FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 2, No. 2, 2025
Print ISSN: 1595-9686
EISSN: 1595-9708

EVALUATION OF THE EFFECT OF PHYSICOCHEMICAL PARAMETERS ON CONCENTRATION OF MICROPLASTICS IN DAM WATERS IN KATSINA STATE, NIGERIA

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https://doi.org/10/33001/jees.2025.0202/003

ABSTRACT

Microplastics (MPs) pollution has appeared as a serious environmental and public health concern, with water systems serving as primary routes for human exposure. This study comprehensively evaluated MPs contamination across ten (10) dams in the three geopolitical zones of Katsina State, Nigeria, using a standard technique. The study determined the concentration of MPs using wet oxidation digestion methods. It analysed the surface morphology and polymer types of the samples using Scanning Electron Microscopy – Energy Dispersive X-ray (SEM-EDX) and Fourier Transform Infrared Spectroscopy (FTIR). The results revealed significant spatial variability with MPs concentrations ranging from 28.00 ± 4.00 to 48.00 ± 4.00 particles L^{-1}. Among the dams, Zobe dam exhibited the highest Contamination Factor (CF=1.71), Polymer Risk Index (PRI=19.7), and Microplastic Pollution Risk Index (MPRI = 33.7), indicating a critical risk. The Dam samples contained five polymer types: polyethene (PE), polystyrene (PS), nylon, polyvinyl alcohol (PVA), and polyethene terephthalate (PET). Furthermore, MPs were classified into four groups based on their physical characteristics, with fragments being the most abundant, followed by fibres, films, and pellets. The estimated daily intake (EDI) of MPs was higher in children than in adults, indicating a potential health risk for consumers of these waters. The prevalence of MPs, particularly Polystyrene (PS) dominated particles at Zobe Dam, poses critical health risks, with children being disproportionately vulnerable. The study recommends immediate source reduction strategies targeting polystyrene-based products and other polymer types, establishing stringent MP monitoring programs, and developing public awareness campaigns to minimise exposure risks, especially among adults and children.

Keywords: Dam water, Fragments, Health risk, Microplastics, Wastes

INTRODUCTION

Plastic waste is considered the primary source of microplastics in our environment; hence, most plastics are single-use items commonly used as packaging materials. However, 50% of these plastic products belong to the one-use product class (Aliyu *et al.,* 2023). Plastics production has grown steadily, reaching 390.7 million metric tons in 2021, up from 1.5 million metric tons in 1950. Despite the environmental concerns, the industry's adaptability has allowed it to continue. However, plastic emissions have increased over the last six decades, becoming a global threat. By 2025, 46 million metric tons of plastic garbage are expected to be released into rivers, lakes, and oceans (Gideon *et al.,* 2024). Microplastics are plastic particles smaller than 5 mm in size (Niyitanga *et al.,* 2021; Aliyu *et al.,* 2023). Microplastics were first discovered in North America as spherules in plankton tows along the coast of New England in the 1970s. Hence, microplastics have been detected in most large bodies of water, including oceans, seas, lakes, dams, and rivers (Masura *et al.,* 2015). More recently, a study involving four rivers in Nigeria found microplastics in every sample collected (Khdre *et al.*, 2023). However, various studies reported a mean microplastic concentration in water of 12.5 L-1, with an extreme of 54 L^{-1} (Sarkar *et al.,* 2023). Similarly, another study on the Lagos Lagoon, one of Nigeria's largest estuaries, found that the mean microplastic concentration in water was 14.5 L-1, with an extreme level of particles of 86 L^{-1} (Akindele *et al.,* 2020). Therefore, plastic waste is extensively discarded into various niches of the environment. The potential threats of microplastics to human health have garnered significant attention since the widespread detection of microplastics in various human-related environments and food sources, including sediment, air, milk, seafood, table salt, dam water, and drinking water (Aliyu *et al.,* 2023). This study evaluates the concentration of microplastics in water samples collected from dams in Katsina State, Nigeria. The aim of the study is achieved through the objectives, such as physicochemical properties of waters from dams, concentration of microplastics, characterisation of the microplastics using Scanning Electron Microscopy -Energy Dispersive X-ray (SEM-EDX), Fourier Transform Infrared Spectroscopy (FTIR), determination of the contamination factor, pollution risk index, polymeric risk indices, and estimated daily intake of microplastics. More recently, a study on microplastics in northern Nigeria disclosed that microplastics are present in raw water, treated water, salt, and branded bottled water in Kaduna metropolis (Aliyu *et al.,* 2023). According to Onyekachi *et al.,* (2022) the amount of waste produced between 2007 and 2017 was high in Katsina State, for the reason that, Katsina State is among the three states that generate the majority of the plastic waste in Nigeria with the following data analysis; the total quantity of plastic waste generated is 3658644.59 metric tons, the quantity recycled is 439037.35 metric tons and the quantity of plastic not recycled are 3219607.24 metric tons. To assess the impact of plastic waste on the environment, water sources are a plausible means of monitoring this, hence the determination of microplastics. Secondary and primary microplastics are formed by physical, biological, and chemical degradation of microscopic plastic parts and are the primary source of microplastics released into the environment. Hence, there is a need to assess the level of microplastics in Katsina State, given the high volume of plastic waste generated and the scarcity of data on their concentration in the state. The findings of this study will help policymakers in Katsina State take the most appropriate action and explore additional ways to mitigate the situation in the state.

According to (Aliyu *et al.,* 2023; Gedeoun *et al.,* 2024), microplastic contamination factors are categorised as follows: MPs contamination factor < 1, low contamination; MPs contamination factor 1-3, moderate contamination; MPs contamination factor 3 - 6, considerably contaminated; and MPs contamination factor ≥ 6, very highly contaminated. There are almost 13 types of microplastics, these microplastics includes, high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), polyvinylchloride (PVC), polyethylene terephthalate (PET), Polyurethane resins (PUR), polyester, polyamide, and acrylic fibers are the most common types of plastics (Turhan *et al.,* 2022).

The pH is a measure of the acidity or basicity of a solution and ranges from 0 to 14, with zero being the most acidic and 14 the most basic, while seven is neutral. A pH less than 7 indicates acidity, whereas a pH greater than 7 indicates basicity. Electrical conductivity (EC) measures the ability of water to conduct an electrical current. The units of water conductivity are Microsiemens per centimetre (µS/cm). Total dissolved solids (TDS) are the total amount of solids dissolved in the water. In other words, it is the mass of solid material dissolved in a given volume of water and is

FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 2, No. 2, 2025
Print ISSN: 1595-9686
EISSN: 1595-9708

measured in grams per litre. Furthermore, total suspended solids (TSS) can include anything that floats in water.

Study Area

The study areas are in Katsina State. Katsina State lies between Latitudes 11º 3000' N and 13º 1500' North of the equator and Longitudes 6º 5200' E and 9º 2000'E. The study areas were (i) Sabuwa dam with coordinates: 11.178993º N, 7.129580º E; (ii) Dutsin-Ma Dam with coordinates: 12.468101º N, 7.499096º E; (iii) Zobe Dam with coordinates: 12.368968º N, 7.510034º E; (iv) Ajiwa Dam with coordinates: 12.941201º N, 7.755725º E; (v) Jibia Dam with coordinates: 13.070099º N, 7.234561º E; (vi) Mairuwa Dam with coordinates: 11.586235º N, 7.241110º E; (vii) Gwaigwaye Dam with coordinates: 11.573198º N, 7.204663º E; (viii) Sabke Dam with coordinates: 13.058229º N, 8.158714º E; (ix) Kurfi Dam with coordinates: 12.673275º N, 7.488221º E; (x) Mashigi Dam with coordinates: 11.865134º N, 7.606703º E as shown in Figure 1.

