M. and AKANDU, A. U. (2019). Occurrence of microplastics in surface sediments of beaches in Lagos, Nigeria. *European Chemical Bulletin*, 8(11): 371 – 375.

IWAR, R. T., UTSEV, J. T. and HASSAN, M. (2021). Assessment of heavy metal and physico-chemical pollution loadings of River Benue water at Makurdi using water quality index (WQI) and multivariate statistics. *Applied Water Science*, 11(7): 124. https://doi.org/10.1007/s13201021-01456-8

KABIR, M. S., WANG, H., LUSTER-TEASLEY, S., ZHANG, L. and ZHAO, R. (2023). Microplastics in landfill leachate: Sources, detection, occurrence, and removal. *Environmental Science and Ecotechnology*, 16: 100256. https://doi.org/10.1016/j.ese.2023.100256

LAMBERT, S., SCHERER, C. and WAGNER, M. (2017). Ecotoxicity testing of microplastics: Considering the heterogeneity of physicochemical properties. *Integrated Environmental Assessment and Management*, 13(3): 470 – 475.

LEHIGH ENVIRONMENTAL INITIATIVE (2023). *Alkalinity*. Lehigh Education. https://ei.lehigh.edu/envirosci/watershed/wq/wqbackground/alkalinitybg.html Accessed December 23, 2023.

LEVIN, K. A. (2006). Study design III: Cross-sectional studies. *Evidence-Based Dentistry*, 7(1): 24 – 25.

LI, J., GREEN, C., REYNOLDS, A., SHI, H. and ROTCHELL, J. M. (2018). Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. *Environmental Pollution,* 241: 35 – 44.

LI, Y., TAO, L., WANG, Q., WANG, F., LI, G. and SONG, M. (2023). Potential health impact of microplastics: a review of environmental distribution, human exposure, and toxic effects. *Environment and Health*, 1(4): 249 – 257.

LIM, E., TANAKA, H., NI, Y., BAI, Y. and ITO, K. (2022). Microplastics/microfibers in settled indoor house dust – an exploratory case study for 10 residential houses in the Kanto area of Japan. *Japan Architectural Review*, 5(4): 682 – 690.

LÖDER, M. G. J. and GERDTS, G. (2015). Methodology used for the detection and identification of microplastics – a critical appraisal. Pages 201 – 227. *In:* BERGMANN, M., GUTOW, L. and KLAGES, M. (Eds.). *Marine Anthropogenic Litter*. Springer, Cham. https://doi.org/10.1007/978-3-319-16510-3_8

LUSHER, A. L. (2015). Microplastics in the marine environment: distribution, interactions, and effects. Pages 245 – 307. *In:* BERGMANN, M., GUTOW, L. and KLAGES, M. (Eds.). *Marine Anthropogenic Litter*. Springer, Cham. https://doi.org/10.1007/978-3-319-16510-3_10

LUSHER, A. L., HOLLMAN, P. and MENDOZA-HILL, J. (2017). *Microplastics in fisheries and aquaculture: status of knowledge on their occurrence and implications for aquatic organisms and food safety*. Agricultural Organization of the United Nations, Rome, Italy. http://www.fao.org/3/ai7677e

LUSHER, A. L., MCHUGH, M. and THOMPSON, R. C. (2013). Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. *Marine Pollution Bulletin*, 67(1-2): 94 – 99.

MIRANDA-PEÑA, L., URQUIJO, M., ARANA, V. A., GARCÍA-ALZATE, R., GARCÍA-ALZATE, C. A. and TRILLERAS, J. (2023). Microplastics occurrence in fish from Tocagua Lake, low basin Magdalena River, Colombia. *Diversity*, 15(7): 8 – 21.

MORAES, G. and DE ALMEIDA, L. C. (2020). Nutrition and functional aspects of digestion in fish. Pages 251 – 271. *In:* BALDISSEROTTO, B., URBINATI, E. C. and CYRINO, J. E. P. (Eds.). *Biology and Physiology of Freshwater Neotropical Fish.* Academic Press, Cambridge, Massachusetts, United States.

NAU (2023). Map of Amansea showing Ezu River**.** Cartography Laboratory, Departtment of Geography and Meteorology, Nnamdi Azikiwe University (NAU), Awka, Anambra State, Nigeria.

NWANNA, E. C., EJE, B. E. and EZE, P. C. (2022). Physicochemical analysis of Obizi River in Awka South Local Government Area of Anambra State, Nigeria for domestic purposes. *Nigerian Journal of Technology*, 41(5): 895 – 901.

