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Original Article

Microplastics in Well Water in Birnin Kebbi, Northwestern Nigeria, Pose Health Risks to Consumers

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Abstract

Background and Objectives: Microplastic pollution is a global concern due to its widespread dissemination and potential toxicity. Although various water bodies have been globally evaluated for microplastic pollution to enable effective remediation and management, documented information on the microplastic pollution of drinking water in Nigeria is scarce. Therefore, this study aimed to determine the abundance and associated risks of microplastics in well water in the Kalgo, Rafin-Atiku, Gwadan-Gwaji, Unguwan-Jeji, Aliero-Quarters, and Tarasa areas in Birnin Kebbi, Nigeria.

Materials and Methods: Microplastics were extracted from the water and then analyzed using spectroscopy and microscopy.

Results: The results revealed a significant difference ($P<0.05$) in microplastic concentration between the sampling locations. Samples obtained from Kalgo (92.63 MPs/L), Rafin-Atiku (91.23 MPs/L), Gwadan-Gwaji (89.77 MPs/L), Unguwan-Jeji (85.60 MPs/L), Aliero-Quarters (85.27 MPs/L), and Tarasa (80.5 MPs/L) had the highest concentrations of microplastics, respectively. Fiber (58%), fragments (22%), foams (12%), and pellets (8%) were predominant microplastic shapes, respectively. Nylon, polypropylene, polyethylene, and polyethylene terephthalate were the dominant polymers in the water. The dominant risk grade among the polymers was II (low risk) or III (moderate risk). Nylon posed a grade IV risk (high risk), indicating that the polymer poses the greatest risk. Gwadan-Gaji samples (5.10), Rafin-Atiku (4.50), Aliero-Quarters (4.10), Unguwan-Jeji (3.20), Kalgo (2.00), and Tarasa (1.80) had the highest contamination factor, respectively. Oral daily intake of microplastics exceeded the threshold of 1.

Conclusion: Overall, microplastics in well water pose health hazards to consumers in the area. Consequently, well water in these areas requires microplastic remediation and control.

Keywords: Fibers, Microplastics, Polymers, Polypropylene, Well water

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1. Introduction

Microplastic pollution has emerged as a global concern due to its prevalent dissemination and potential toxicity (1,2). In addition, microplastics have been identified in various environments, including lagoons (3), rivers (4), coastal areas, and marine settings (5), primarily transported from land sources (6). It is noteworthy that the majority of microplastics enter water bodies as a result of municipal and industrial wastewater discharge (7). Furthermore, microplastics have been detected in human gut, blood, and stool samples (8,9), as well as in vegetables, fruits, and crops (10). Moreover, the environmental spread of microplastics is exacerbated by rapid industrialization, urbanization, and population expansion (11). Due to their persistence and widespread presence and the potential ecotoxicity of their constituent elements, microplastics adversely affect water quality, aquatic biodiversity, and human health (12).

Microplastics are defined as synthetic solid particles or polymeric matrices of primary or secondary manufacturing origin that are insoluble in water. They exhibit a regular or asymmetrical shape within the size range of 0.1 µm to 5 mm (13). Primary microplastics are intentionally manufactured in industries, while secondary microplastics result from the photodegradation of larger plastic materials through mechanical forces, microbial activities, and other environmental factors (2,14). The majority of secondary microplastics are composed of fibers from washing synthetic clothing, abrasion particles from plastic coatings, and tire debris (15). While the

immediate effects of microplastics upon entering the human body remain unclear, some researchers theorize that they may be internalized into cells by macrophages or endothelial cells of blood vessels (15). It should be noted that microplastics can negatively impact digestive tracts, immunotoxicological responses, growth, and gene expression (16,17). Additionally, they may act as carriers for various micropollutants, including antibiotics and metals (2). Likewise, the absorption of microplastics affects the growth and development of plants and animals, as well as the properties of soil and the microbial community (18,19).