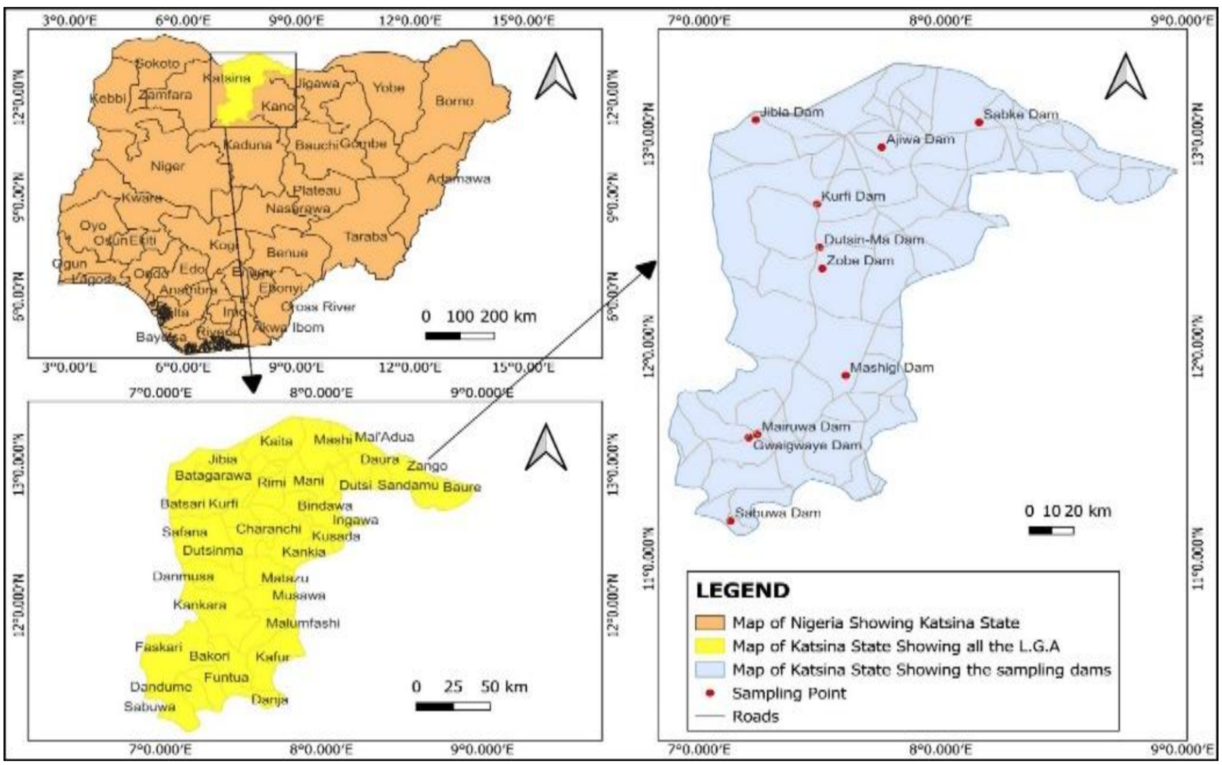


Figure 1: Map of Katsina State Showing the Sampling Sites
Source: Map drawn with QGIS 3.34.9 – OpenStreetMap

MATERIALS AND METHODS

Sample Collection and Physicochemical Analysis

The samples were collected in the rainy season from the designated sampling points shown in Figure 1. From each dam, a random grab of surface water was collected from the left, right, and middle of the dam. The collected samples were homogenised to create a composite sample, and each sample was then placed in a glass bottle. The bottles were tightly capped with aluminium foil, correctly labelled, and kept in an icebox to maintain their properties. The samples were collected and transported to Federal University Dutsin-Ma, the new chemistry laboratory (NCL) for physicochemical parameters, extraction of microplastics, counting and identification of microplastics.

The pH, dissolved solids, and electrical conductivity were determined with a Hanna pH meter and Consort digital conductometer, respectively, while total suspended solids were determined by gravimetry.

Extraction of Microplastics

The wet peroxide oxidation (WPO) method was used to remove organic matter (Masura *et al.,* 2015). Measured 250 mL of the water sample into a cleaned and dried 500 mL beaker, added 20 mL of 0.05 M Fe (II) solution, and 20 mL of 30% Hydrogen Peroxide (H_2O_2). Then, the mixture was heated at 75 ^{0}C on a hot plate with stirring for 30 minutes, loosely covered with aluminium foil to prevent atmospheric deposition during the reaction. Similarly, 20 mL of 30% (H_2O_2) was added to the sample throughout the stirring and heating process to ensure there was no organic matter in the digested sample. Repeated the procedure until no natural organic materials were visible, then kept the sample covered and digested for 24 hours (Anderson *et al.,* 2017). The dish was kept in a desiccator, and the filter was allowed to dry (Gadeon *et al.,* 2024).

Identification and characterisation of microplastics

All the extracted samples were carefully examined for microplastics under a Stereomicroscope (equipped with a camera) and a Scanning Electron Microscope (SEM-EDX), providing magnifications up to 5000×. The qualitative analysis of microplastic composition was performed using an FTIR (Agilent Technologies). Microplastics were identified according to the standard guidelines recommended by Sherrington et al. (2022). The identified particles were classified according to shape (fragment, pellet, fibre, and film). Nile blue was used to stain the samples for easier identification and counting of microplastics (Nelle *et al.,* 2022). Nile blue is an extremely photostable and fluorescent organic dye from the benzo(a)phenoxazine family. It was used due to its affinity for plastics but not for naturally occurring materials, and because it produced smaller particles that could be detected by fluorescence at specific wavelengths of light (Ibeto *et al.,* 2021).

Microplastics Contamination Factors and Pollution Load Index

The factor contributing to microplastics contamination (MPCF) and the microplastic pollution load index (MPLI) in dam water were assessed using various studies (Ibeto *et al.,* 2021; Gadeon *et al.,* 2024). Essentially, the MPCf measures the level of microplastics in the dam water compared to baseline values. It serves as a standardised method for monitoring and evaluating contamination levels across different samples. The calculations for both the MPCf and MPLI were carried out using equations (1) and (2). Where MPi is the quantity of microplastics in sample i, while MPb is the minimum baseline concentration taken from the lowest microplastics abundance.

$$MPCf = \frac{MPi}{MPb} \quad (1)$$

$$MPPLI_{Area} = (MPC_{f1} \times MPC_{f2} \times MPC_{f3} \ldots\ldots MPC_{fn})^{1/n} \quad (2)$$

Microplastics, Polymer Risk Indices, and Pollution Risk Index

The risk indices for microplastics and pollution levels in ten different dam samples were calculated using the methods outlined by Ibeto *et al.* (2021). The equations for determining the polymer risk indices (Hi) and the pollution risk index are presented in equations (3) and (4). The polymeric risks used hazard scores based on the toxicity levels of these plastics to ecosystems to derive the risk score (Sj) for the microplastic polymers identified in the samples. The hazard scores for the polymers found in the samples were as follows: PE = 11, PET = 4, PP = 1, PS = 47, and Nylon. Additionally, Pji represents the count of each specific microplastic polymer identified in sample i, and the MPR_{Area} is calculated as the nth root of the products of the polymer risk indices.

$$H_i = \sum\left(\frac{Pij}{MPi} \times Sj\right) \quad (3)$$

$$MPR_{Area} = (H_A \times H_B \times H_C \times \ldots\ldots H_n)^{1/n} \quad (4)$$

To calculate the microplastic pollution risk index (MPRI), equations (5) and (6) are adopted as described by Ibeto et al. (2021).

$$MPRI_i = H_i \times MPCf_i \quad (5)$$

$$MPRI_{Area} = (MPRI_A \times MPRI_B \times MPRI_C \times MPRI_D \ldots\ldots : MPRIn)^{1/n} \quad (6)$$

Estimated Daily Intake

The risks associated with human exposure to microplastic contamination in water include one significant pathway: oral ingestion. Estimate the daily intake (EDI) of microplastics from drinking contaminated water. The following equation was used to estimate the daily intake for adults and children.

$$EDI_q = \frac{MPi \times IR}{Bw} \quad (7)$$

In this equation, EDIq represents the estimated daily intake of microplastics through water ingestion (p/L). MPi is the average concentration of microplastics in water (p/L), IR is the ingestion rate (2.2 litres per day for adults and 1.8 litres per day for children), and Bw is the average body weight (70 kg for adults and 15 kg for children) as outlined by Ibeto *et al.* (2021) and Aliyu *et al.* (2023).

RESULTS

Physicochemical Parameters of Water Samples

The mean and standard deviation of physicochemical parameters of water samples collected from different dams are presented in Table 1, which includes pH, electrical conductivity (EC), total dissolved solids (TDS), and total suspended solids (TSS). The results show significant variation ($P < 0.05$) occurred across the sites for different water parameters.