NWONUMARA, G. N., OKORO, P. O. and OKOGWU, O. I. (2021). Assessment of the incidence of microplastics at Ndibe, Cross River, Nigeria. *The Zoologist*, 19(1): 46 – 51.

NZOIWU, C. P., EZENWAJI, E. E., ENETE, I. C. and IGU, N. I. (2017). Analysis of trends in rainfall and water balance characteristics of Awka, Nigeria. *Journal of Geography and Regional Planning*, 10(7): 186 – 196.

O'BRIEN, S., OKOFFO, E. D., RAUERT, C., O'BRIEN, J. W., RIBEIRO, F., BURROWS, S. D., TOAPANTA, T., WANG, X. and THOMAS, K. V. (2021). Quantification of selected microplastics in Australian urban road dust. *Journal of Hazardous Materials*, 416: 125811. https://doi.org/10.1016/j.jhazmat.2021.125811

OGBUAGU, J. O., OBI, E. N., OKEKE, A. P. and UKPAI, U. E. (2021). Pollution status and health risk assessment of polycyclic aromatic hydrocarbons in surface water, sediment and fish from Ezu River, Anaku, Anambra State, Nigeria. *Asian Journal of Applied Chemistry Research*, 10(1): 26 – 39.

OKOYE, C. K., OGUNJIOFOR, E. I., OKOYE, E. C. S. and OKOYE, L. C. (2023). Impact of abattoir waste effluent on water bodies: A case study of Ugwuoba Abattoir activites on Ezu River, Enugu State, Nigeria*. International Journal of Ecology and Environmental Sciences,* 5(2): 19 – 25.

OMER, N. H. (2019). Water quality parameters. *In:* SUMMERS, J. K. (Ed.). *Water Quality-Science, Assessments, and Policy*, IntechOpen, London. https://doi.org/10.5772/intechopen.89657

PRISCILLA, V., SEDAYU, A. and PATRIA, M. P. (2019). Microplastic abundance in the water, seagrass, and sea hare *Dolabella auricularia* in Pramuka Island, Seribu Islands, Jakarta Bay, Indonesia. *Journal* *of Physics: Conference Series,*1402(3): 033073. https://doi.org/10.1088/1742-6596/1402/3/033073

QIAO, R., SHENG, C., LU, Y., ZHANG, Y., REN, H. and LEMOS, B. (2019). Microplastics induce intestinal inflammation, oxidative stress, and disorders of metabolome and microbiome in zebrafish. *Science of the Total Environment*, 662: 246 – 253.

RAJU, P., SANTHANAM, P. and PERUMAL, P. (2022). Impacts of microplastics on marine organisms: present perspectives and the way forward. *The Egyptian Journal of Aquatic Research*, 48(3): 205 – 209.

ROCHMAN, C. M. (2015). The complex mixture, fate and toxicity of chemicals associated with plastic debris in the marine environment. Pages 117 – 140. *In:* BERGMANN, M., GUTOW, L. and KLAGES, M. (Eds.). *Marine Anthropogenic Litter*. Springer, Cham. https://doi.org/10.1007/978-3-319-16510-3_5

ROCHMAN, C. M., HOH, E., KUROBE, T. and TEH, S. J. (2013). Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. *Scientific Reports*, 3: 3263. https://doi.org/10.1038/srep03263

ROCHMAN, C. M., TAHIR, A., WILLIAMS, S. L., BAXA, D. V, LAM, R., MILLER, J. T., TEH, F. C., WERORILANGI, S. and TEH, S. J. (2015). Anthropogenic debris in seafood: Plastic debris and fibres from textiles in fish and bivalves sold for human consumption. *Scientific Reports,* 5: 14340. https://doi.org/10.1038/srep14340

ROWLEY, K. H., CUCKNELL, A. C., SMITH, B. D., CLARK, P. F. and MORRITT, D. (2020). London's river of plastic: High levels of microplastics in the Thames water column. *Science of the Total Environment*, 740: 140018. https://doi.org/10.1016/j.scitotenv.2020.140018

SARAVANAN, A., THAMARAI, P., KUMAR, P. S. and RANGASAMY, G. (2022). Recent advances in polymer composite, extraction, and their application for wastewater treatment: A review. *Chemosphere*, 308(2): 136368. https://doi.org/10.1016/j.chemosphere.2022.136368