Given the threat posed by microplastic pollution, there is a pressing need to assess the spread and risk of microplastics in all routes of human exposure, including water, food, and air. In this regard, several studies have been conducted on drinking water. Notably, Fajaruddin Natsir et al (20), Oni and Sanni (21), Aliyu et al (22), and Alvarado-Zambrano et al (23) have focused on well water (Indonesia), borehole water (Lagos, Nigeria), sachet water (Kaduna, Nigeria), and borehole water (Mexico), respectively. These studies, among others, have consistently identified abundant microplastics in evaluated water sources, raising public concern. In Birnin Kebbi, Nigeria, groundwater (e.g., well water) is the primary source of drinking water due to its affordability, accessibility, and relative safety. However, existing evidence indicates that these water sources have not been assessed for the presence and risks of microplastics. Conducting such an assessment would assist residents and policymakers in the city in developing effective strategies for microplastic pollution management to prevent potential health risks. Filtration is considered one of the most cost-effective and frequently used methods to determine the concentrations of microplastics in water. After filtration, the water is characterized by spectroscopy and microscopy (3). This study, therefore, aims to determine the abundance, characteristics, and risks of microplastics in well water in Birnin Kebbi, Kebbi State, Nigeria, using filtration, spectroscopy, and microscopy.

2. Materials and Methods

2.1. Description of the Study Area

This study was conducted in Birnin Kebbi, Kebbi State, northwestern Nigeria, situated at latitude 12°25'54.33"N and longitude 4°11'44.24"E (Fig. 1). Kebbi shares borders with the Niger Republic to the west, the Benin Republic to the southwest, and the Nigerian states of Sokoto and Zamfara to the north and east, with Niger to the south. As of 2024, the city had an estimated population of 428,676 (24). As regards ethnicity, the most common groups in the state are the Hausa, Fulani, Dakarki, and Kamberi, with Islam being the predominant religion. While the indigenous population engages in farming and animal rearing, settlers are involved in artisanal work and the sale of materials, much of which involves packaging that requires plastic materials.

In addition, the climate of the area follows a typical tropical climate, characterized by distinct wet and dry seasons (25). The dry season usually spans 7 months,