Table 1: Mean ± SD of Physicochemical Parameters of Water Samples

S/N	Sites	pH	EC (µS/cm)	TDS (mg/L)	TSS (mg/L)
1	Zobe Dam	6.27±0.15^{c}	80±0.00^{a}	70.00±0.00^{b}	286.67±11.55^{cde}
2	Sabuwa Dam	5.47±0.06^{a}	156±010^{e}	119.67±1.15^{f}	293.33±50.33^{d}
3	Dutsin-Ma Dam	5.97±0.06^{b}	120±0.00^{c}	92.67±0.58^{d}	333.33±11.55^{e}
4	Mairuwa Dam	7.03±0.15^{ef}	140±0.00^{d}	106.33±0.58^{e}	273.33±30.55^{bcd}
5	Gwaigwaye Dam	7.13±0.15^{f}	516±0.01^{i}	45.33±1.15^{a}	253.33±11.55^{abcd}
6	Mashigi Dam	6.87±0.06^{e}	233±0.01^{h}	177.00±1.73^{i}	200.00±0.00^{a}
7	Jibia Dam	6.47±0.06^{cd}	200±0.00^{f}	150.67±1.15^{h}	233.33±11.55^{abc}
8	Ajiwa Dam	7.10±0.00^{f}	110±0.00^{b}	82.67±0.58^{c}	220.00±20.00^{ab}
9	Sabke Dam	6.57±0.06^{d}	210±0.00^{g}	138.00±1.00^{g}	226.67±23.09^{ab}
10	Kurfi Dam	6.03±0.15^{b}	133±0.01^{d}	81.67±0.58^{c}	266.67±50.33^{bcd}

FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 2, No. 2, 2025
Print ISSN: 1595-9686
EISSN: 1595-9708

Mean values in the same column followed by the same superscript letters are not significantly different ($p > 0.05$)

Correlation of Physicochemical Parameters

The correlation analysis of the physicochemical parameters of water samples collected from 10 dams in Katsina State is shown in Table 2. The parameters include pH, electrical conductivity (EC), total dissolved solids (TDS), and total suspended solids (TSS) for all the samples.

Table 2: Correlation of Physicochemical Parameters of Water Samples

Parameter	TSS	pH	TDS	EC
TSS	1.000			
pH	-0.513**	1.000		
TDS	-0.408*	-0.063	1.000	
EC	-0.250	0.430*	-0.177	1.000

***. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).**

The Concentrations and Shapes of Microplastics

The concentrations and shapes of microplastics across the sampling sites are shown in Figures 2 and 3. The concentration revealed significant variability, with Zobe dam exhibiting the highest levels (48.00±4.00 p/L), and Kurfi dam the lowest (28.00±4.00 p/L). The statistically significant differences, as denoted by the letter groupings of Duncan, suggest varying anthropogenic influences, with concentrations likely reflecting proximity to agricultural runoff, local sources, and relatively pristine conditions (Wang *et al*., 2022). The widespread detection of MPs across all sites aligns with recent findings demonstrating the pervasive contamination of aquatic ecosystems globally (Kumar *et al.,* 2023).

Notably, the moderate concentrations observed at sites such as Sabuwa dam and Gwaigwaye dam, with MP concentrations of 32.00±4.00 p/L, originated from surface runoff, agricultural activities, and anthropogenic activities, which have been increasingly recognised as essential pathways for microplastics pollution (Allen *et al.,* 2021).

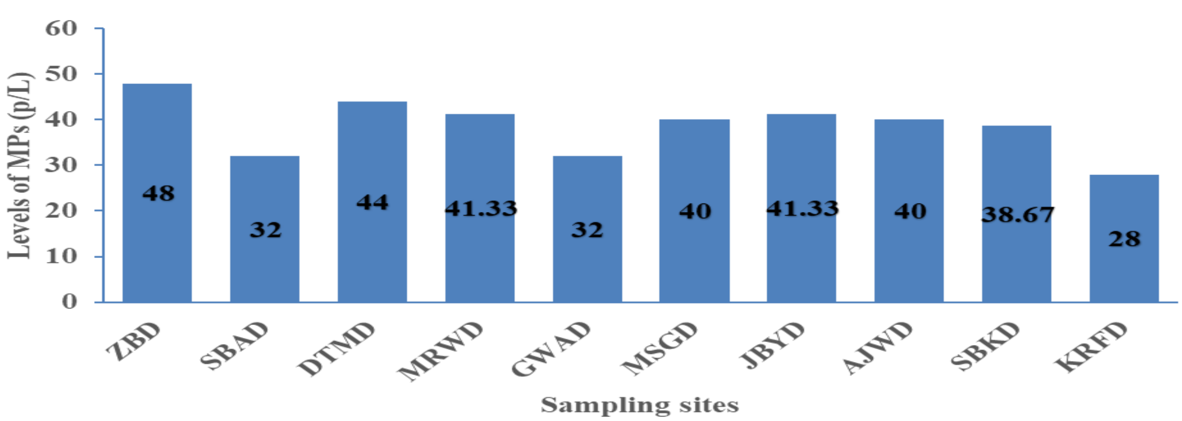


Figure 2: The Mean Concentration of Microplastics; Zobe dam (ZBD), Sabuwa dam (SBAD), Dutsin-Ma dam (DTMD), Mairuwa Dam (MRWD), Gwaigwaye dam (GWAD), Mashigi dam (MSGD), Jibia dam (JBYD), Ajiwa dam (AJWD), Sabke dam (SBKD) and Kurfi dam (KRFD).

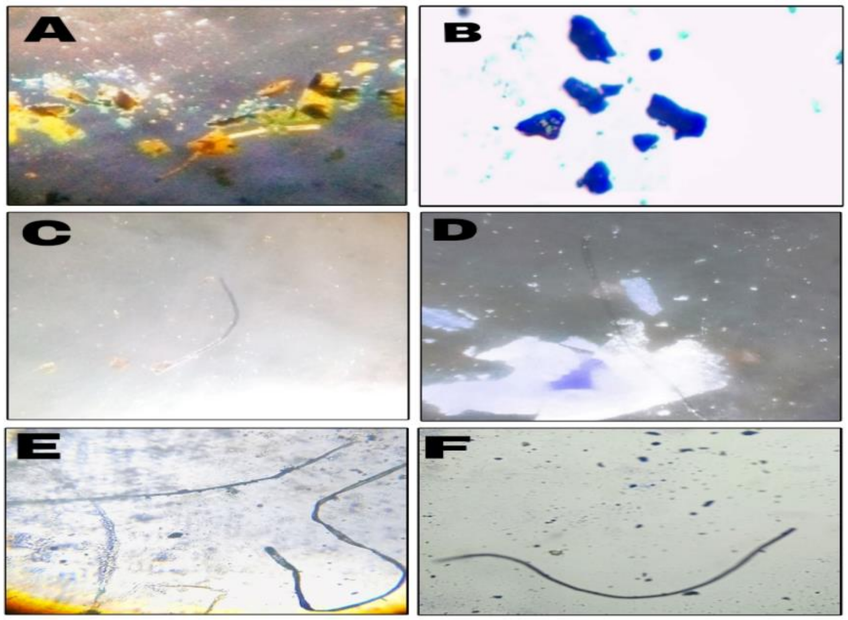


Figure 3: Shapes of Microplastics Identified in Dam Waters: (A & D) Film (B) Fragments and Pellet (C, E and F) Fibres

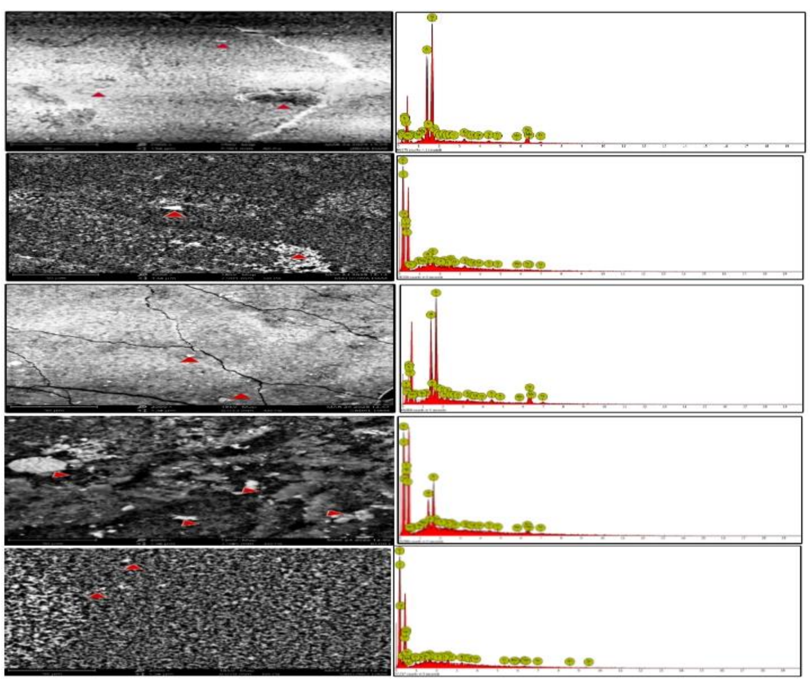


Figure 4: Microscopic image taken by Scanning Electron Microscopy - Energy Dispersive X-ray (SEM-EDX)

Microplastics polymer types in the water sample by using the FTIR functional group

Table 4 and Figure 5 disclose the absorbance peaks and functional groups of polymers identified in the water Samples. A sample from Ajiwa dam shows absorption peaks at 3265 cm-1 and 3690 cm-1, which indicate O-H stretching, suggesting the presence of polyvinyl alcohol (PVA). Another peak at 1766 cm^{-1}, identified as the C=O stretching mode, indicates the presence of polyethene terephthalate (PET). Additionally, absorption peaks at 991 cm^{-1}, 909 cm^{-1} and 1431 cm^{-1} correspond to C=C bending and C-H bending, indicating the presence of polyethene (PE). Peaks at 790 cm^{-1} and 1632 cm^{-1}, attributed to C=C stretching, suggest the presence of polystyrene (Kerubo *et al.,* 2022).
The Dutsin-Ma dam displayed notable peaks at 3250 cm-1 and 3690 cm-1, which also indicate O-H stretching, suggesting the presence of polyvinyl alcohol. A peak at 1640 cm^{-1} associated with C=O stretching suggests the presence of polyamide (Nylon). Furthermore, vibration peaks at 909 cm^{-1}, 991 cm^{-1} and 1438 cm^{-1} show C=C bending and CH_2 bending, indicating polyethylene (PE).