SAVOCA, S., BOTTARI, T., FAZIO, E., BONSIGNORE, M., MANCUSO, M., LUNA, G.M., ROMEO, T., D'URSO, L., CAPILLO, G., PANARELLO, G. and GRECO, S. (2020). Plastics occurrence in juveniles of *Engraulis encrasicolus* and *Sardina pilchardus* in the Southern Tyrrhenian Sea. *Science of the Total Environment*, 718: 137457. https://doi.org/10.1016/j.scitotenv.2020.137457

SETIA, M. S. (2016). Methodology series module 3: Cross-sectional studies. *Indian Journal of Dermatology*, 61(3): 261 – 264.

SHELTON, L. R. and CAPEL, P. D. (1994). *Guidelines for Collecting and Processing Samples of Stream Bed Sediment for Analysis of Trace Elements and Organic Contaminants for the National Water-Quality Assessment Program*. Volume 94, Number 458, US Geological Survey, Reston, Fairfax County, Virginia, United States.

SUSSARELLU, R., SUQUET, M., THOMAS, Y., LAMBERT, C., FABIOUX, C., PERNET, M. E. J., LE GOÏC, N., QUILLIEN, V., MINGANT, C., EPELBOIN, Y. and CORPOREAU, C. (2016). Oyster reproduction is affected by exposure to polystyrene microplastics. *Proceedings of the National Academy of Sciences*, 113(9): 2430 – 2435.

SYVITSKI, J., COHEN, S., MIARA, A. and BEST, J. (2019). River temperature and the thermal-dynamic transport of sediment. *Global and Planetary Change*, 178: 168 – 183.

TALBOT, R., GRANEK, E., CHANG, H., WOOD, R. and BRANDER, S. (2022). Spatial and temporal variations of microplastic concentrations in Portland's freshwater ecosystems. *Science of the Total Environment*, 833: 155143. https://doi.org/10.1016/j.scitotenv.2022.155143

TIEN, C. J., WANG, Z. X. and CHEN, C. S. (2020). Microplastics in water, sediment and fish from the Fengshan River system: Relationship to aquatic factors and accumulation of polycyclic aromatic hydrocarbons by fish. *Environmental*

Pollution, 265(B): 114962. https://doi.org/10.1016/j.envpol.2020.114962

UNNIKRISHNAN, V., VALSAN, G., AMRUTHA, K., SEBASTIAN, J. G., RANGEL-BUITRAGO, N., KHALEEL, R., CHANDRAN, T., RESHMA, S. R. and WARRIER, A. K. (2023). A baseline study of microplastic pollution in a Southern Indian Estuary. *Marine Pollution Bulletin*, 186: 114468. https://doi.org/10.1016/j.marpolbul.2022.114468

USEPA (1983). *Water Quality Standards Handbook*. US Environmental Protection Agency, Office of Water Regulations and Standards, Washington DC., USA..

VANDERMEERSCH, G., VAN CAUWENBERGHE, L., JANSSEN, C. R., MARQUES, A., GRANBY, K., FAIT, G., KOTTERMAN, M. J., DIOGÈNE, J., BEKAERT, K., ROBBENS, J. and DEVRIESE, L. (2015). A critical view on microplastic quantification in aquatic organisms. *Environmental Research*, 143: 46 – 55.

VASISTHA, P. and GANGULY, R. (2020). Water quality assessment of natural lakes and its importance: An overview. *Materials Today: Proceedings*, 32(4): 544 – 552.

VOLKOFF, H. and PETER, R. E. (2006). Feeding behavior of fish and its control. *Zebrafish*, 3(2): 131 – 140.

WHO (2017). *Guidelines for Drinking-Water Quality.* Fourth Edition Incorporating the First Addendum. World Health Organization, Geneva, Switzerland. https://www.who.int/publications/i/item/9789241549950

WRIGHT, S. L., ROWE, D., THOMPSON, R. C. and GALLOWAY, T. S. (2013). Microplastic ingestion decreases energy reserves in marine worms. *Current Biology*, 23(23): 1031 – 1033.

XU, Y., CHAN, F. K. S., JOHNSON, M., STANTON, T., HE, J., JIA, T. and YU, X. (2021). Microplastic pollution in Chinese urban rivers: The influence of urban factors. *Resources, Conservation and Recycling*, 173: 105686. https://doi.org/10.1016/j.resconrec.2021.105686