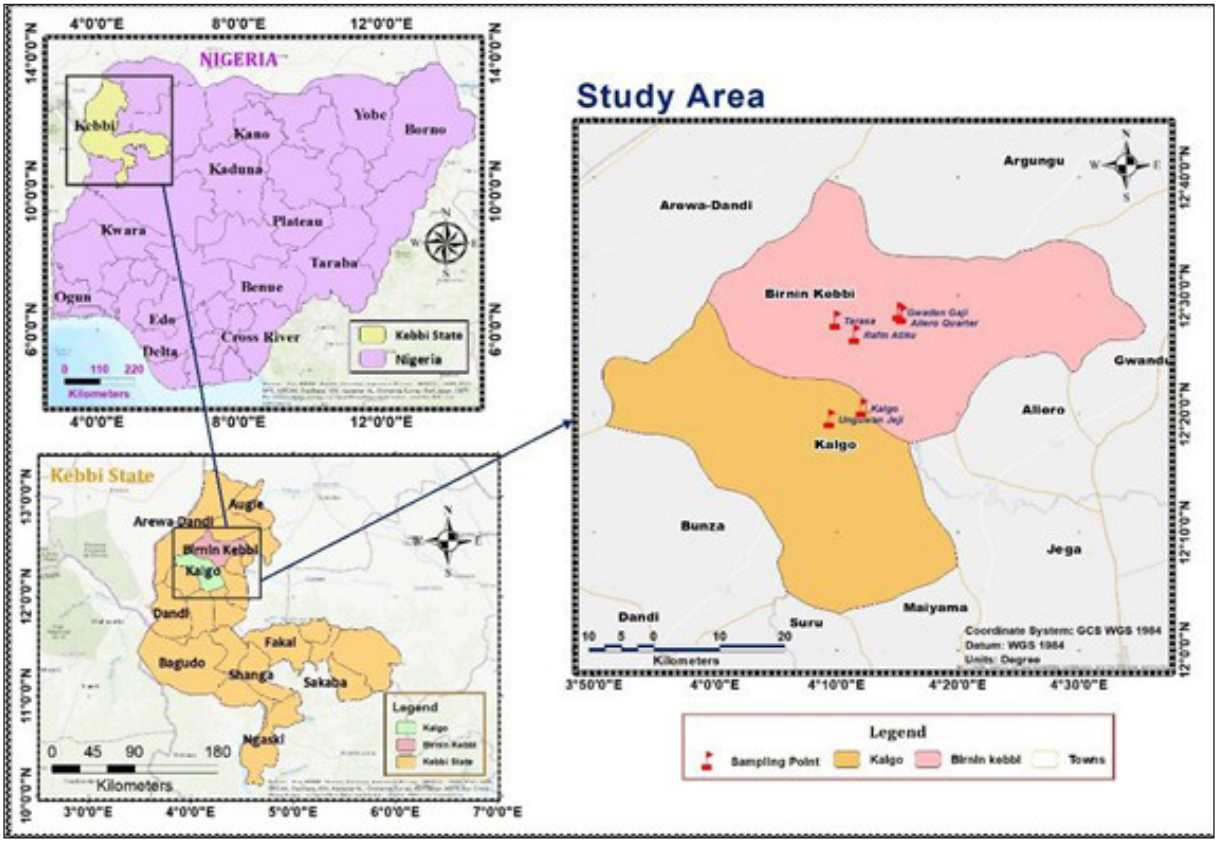

Fig. 1. Map of the Study Area. *Note*. This map was drawn with ArcGIS, version 10.3

primarily from November to May, while the rainy season lasts for 4–5 months, typically from June to October (25). Moreover, the mean annual rainfall in the state varies significantly from the northern part (733 mm) to the southern area (1045 mm). Average daily temperatures can drop below 20 ˚C during the harsh cold weather or rise above 40 ˚C during the hot weather in June. It should be noted that pollution control and management in the city are poor, as evidenced by the indiscriminate dumping of waste, including plastic materials. This habit could adversely impact water quality, thereby necessitating periodic monitoring, which is the primary objective of the present study.

2.2. Water Collection

Five water samples were randomly collected from wells in the Unguwan-Jeji, Rafin-Atiku, Aliero-Quarters, Gwadan-Gwaji, Kalgo, and Tarasa areas of Birnin Kebbi in August 2023, following the procedures of Oni and Sanni (21). Then, a total of 30 samples were collected and transported to the laboratory for analysis. The locations were evenly selected to cover the upper, middle, and lower socioeconomic classes in the city. Next, quality control measures were implemented during sampling, involving the use of clean, non-plastic materials. Specifically, non-plastic jars pre-cleaned with ultrapure water were utilized for sampling. In addition, gloves and overalls were worn to prevent microplastic contamination. Prior to the sampling, the container was rinsed with water from the well where the samples were collected. Afterward, water was pumped out using a drawer from each well for at least 10–15 minutes before sampling.

2.3. Microplastic Extraction from Water Samples

Microplastics were extracted from the water samples as outlined by Yahaya et al (26). The samples were digested by oxidative digestion with 50 mL of hydrogen peroxide to remove organic debris. Then, the digested materials were poured into a separating funnel containing an aqueous potassium formate solution. The particles in the water were separated in the funnel, with the lowest phase having the finest particles. The water from the lowest phase was further filtered using a nanopore inorganic membrane filter with a pore size of 0.2 µm to isolate the microplastics. Next, the filtered materials were covered and stored in an airtight container to prevent contamination. Furthermore, to avoid background contamination of the samples during extraction, blank samples represented by ultrapure water were periodically tested as recommended by Miller et al (27).