The Gwaigwaye dam sample shows peaks at 3250 cm^{-1} and 3690 cm^{-1} again suggesting O-H stretching, which reinforces the presence of polyvinyl alcohol (PVA). The bands at 1282 cm^{-1} and 1744 cm^{-1} correspond to C-O asymmetric stretching and C=O stretching, which are typical of polyethene terephthalate (PET). Strong C=C bending and C-H bending at 909 cm^{-1} and 1431 cm^{-1} align with polyethene terephthalate (PET). The peaks at 909 cm^{-1} and 1431 cm^{-1} may arise from C=C bending and C-H bending, indicating polyethene (PE). Lastly, an absorption peak at 678 cm^{-1} suggests C=C bending, which indicates polystyrene (Gela *et al.,* 2022).

Jibia dam exhibits an absorption peak at 1640 cm-1, attributed to the C=C stretching mode, indicating the presence of polyvinyl chloride (Pandey *et al.,* 2016). Additionally, peaks at 909 cm^{-1} and 1431 cm^{-1} associated with C=C bending and C-H bending, suggest that polyethene is also present. Furthermore, the peaks at 693 cm^{-1} and 752 cm^{-1} correspond to C=C bending and CH_2 stretching, respectively, hinting at the possible presence of polystyrene (Sathish *et al.,* 2020).

Kurfi dam analysis, as shown in Figure 5, an absorption peak at 1282 cm-1 along with those at 3265 cm-1 and 3622 cm-1 indicates C-O asymmetric stretching and O-H stretching, suggesting the presence of polyethene terephthalate (PET) and polyvinyl alcohol (PVA). The absorptions at 678 cm^{-1} and 1640 cm^{-1}, which correspond to C=C bending and C=C stretching, further imply the presence of polystyrene (Aliyu *et al.,* 2023).

Mairuwa dam shows absorption peaks at 3250 cm-1, 3622 cm-1, and 3690 cm-1, which are attributed to O-H stretching, indicating the presence of polyvinyl alcohol (PVA). Similarly, the absorptions at 1282 cm^{-1} and 1766 cm^{-1} suggest C-O stretching and C=O stretching, respectively, confirming the presence of polyethene terephthalate (Periera *et al.,* 2017). The peak at 1640 cm^{-1} represents C=C stretching, indicating polystyrene, while the peaks at 909 cm^{-1}, 991 cm^{-1} and 1431 cm^{-1} correspond to C=C bending and CH_2 bending, confirming the presence of polyethene (PE) (Sathish *et al.,* 2020).

Mashigi dam exhibits characteristic peaks at 2922 cm-1 and 1006 cm-1, indicating CH2 and C-O stretching, confirming the presence of polyvinyl alcohol (PVA). The absorption peaks at 3205 cm^{-1}, 3697 cm^{-1}, and 1110 cm^{-1} represent O-H stretching and C-O stretching, suggesting the presence of polyethene (PE) (Sathish *et al.,* 2020). The peaks at 685 cm-1 and 790 cm-1 are attributed to C=C bending and C-H bending, respectively, confirming the presence of polystyrene (Gela et *al.,* 2022).

Sabke dam shows absorbance peaks at 670 cm^{-1}, 790 cm^{-1}, and 1662 cm^{-1}, indicating C=C and C-H bends, consistent with the presence of polystyrene (PS). This type of plastic is often found in food packaging and disposable items, highlighting a significant contribution from waste (Andrady *et al.,* 2021). Additionally, the absorbance peaks at 909 cm^{-1}, 1431 cm^{-1}, and 3272 cm^{-1} suggest C=C and C-H bends, indicating the presence of polyethene (PE). This finding aligns with global research identifying these polymers as prevalent in freshwater systems, mainly due to their extensive use in single-use plastics (Lebreton *et al.,* 2022). Furthermore, the peak at 1766 cm^{-1} indicates C=O stretching, revealing the presence of polyethene terephthalate (PET), which may originate from textile fibres and beverage containers known to break down into secondary microplastics (Browne *et al.,* 2020). Interestingly, a peak at 3697 cm^{-1} was associated with the O-H stretching mode of the functional group, suggesting the presence of polyvinyl alcohol (PVA). This could indicate wastewater discharge, as polyvinyl alcohol is commonly used in water-soluble industrial products (Hernandez *et al.,* 2023).

The Sabuwa dam shows absorbance peaks at 678 cm^{-1} and 827 cm^{-1}, indicating C=C bending and CH2 bending, consistent with polystyrene. Additionally, the absorbance peaks at 1274 cm^{-1} and 1744 cm^{-1}, indicating C-O stretching and C=O stretching, respectively, suggesting that polyethene terephthalate (PET) is present. These observations align with previous research connecting PS and PET to consumer waste and synthetic textiles (Geyer *et al.,* 2021). The peak at 2922 cm^{-1}, associated with N-H stretching, suggests nylon, which is often linked to fishing nets (Sherrington *et al.,* 2022). This implies that local fishing activities are impacting the Sabuwa dam. Similarly, the peak at 3429 cm^{-1} indicates O-H stretching, suggesting the presence of polyvinyl alcohol, likely due to inputs from domestic wastewater (Hernandez et al., 2023).

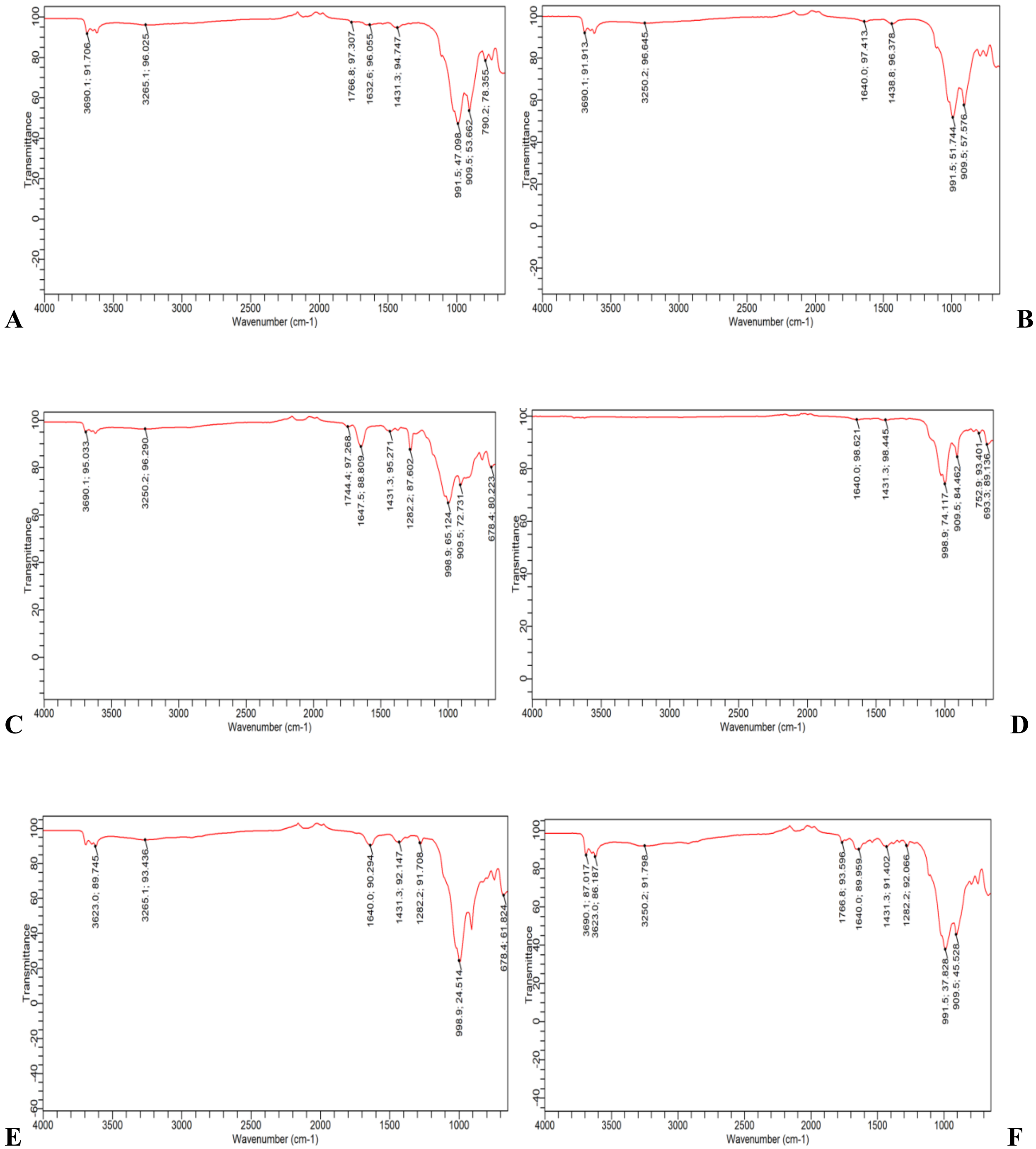
Lastly, a sample from Zobe dam, as shown in Figure 13, displayed absorbance peaks at 991 cm^{-1} and 1438 cm^{-1}, suggesting C=C bending and CH2 bending, which indicates the presence of polyethene (PE). This is commonly found in agricultural films and packaging debris (Ng *et al.,* 2021). The significant presence of these polymers suggests a strong link to farming activities and to waste runoff into the dam, as polyethene is widely used. Additionally, the absorption at 1633 cm^{-1} is consistent with C=O stretching, indicating the presence of nylon, which originated from fishing nets and other materials (Sherrington *et al.,* 2022). The robust signals at 3258 cm^{-1}, 3622 cm^{-1}, and 3690 cm^{-1} indicate O-H stretching, which may also point to potential municipal wastewater contamination from detergents (Hernandez *et al.,* 2023).

FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 2, No. 2, 2025
Print ISSN: 1595-9686
EISSN: 1595-9708

Table 4: Microplastics Types Using FTIR Spectrum

S/N	Sampling sites	Wavelength (cm^{-1})	Functional group	Types of polymers
1	Ajiwa Dam	790, 1632	C=C stretching	Polystyrene
		991, 909, 1431	C=C bending, C-H bending	Polyethylene
		1766	C=O stretching	PET
		3265, 3690	O-H Stretching	PVA
2	Dutsin-Ma Dam	909, 991, 1438	C=C bending, C-H bending	Polyethylene
		1640	C=O	Nylon
		3250, 3690	O-H stretching	PVA
3	Gwaigwaye Dam	678	C=C bending	Polystyrene
		909, 1431	C=C bending, C-H bending	Polyethylene
		1282, 1744	C-O asymmetric stretching C=O stretching	PET
		3250,3690	O-H stretching	Polyvinyl alcohol
		1647	C=O stretching	Nylon
4	Jibia Dam	693, 752	C=C-H bending, C-H,	Polystyrene
		909, 1431	C=C bending, C-H bending	Polyethylene
		1640	C=C stretching	PVC
5	Kurfi Dam	678, 1640	C=C bending, C=C stretching	Polystyrene
		1431	C-H bending	PE
		3265, 3622	O-H stretching	Polyvinyl alcohol
		1282	C-O asymmetric stretching	PET
6	Mairuwa Dam	909, 991, 1431	C=C bending, C-H bending	Polyethylene
		1640	C=C stretching	Polystyrene
		1282, 1766	C-O stretching, C=O stretching	PET
		3250, 3622, 3690	O-H stretching	Polyvinyl alcohol
7	Mashigi Dam	685, 790	C=C bending C-H bending	Polystyrene
		909,	C=C bending	Polyethylene
		3205, 3697, 1110	O-H stretching, C-O stretching	PET
		2922, 1006	CH2, C-O stretching	PVA
8	Sabke Dam	670, 790, 1662	C=C bending, C=C stretching	Polystyrene
		909, 1431, 3272	C=C bending, C-H bending	Polyethylene,
		1766	C=O stretching	PET
		3697	O-H stretching	Polyvinyl alcohol
9	Sabuwa Dam	678, 827	C=C bending, C-H bending	Polystyrene
		1274, 1744	C-O stretching, C=O stretching	PET
		2922	N-H stretching,	Nylon
		3429	O-H stretching	Polyvinyl alcohol
10	Zobe Dam	991, 1438	C=C bending, C-H bending	Polyethylene
		1633	C=O stretching	Nylon
		3258, 3622, 3690	O-H stretching	Polyvinyl alcohol

Note: PET – polyethene terephthalate; PE – polyethene; PU – Polystyrene; PVA- Polyvinyl alcohol; N – Nylon (polyamide).


A
3690.1; 91.706
3265.1; 96.025
1766.8; 97.307
1632.6; 96.055
1431.3; 94.747
991.5; 47.098
909.5; 53.662
790.2; 78.355
B
3690.1; 91.913
3250.2; 96.645
1640.0; 97.413
1438.8; 96.378
991.5; 51.744
909.5; 57.576
C
3690.1; 95.033
3250.2; 96.290
1744.4; 97.268
1647.5; 88.809
1431.3; 95.271
1282.2; 87.602
998.9; 65.124
909.5; 72.731
678.4; 80.223
D
1640.0; 98.621
1431.3; 98.445
998.9; 74.117
909.5; 84.462
752.9; 93.401
693.3; 89.136
E
3623.0; 89.745
3265.1; 93.436
1640.0; 90.294
1431.3; 92.147
1282.2; 91.708
998.9; 24.514
678.4; 61.824
F
3690.1; 87.017
3623.0; 86.187
3250.2; 91.798
1766.8; 93.596
1640.0; 89.959
1431.3; 91.402
1282.2; 92.066
991.5; 37.828
909.5; 45.528
Transmittance
Wavenumber (cm-1)

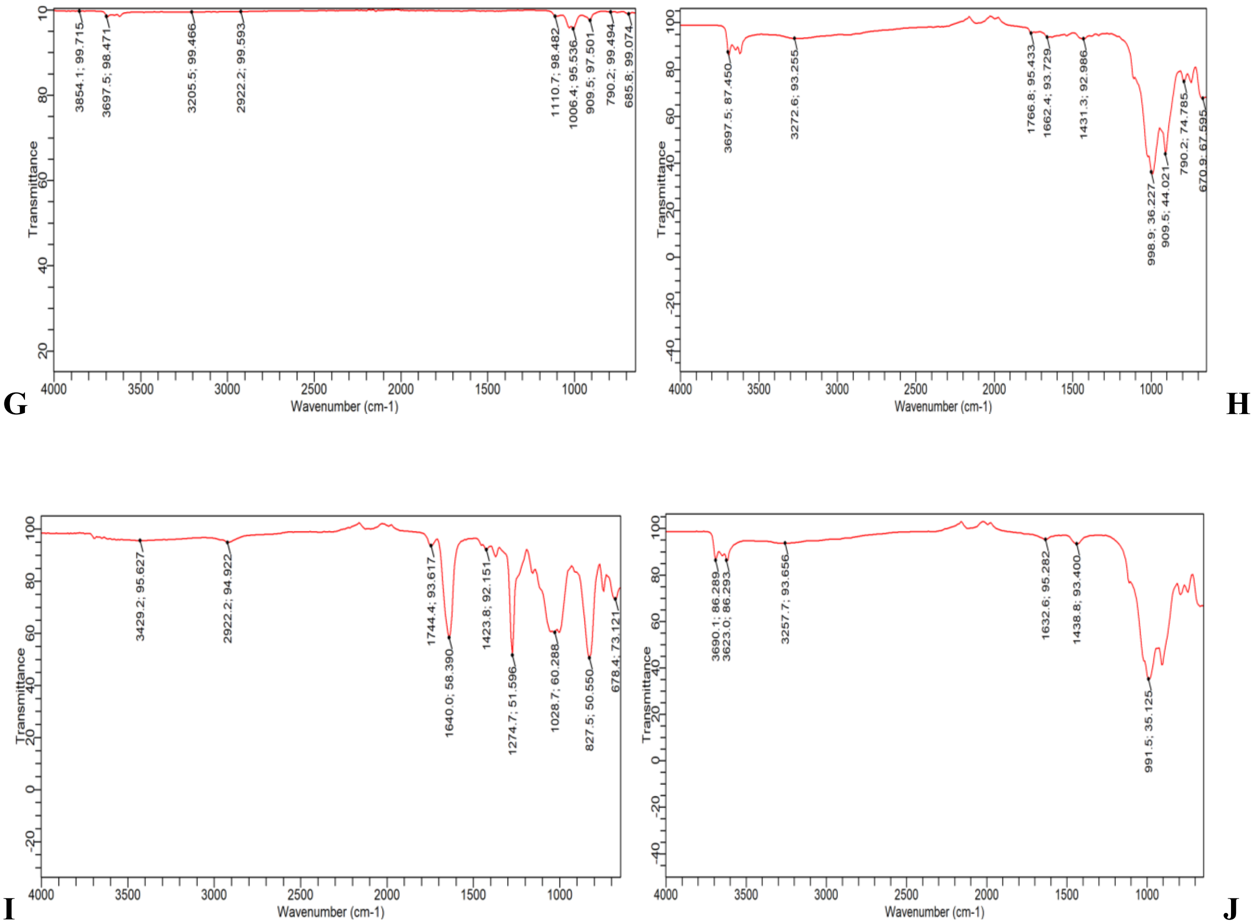


Figure 5: Spectra of the polymers in the water samples as obtained by FTIR: (A) represents Ajiwa dam. (B) Dutsin-Ma dam (C) Gwaigwaye dam (D) Jibia dam (E) Kurfi dam (F) Mairuwa dam (G) Mashigi dam (H) Sabke dam (I) Sabuwa dam (J) Zobe Dam