2.4. Identification and Characterization of Microplastics

The particles collected on the filter paper were dried, and then microplastics were picked with a hot needle and counted using the AmScope Trinocular Stereo Zoom Microscope SM-1TY-144-18M3 equipped with an 18.0 MP digital camera (26). The particle counts were recorded as particles per 50 mL. Additionally, microplastics were categorized based on shape (fibers, fragments, pellets, and films), color (black, grey, red, transparent, and the like), and size range (0–100, 100–500, and 500–1000 µm), following the protocol outlined by Yahaya et al (26). The photographs of the particles were taken using an 18.0 MP digital camera. Subsequently, the microplastics were identified, confirmed, and characterized using a Nicolette Nexus 470 attenuated total reflection-Fourier transform infrared spectroscopy instrument (Thermo, USA) by Omic software. The spectral range for the study was set at 650–4000 cm^{-1} with a resolution of 4 cm^{-1}. A background air spectrum was regularly checked throughout the process to correct the errors. The obtained spectra were then compared with those from published studies referenced in the results section of this study. Polymer types were identified as polypropylene (PP), polyethylene (PE), polyvinyl chloride, polyamide (nylon: NY), polystyrene (PS), and ethylene-vinyl acetate based on absorbance peaks and functional groups.

2.5. Health Risk Assessment of Microplastics

The microplastic-related health risks associated with the water were evaluated through the assessment of microplastic contamination factors (MPCF), microplastic pollution load index (MPPLI), polymer risk index (PRI), and oral and dermal daily ingestion (26,28). The MPCF measures the levels of microplastic contamination in the tested water samples in comparison to background values. The ideal background values refer to microplastic abundance before the rapid development of the plastic industry (29). Both MPCF and MPPLI were mathematically computed using equations (1) and (2), respectively, while the PRI was determined through Eq. (3). Moreover, oral and dermal estimated daily ingestion (EDI) were obtained using Eqs. (4) and (5).

In Eq. (1), MPi represents the quantity of microplastics in each sample i. In addition, MPb is the minimum baseline concentration obtained from well water samples analyzed in this study and denotes background values. This is often used when there is no literature on the ideal background values, as in the case of the current study, which is the first of its kind in the study area (29). MPCF was categorized as no contamination (with a value of ≤ 0), low contamination (< 1), moderate contamination (1–3), considerable contamination (> 3–6), and extremely high contamination (> 6) (29).

PMP in Eq. (3) signifies the percentage of each microplastic polymer in the water samples, while PS denotes the hazard score of each polymer, which is constant. The hazard scores are as follows:

PP = 1, PE = 11, polyethylene terephthalate (PET) = 22, PS = 30, and NY = 47 (23)

These hazard scores were obtained from the literature and then ranked based on monomer classification, annual global waste generation, particle size, degradation time, and the mean density of each polymer (30). The risk level

(PRI) was categorized based on several scoring ranges: less than 10 was designated as risk level I (very low risk), 10–100 as risk level II (low risk), 100–1000 as risk level III (moderate risk), and greater than 1000 as risk level IV (high risk) (26).

In Eqs. (4) and (5), CMP, RI, and BW denote the number of microplastics detected in a sample, the ingestion rate (2.2 L/day), and the average body weight (65 kg), respectively (31, 32). In addition, FE, ED, and AT represent exposure frequency (365 days/year), exposure duration (55 years), and average time (365 days/year × 55 years), respectively. Moreover, SA (18000 cm^2), dp (cm/hour), and ABS (unitless) indicate the skin area available for contact, the pore diffusion coefficient (1.0), and the dermal absorption factor (0.001), respectively. Additionally, ET (0.58 h/event) is the exposure time, and CF (0.001 L/cm^3) implies the unit conversion factor (33). EDIs via oral or dermal contact less than 1 demonstrate a low daily intake of microplastics and therefore may pose no risks.

$$MPCF = MPi/MPb \quad (1)$$

$$MPPLi = (MPCF1 \times MPCF2 \times MPCF3 \ldots\ldots\ldots\ldots MPCFn)\ ^{1}/n \quad (2)$$

$$PRI = \sum PMP \times PS \quad (3)$$

$$EDI\ ingestion = CMP \times RI/BW \quad (4)$$

$$EDI\ \ dermal = CMP \times SA \times Dp \times ABS \times ET \times FE \times ED \times CF/BW \times AT \quad (5)$$

3. Results and Discussion

3.1. Concentrations of Microplastics in the Water

Table 1 presents the concentrations of microplastics in well water samples obtained in Birnin Kebbi. The results showed a significant difference ($P < 0.05$) in microplastic concentrations between the sampling locations. It was revealed that Kalgo had the highest concentrations of microplastics (92.64 p/L), followed by Rafin-Atiku (91.30 MPs/L), Gwadan-Gwaji (89.78 MPs/L), Unguwan-Jeji (85.60 MPs/L), Aliero Quarter (85.28 MPs/L), and Tarasa (80.52 MPs/L), respectively.

This result aligns with the findings of Oni and Sanni (21), displaying abundant microplastics in borehole water in Lagos, Nigeria. Similarly, Aliyu et al (22) identified substantial microplastics in drinking water in Kaduna, Nigeria. Additionally, Severini et al (34) and Alvarado-Zambrano et al (23) found abundant microplastics in groundwater in northern Italy and northwest Mexico, respectively. Considering that Birnin Kebbi is not an industrialized town, the possible primary sources of microplastics in groundwater are indiscriminate dumping of used plastic materials coupled with poor sanitation, which are common occurrences throughout the town. Compared to previous studies conducted in the country, the concentrations of microplastics in well water in Birnin Kebbi are lower. For instance, Oni and Sanni (21) reported 206 to 1691 MPs/L in borehole water in Lagos, while Aliyu et al (22) found an average of 153 MPs/L in Kaduna. According to Oni and Sanni (21) and Jessieleena et al (35), areas with high population density and intense industrial activities tend to have more microplastics compared to places with low population densities and reduced industrial activities. Birnin Kebbi has lower population densities and fewer industries, contributing to its lower microplastic abundance. However, compared to studies performed outside the country, microplastics are more abundant in well water in Kebbi. For example, Alvarado-Zambrano et al (23) reported a microplastic abundance of 10 MPs/L to 34 MPs/L in borehole water in Northwest Mexico, while Severini et al (34) noted an average of 26.88 MPs/L. Although these countries are more populated and industrialized than Kebbi, compliance with environmental protection and sanitation

Table 1. Concentrations of Microplastics in Well Water in Birnin Kebbi

Location	Sample	Concentration of Microplastics (MPs/L)	Mean Concentration of Microplastics (MPs/L)	Standard deviation of Concentration of Microplastics (MPs/L)
Unguwan-Jeji	A	94.50	85.60 ^{abc}	9.86
	B	87.30		
	C	75.00		
	D	78.40		
	E	92.80		
Rafin-Atiku	A	90.10	91.30^{bc}	2.60
	B	94.30		
	C	89.40		
	D	92.50		
	E	90.20		
Kalgo	A	95.60	92.64^{c}	2.90
	B	92.50		
	C	89.80		
	D	96.80		
	E	88.45		
Aliero-Quarters	A	88.60	85.28 ^{ab}	6.84
	B	89.80		
	C	77.40		
	D	80.30		
	E	90.30		
Gwadan-Gaji	A	94.20	89.78^{bc}	3.87
	B	88.00		
	C	87.10		
	D	90.20		
	E	89.40		
Tarasa	A	86.20	80.52^{a}	5.10
	B	79.10		
	C	76.30		
	D	83.00		
	E	78.00		

Note: Values with different superscripts across the column show a significant difference ($P < 0.05$) and vice versa.

is more rigorous, potentially leading to lower microplastic abundance.