Nearest Neighbour and Nearest Distance

The nearest neighbours and distances between microplastics in the samples are shown in Figure 6 and Table 5. The table shows the nearest neighbour and the nearest distance between each sample. The distance is measured in millimetres (mm) and represents the Euclidean distance between the two samples.

The numeric value between 0 and 2.15 indicates whether the samples are random (1), regular (greater than one and less than 2.15), or clustered (0 to less than 1).

FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 2, No. 2, 2025
Print ISSN: 1595-9686
EISSN: 1595-9708

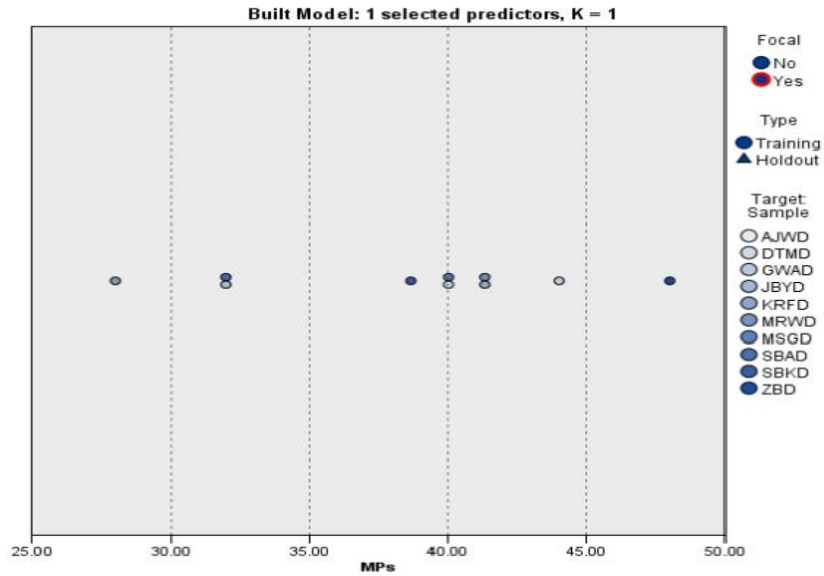


Figure 6: Nearest Neighbour Quadrant Mapping for Ten Different Water Samples

Table 5: Nearest Neighbours and Distances for Microplastic Between Samples

S/N	Samples	Nearest Neighbours	Nearest distances
1	Zobe Dam	Dutsin-Ma Dam	0.400
2	Dutsin-Ma Dam	Mairuwa Dam	0.267
3	Jibia Dam	Mairuwa Dam	0.000
4	Mairuwa Dam	Jibia Dam	0.000
5	Mashigi Dam	Ajiwa Dam	0.000
6	Ajiwa Dam	Mashigi Dam	0.000
7	Sabke Dam	Ajiwa Dam	0.133
8	Gwaigwaye Dam	Sabuwa Dam	0.000
9	Sabuwa Dam	Gwaigwaye Dam	0.000
1	Kurfi Dam	Gwaigwaye Dam	0.400

Principal Component Analysis of the dam water

Table 6 shows the initial eigenvalues, extraction sums of squared loadings and rotation sums of squared loadings for each component. The initial eigenvalues represent the amount of variance explained by each component. In contrast, the extraction and rotation sums of squared loadings represent the amount of variance explained by each variable in each component. Therefore, component number 1 describes 67.221% of the total variance, while component number 2 explains 32.779% of the total variance. Similarly, these two components describe 100% of the total variance. However, components 3, 4, and 5 do not contribute significantly to the variance. The component plot in rotated space in Figure 15 shows how variables pH and MPs relate to each other, as indicated in the red line.

Table 6: Total Variance of Physicochemical Parameters and Microplastics Levels in Dam Water

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.050	67.221	67.221	6.050	67.221	67.221	5.361	59.570	59.570
2	2.950	32.779	100.000	2.950	32.779	100.000	3.639	40.430	100.000
3	4.398E-16	4.887E-15	100.000						
4	1.065E-16	1.183E-15	100.000						
5	3.351E-17	3.723E-16	100.000						

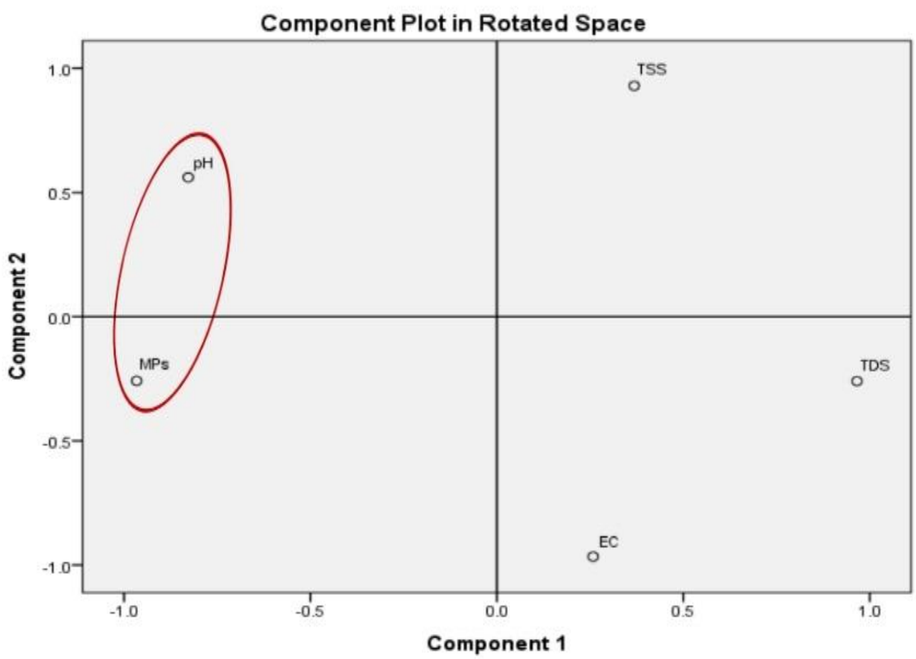


Figure 7: Principal Component Plot of Physicochemical Parameters and MPs

Contamination Factor and Pollution Load Index of Microplastics

The contamination factor (CF), calculated as the ratio of microplastic concentration at each site to the baseline concentration, indicated high contamination at Zobe Dam and Dutsin-Ma Dam, with contamination factors of 1.71 and 1.57, respectively. This suggests that a strong anthropogenic influence, such as local runoff, agricultural activities, and other factors (Wang *et al.,* 2022), exists. Similarly, moderate contamination factors (1.14 to 1.38) were observed at Sabuwa dam, Gwaigwaye dam, Mairuwa dam, Mashigi dam, Ajiwa dam, and Sabke dam due to fragmented plastic debris (Allen *et al.,* 2021).

Table 7: Contamination Factor and Pollution Health Index of Microplastics

S/N	Sites	MPCF	Risk level
1.	Zobe Dam	1.71	Moderate
2.	Sabuwa Dam	1.14	Low
3.	Dutsin-Ma Dam	1.57	Moderate
4.	Mairuwa Dam	1.48	Moderate
5.	Gwaigwaye Dam	1.14	Low
6.	Mashigi Dam	1.43	Moderate
7.	Jibia Dam	1.48	Moderate
8.	Ajiwa Dam	1.43	Moderate
9.	Sabke Dam	1.38	Moderate
1(	Kurfi Dam	1.00	Low
$(MPPLI_{Dam}) = 1.19$			

The overall pollution load index of 1.19, derived from the geometric mean of all contamination factor values, confirmed a low, moderate, and high level of microplastic pollution across the sampling sites, highlighting the pervasive nature of microplastic contamination even in less-polluted sites (Kumar *et al.,* 2023). These findings aligned with a global study emphasising the ubiquity of microplastics in aquatic systems (Brahney *et al.,* 2024).