3.2. Shapes of Microplastics in the Water

Table 2 presents the percentage distribution of microplastic shapes in the water samples. Fibers had the highest percentage (58%), followed by fragments (22%), foams (12%), and pellets (8%), indicating that fibers, fragments, foams, and pellets were the predominant shapes in the well water samples, respectively. Photomicrographs showing these microplastics are displayed in Fig. 2.

Our results are in line with those of Wu et al (36), confirming the dominance of fibers and fragments in groundwater in North China. Alvarado-Zambrano et al (23) also reported the preponderance of fibers, fragments, and foams, respectively, in groundwater in northwest Mexico. However, Fred-Ahmadu et al (37) and Oni and Sanni (21) reported the dominance of fragments in water in Lagos, Nigeria. Similarly, Ibeto et al (38) found fragments in bottled water sold in southeastern Nigeria. The dominance of fibers and fragments in the water suggests that most microplastics in the water are of the secondary type. Some sources of microplastic fibers in the environment are from clothing, particularly laundry activities, and wastewater from washing machines (39,40). Regarding fragments, their primary source in the environment is the mechanical and photodegradation of larger plastics (41,42). Microplastic foams are commonly used for food packaging, consumer product protective packaging, and building insulation materials, demonstrating their sources in the water under study (43). Pellets in the water can emanate from sewage sludge and plastic pellets employed in the manufacture of plastic products (44). Thus, based on the foregoing, most of the microplastics in the well water samples were released from textile garments during home laundering through sewage effluents and/or sludge. Moreover, a substantial amount was released from the photodegradation of larger plastic materials (e.g., plastic buckets, jerry cans, polybags, and the like). Similarly, food packaging and building materials contributed some amounts.

3.3. Sizes of Microplastics in the Water

Fig. 3 illustrates the percentage distribution of microplastic sizes in the water samples. With 65%, the 0–100 µm microplastic size dominated in Anguwar-Jeji, followed by 100–500 µm with 29% and 500–1000 µm with 5%. In Rafin-Atiku, 1000–5000 µm dominated, constituting 50%, followed by 500–1000 µm with 22%, and 100–500 µm with 10%. 0–100 µm microplastic size was the dominant size in Kalgo with 59%, followed by 100–500 µm with 30% and 0–100 µm with 20%. In Aliero-Quarters, 1000–5000 µm dominated with 75%, followed by 500–1000 µm with 15% and 100–500 µm with 10%. With 65%, 1000–5000 µm dominated in Gwadan-Gaji, followed by 500–1000 µm with 15% and 0–100 µm with 17%. In Taraza, the 0–100 µm microplastic size dominated with 55%, followed by 100–500 µm with 32% and 500–1000 µm with 15%.

The dominance of 0–100 µm microplastic size in UgwanJeji, Kalgo, and Taraza against that of 500–1000 µm microplastic size in Rafin-Atiku, Gwadan-Gaji, and Aliero-Quarters suggests that samples from the former group may elicit more toxic effects. Small-sized microplastics easily cross the cell membrane and accumulate in cells compared with larger ones (45). Additionally, small sizes are associated with increased surface energies and interactions (45).

3.4. Colours of Microplastics in the Water

The colour distribution among microplastics in the water sample is depicted in Fig. 4. Transparent microplastics were dominant in Anguwar-Jeji (52%), followed by black