Estimated Daily Intake

The estimated daily microplastic intake from the studied water for adults and children is presented in Table 8. The estimated daily intake at the Kurfi dam is generally less than 1, indicating a low microplastic intake. Therefore, it may pose no risk from daily consumption. Similarly, the Zobe dam, with an EDI of 1.51, and other dams ranged from 1.01 to 1.38, were classified as critical to moderate risk. However, results generally show higher microplastic intake in children than in adults.

Table 8: Microplastics Polymer Risk Indices, Pollution Risk Index and Estimated Daily Intake

Sampling sites	Polymeric risk indices (Hi)	MPs pollution risk index (MPRI)	Quantity-based Estimated daily intake (EDI)	
			Adult	Children
Zobe Dam	19.70	33.70	1.51	5.76
Sabuwa Dam	13.40	15.30	1.01	3.84
Dutsin-Ma Dam	18.30	28.70	1.38	5.28
Mairuwa Dam	17.10	25.30	1.30	4.96
Gwaigwaye Dam	13.40	15.30	1.01	3.84
Mashigi Dam	16.20	23.20	1.26	4.80
Jibia Dam	17.10	25.30	1.30	4.96
Ajiwa Dam	16.20	23.20	1.26	4.80
Sabke Dam	15.80	21.80	1.22	4.64
Kurfi Dam	09.50	09.50	0.88	3.36

Source: Using Ibeto *et al. (2021) formula as shown in equations* 3, 5 and 7.

Recent research has generally reported higher microplastic intake in children than in adults (Aliyu *et al.,* 2023; Ibeto *et al.,* 2021). Evidence on the risks of microplastics to children's and adults' health remains very unclear. Other than exposure, the fate and transport of ingested microplastics in the human body, which combine intestinal assimilation and biliary discharge, have not been studied in the previous investigation and remain generally obscure (Ibeto *et al.,* 2021)

DISCUSSION

These findings evaluated microplastic concentrations across 10 dams and measured their physicochemical parameters, including pH, TDS, EC, and TSS. The physicochemical analysis reveals a concerning deviation from drinking water standards across several key parameters in the studied dams. The acidic pH levels recorded at Sabuwa and Dutsin-Ma Dams, which fall below the permissible range of 6.5–8.5, indicate a significant risk and are a known public health concern (WHO, 2018). While the Total Dissolved Solids (TDS) for all sites were commendably within the recommended limit of <500 mg/L, the elevated Electrical Conductivity (EC) at Gwaigwaye Dam suggests a higher concentration of ionic constituents, potentially impacting palatability (SON, 2007). Most critically, the pervasive exceedance of the Total Suspended Solids (TSS) standard across all locations points to widespread turbidity issues, likely stemming from watershed erosion and surface runoff; high TSS can harbour pathogens and interfere with disinfection processes, thereby increasing the microbial risk and deteriorating overall water quality (Uddin *et al.,* 2021).

The correlation matrix reveals significant interrelationships among the water quality parameters, providing insight into their combined behaviour within the dam systems. The strong negative correlation between Total Suspended Solids (TSS) and pH ($r = -0.513$, $p < 0.01$) suggests that as water becomes more acidic (lower pH), the concentration of suspended particles increases, consistent with findings by Uddin et al. (2021). The positive correlation between Electrical Conductivity (EC) and pH ($r = 0.430$, $p<0.05$) aligns with the principle that alkaline conditions often accompany higher concentrations of dissolved basic ions, such as carbonates and bicarbonates, which contribute to conductivity (WHO, 2018). Furthermore, the significant negative correlation between TSS and Total Dissolved Solids (TDS) ($r = -0.408$, $p < 0.05$) implies a potential competitive or inverse relationship between particulate and dissolved loads, with suspended sediments diluting dissolved ion concentrations or vice versa. The lack of a strong correlation between EC and TDS ($r = -0.177$, $p > 0.05$) indicates that the composition of dissolved ions is not uniform across sites, and that TDS is not solely estimated from EC (SON, 2007).

CONCLUSION

In conclusion, four physicochemical parameters of dam water samples were determined, including pH, electrical conductivity (EC), total dissolved solids (TDS), and total suspended solids (TSS). The concentrations, shapes and types of microplastics present in ten (10) dams in Katsina State, Nigeria were determined and reported in this research; most of the dam samples revealed some differences among their levels of contamination with microplastics. The highest microplastic concentration was detected in Zobe dam (48 p/L), while the lowest was in Kurfi dam (28 p/L). Fragments, pellets, fibres, and film were the dominant microplastic shapes detected in all samples. While polyethene (PE), polyvinyl chloride (PVC), polyethene terephthalate (PET), polyvinyl alcohol (PVA), Nylon and Polystyrene (PS) were the main types of microplastics examined using Fourier Transform Infrared Microscopy (FTIR) and Scanning Electron Microscopy – Energy Dispersive X-ray Microscopy (SEM-EDX). The contamination factor and pollution load index of all the water samples were evaluated. Zobe dam had the highest contamination factor (1.71), indicating moderate contamination. However, the Kurfi dam had the lowest contamination factor (1.00, Little contamination). Similarly, the overall pollution load index of all the samples was calculated (1.12) using the geometric mean of all the contamination factors previously evaluated. The estimated daily intake (EDI) of MPs was higher in children than in adults, indicating a potential health risk for consumers of these waters.

RECOMMENDATIONS

i. Governments should provide and monitor proper recycling and waste disposal systems across all three zones to prevent plastic litter. Similarly, the government should establish agencies to monitor microplastic levels in water, sediment, air, and food to assess their long-term health effects.
ii. Plastic manufacturers should develop new techniques to reduce polymer use, create harmless, biodegradable alternatives to single-use plastics and support studies to gather crucial data on microplastic pollution, especially in high-risk areas, to inform effective policy decisions.
iii. Educate communities on reducing plastic consumption, proper disposal methods, switching to reusable products and actively removing existing waste from waterways and dams and using filtering nets to prevent further plastic from entering water systems.

Acknowledgement
This work was supported by funding from the Institutional Based Research (IBR) TETFund.

REFERENCES

Adeogun, A. O., Ibor, O. R., Khan, E. A., Chukwuka, A. V., Omogbemi, E. D., & Arukwe, A. (2020). Detection and occurrence of microplastics in the stomach of commercial fish species from a municipal water supply lake in southwestern Nigeria. *Environmental Science and Pollution Research*. 27(25), 31035-31045

Akindele, E. O., Ehlers, S. M., & Koop, J. H. (2020). Freshwater insects of different feeding guilds ingest microplastics in two Gulf of Guinea tributaries in Nigeria. *Environmental Science and Pollution Research*. 27, 33373-33379

Aliyu, A. O; Okunola. O. J Awe, F. E Musa, A. A. (2023). Assessment of Microplastics Contamination in River Water, Bottled Water, Sachet Water and Branded Table Salt Samples in Kaduna Metropolis, Nigeria. *J. Appl. Sci. Environ. Manage*. 27 (6) 1105-1118 DOI: https://dx.doi.org/10.4314/jasem.v27i6.8

Allen, S., Allen, D., Phoenix, V. R., Le Roux, G., Durántez Jiménez, P., Simonneau, A., & Galop, D. (2021). Atmospheric transport and deposition of microplastics in a remote mountain catchment. *Nature Geoscience*. 14(2), 138–142.

Anderson, P.; Warrack, S; Langen, V; Challis, JK; Hanson, M.L.; Rennie, MD (2017). Microplastic contamination in Lake Winnipeg, Canada. *J. of Env. Poll,* 225, 223–231.

Andrady, A. L. (2021). Microplastics in the marine environment. *Marine Pollution Bulletin,* 62(8), 1596–1605.

Badamasi Jamda Saidu, Godwill Geofrey Jidauna, Jamila Kira Sanusi, & Daniel Davou Dabi (2019). The Contribution of Zobe Dam to the Socio-Economic Development of Makera Community, Dutsinma Local Government Area, Katsina State, North-Western Nigeria. *International Journal of Environmental Monitoring and Analysis*. Vol. 7, No. 3, 2019, pp. 75–82. DOI: 10.11648/j.ijema.20190703.13

Bala, U., Abdullahi, S. (2011). Aspects of Reproductive Biology of Fish of Commercial Importance in Sabke Reservoir, Katsina State. *Bayero Journal of Pure and Applied Sciences*. 4(2): 178 – 18 10.4314/bajopas.v4i2.36

Benjamin M Saalidong, Simon Appah Aram, Samuel Otu, & Patrick Osei Lartey (2022). Examining the dynamics of the relationship between water pH and other water quality parameters in ground and surface water systems. *Journal of Pone*. e0262117. DOI: 10.1371/.0262117

Brahney, J., Hallerud, M., Heim, E., Hahnenberger, M., & Sukumaran, S. (2024). Plastic rain in protected areas of the United States. Science. 368(6496), 1257–1260.

Browne, M. A. (2020). Accumulation of microplastics on shorelines worldwide: Sources and sinks. *Environmental Science & Technology*. 45(21), 9175–9179.

Gela SM, Aragaw TA (2022). Abundance and Characterisation of Microplastics in Main Urban Ditches Across the Bahir Dar City, Ethiopia. *Front Environ Sci.* 10:831417. https://doi.org/10.3389/fenvs.2022.831417

Geyer, R. (2021). Production, use and fate of all plastics ever made. *Science Advances*. 3(7), e1700782.

Gideon Aina Idowu a, Adewumi Yetunde Orijia, Kehinde Oluwasiji Olorunfemia, Michael Oluwatoyin Sunday (2024). Why Nigeria should ban single-use plastics: Excessive microplastic pollution of the water, sediments and fish species in the Osun River, Nigeria. *Journal of Hazardous Materials Advances*. 13 (2024) 100409

González, M. A., López, R., & Fernández, J. (2022). Irontitanium oxide mineralogy in igneous systems: Implications for resource exploration. *Journal of Geochemical Exploration*, 240, 107043.

Haruna Saleh, Kabir Idris, & Aliyu Ibrahim Kankara (2018). Economic Impact of Dam Construction, The Challenge and Solution to Agricultural Productivity in Nigeria: A Case Study of Tura Dam in Mashigi Village, Kankara L.G.A., Katsina State. *Journal of Agriculture and Veterinary Sciences*. volume 2

Hernandez, L. S. (2023). Polyvinyl alcohol as an emerging pollutant in aquatic systems. *Environmental Pollution*. 291, 118193.

Ibeto CN; Enyoh CE; Ofomatah AC; Oguejiofor LA; Okafocha T; Okanya V (2021). Microplastic pollution indices of bottled water from Southeastern Nigeria, *Int. J. of Environmental Analytical Chemistry*. DOI: 10.1080/03067319.2021.1982926

Ibrahim, H., Thompson, A., & Sharma, B. (2024). Redox-driven elemental fractionation in soil systems: A spectroscopic approach. Geoderma, 435, 116785.

Ifenna Ilechukwu, Tolulope Abisola Olusina, Odinaka Chidinma Echeta (2020). Physicochemical analysis of water and sediments of Usuma Dam, Abuja, Nigeria. Ovidius University Annals of Chemistry. Volume 31, Number 2, pp. 80 – 87. DOI: 10.2478/auoc-2020-0015

Kerubo JO, Onyari JM, Muthumbi AWN, Andersson DR, Kimani EN (2022). Microplastic Polymers in Surface Waters and Sediments in the Creeks Along the Kenya Coast, Western Indian Ocean (WIO). *Eur J Sustain Dev Res* . 6(1): em0177. https://doi.org/10.21601/ejosdr/11433.

Khdre, A. M., Ramadan, S. A., Ashry, A., & Alaraby, M. (2023). Chironomus sp. as a Bioindicator for Assessing Microplastic Contamination and the Heavy Metals Associated with It in the Sediment of Wastewater in Sohag Governorate, *Egypt. Water, Air, & Soil Pollution*. 234(3), 161.

Kumar, R., Sharma, P., Manna, C., & Jain, M. (2023). Abundance, distribution, and composition of microplastics in the surface water and sediments of a transboundary river. *Environmental Pollution*. 316, 120494.

Lawal, N; Abdullahi, S. A; Abolude, D. S. (2023). Physicochemical Characteristics and Fish Abundance and Diversity of Mairua Reservoir Water, Funtua, Katsina State, North-Western Nigeria. *J. Appl. Sci. Environ. Manage*. 27 (1) 125-132

Lawal, N; Nafiu, Mi; Kuiwa, Ts; Aminu, Am; Usman, M (2020). Phytoplankton Population in Relation to Physicochemical Parameters of Gwaigwaye Reservoir, Katsina State, Nigeria. *J. Appl. Sci. Environ. Manage*. Vol. 24 (1) 73-78

Lebreton, L. (2022). River plastic emissions to the world's oceans. Nature Communications. 8, 15611.

Lee, J., Park, S., & Kim, D. (2023). Titanium speciation in organic vs. inorganic matrices: Insights from XAS and EDX. Chemosphere, 310, 136822.

Li, X., Wang, Y., & Zhang, Q. (2023). Aluminosilicate formation in soils: A synchrotron-based study. Applied Clay Science, 232, 106791.

Masura, J. (2015). Laboratory methods for the analysis of microplastics in the marine environment: recommendations for quantifying synthetic particles in waters and sediments. *NOAA Technical Memorandum.* NOS-OR&R-48.

Nelle Meyers, Ana I. Catarino, Annelies M. Declercq, Aisling Brenan, Lisa Devriese, Michiel Vandegehuchte, Bavo De Witte, Colin Janssen, Gert Everaert (2022). Microplastic detection and identification by Nile red staining: Towards a semi-automated, cost- and time-effective technique. *Science of the Total Environment*. 823 153441

Niyitanga Evode a, Sarmad Ahmad Qamar b, Muhammad Bilal a, Damia Barcelo, Hafiz M.N. Iqbal (2021). Plastic waste and its management strategies for environmental sustainability, Case Studies in Chemical and Environmental Engineering 4 (2021) 100142

Onyekachi NS, Chukwuemeka IS (2022). A Review: State of Plastic Pollution in Nigeria and Measures to Tackle It. *J Anal Toxicol Environ Stud* 2(1): 101

Pandey, M; Joshi, GM; Mukherjee, A; Thomas, P (2016). Electrical properties and thermal degradation of poly (vinyl chloride)/polyvinylidene fluoride/ZnO polymer nanocomposites. Polymer. International. doi:10.1002/pi. 5161.

Pereira, A.; Prado da Silva, MH.; Lima Júnior, EP.; Paula, A.; Tommasini, FJ. (2017). Processing and Characterisation of PET Composites Reinforced with Geopolymer Concrete Waste. *Mat. Res*. 20(2): 411-420 doi.org/10.1590/1980-5373-MR-2017-0734

Salawu, A.O., Musa, O. K., Adama, B. (2021). The Remaining Storage and Rate of Siltation of Mairuwa Dam, Funtua, Katsina State, North-western Nigeria. *Water Resources.* 31:1 -14

Sarkar, S., Diab, H., & Thompson, J. (2023). Microplastic Pollution: Chemical Characterisation and Impact on Wildlife. International Journal of Environmental Research and Public Health, 20(3), 1745.

Sathish, M.; Jeyasanta, I; Patterson, J (2020). Microplastics in Salt of Tuticorin, Southeast Coast of India. Arch. *of Env. Cont. And Toxicol*. https://doi.org/10.1007/s00244-020-00731-0

Sherrington, C. (2022). Fishing gear as a source of microplastics in aquatic ecosystems. *Marine Policy*. 96, 204–211.

Singh, P., Patel, A., & Kumar, R. (2024). Nitrogen-carbon coupling in microbial biomass: Evidence from stable isotope probing. Soil Biology and Biochemistry, 188, 109245.

Standards Organisation of Nigeria (SON) (2007). Nigerian Standard for Drinking Water Quality. SON.

Tongu S. M., Nyijime T. A., Nwankwo, J. O. Odiba (2024). Assessment of Physicochemical Parameters of Hand Dug Well Water in Makurdi, Benue State, Nigeria. *J. Chem. Soc. Nigeria*. Vol. 49, No. 2, pp 153 – 162

Turhan, D.Ö. (2022). Evaluation of Microplastics in the Surface Water, Sediment and Fish of Sürgü Dam Reservoir (Malatya) in Turkey. *Turkish Journal of Fisheries and Aquatic Sciences*. 22(SI), TRJFAS20157.

Uddin, M. G., Nash, S., & Olbert, A. I. (2021). A review of water quality index models and their use for assessing surface water quality. *Ecological Indicators,* 122, 107218. https://doi.org/10.1016/j.ecolind.2020.107218

Wang, L., & Chen, H. (2021). Competitive sorption of organic carbon and silicates in soil aggregates. *Science of the Total Environment*, 756, 143876.

Wang, T., Li, B., Zou, X., Wang, Y., Li, Y., Xu, Y., & Yang, J. (2022). Emission of primary microplastics in mainland China: Invisible but not negligible. *Water Research*. 190, 116784

World Health Organisation. (2018). WHO water quality guidelines: fourth edition, incorporating the first addendum. World Health Organisation.

Zhang, R., Liu, G., & Zhao, Y. (2022). Structural dynamics of clay minerals under varying moisture conditions. *Clays and Clay Minerals*, 70(2), 198–213.