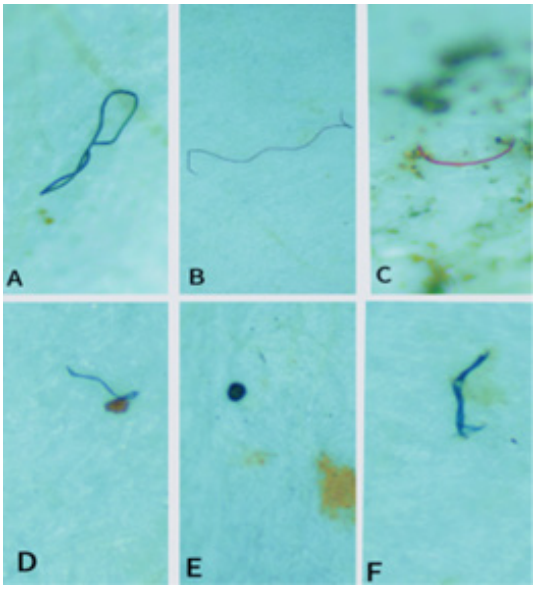

Fig. 2. Microplastic Shapes Identified in the Water Samples: **(A, B, and C)** Fibers, **(D)** fragments, **(E)** Pellet, and **(F)** Foam. *Note*: Fibers also show in plates D and F

Table 2. Proportion of Each Microplastic Shape in the Water

Microplastic Type	Proportion (%)						
	Unguwan-Jeji	Rafin-Atiku	Kalgo	Aliero-Quarters	Gwadan-Gwaji	Tarasa	Total
Fibers	15	5	4	10	11	13	58
Fragments	5	-	5	1	4	7	22
Foams	4	2	3	-	-	3	12
Pellets	3	2	1	-	2	-	8
							100

(52%) and red (5%). In Rafin-Atiku, black was dominant (50%), followed by transparent (20%) and grey (20%). In Kalgo, transparent was dominant with 49%, followed by black with 20% and grey with 15%. In Aliero-Quarters, transparent was dominant (55%), followed by black (30%) and grey (10%). With 45%, transparent dominated in Gwadan-Gaji, followed by black with 35% and grey with 18%. Black (50%), transparent (30%), and grey (20%) dominated in Taraza.

The varieties of colours detected in the water samples represent diverse sources of microplastics in the water. Transparent and grey could emanate from transparent plastic materials such as water sachets, transparent NY bags, and water bottles, among others. Likewise, black microplastics could originate from black PE bags and tire waste.

3.5. Microplastic Polymer Types in the Water Samples

Table 3 provides the absorbance peaks and functional groups of polymers identified in the water samples. The samples from Unguwan-Jeji exhibited a significant peak at 3697.31 cm^{-1}, attributed to CH_3 stretching, indicating the presence of PP. A peak at 2456.3 cm^{-1}, associated with C-H, confirms PE. Furthermore, a vibration peak at 1203.93 cm^{-1}, similar to CH stretching, demonstrates the presence of PS. An intense peak at 1636.30 cm^{-1},

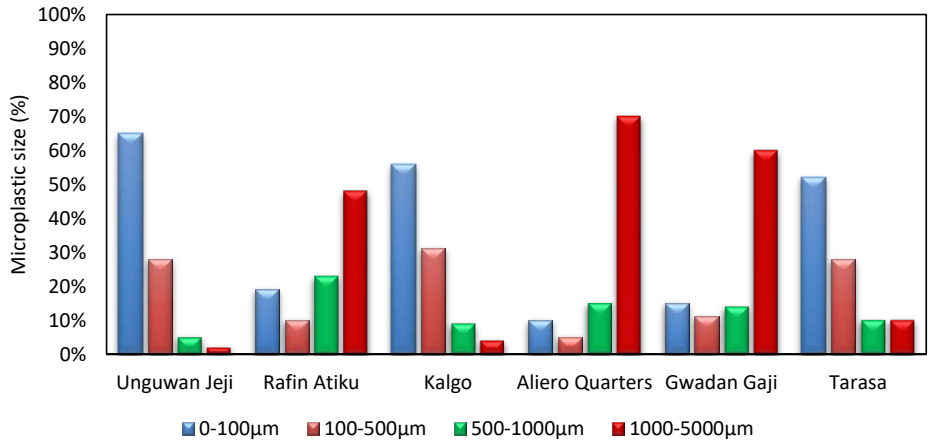

Fig. 3. Microplastic Sizes in Well Water Samples

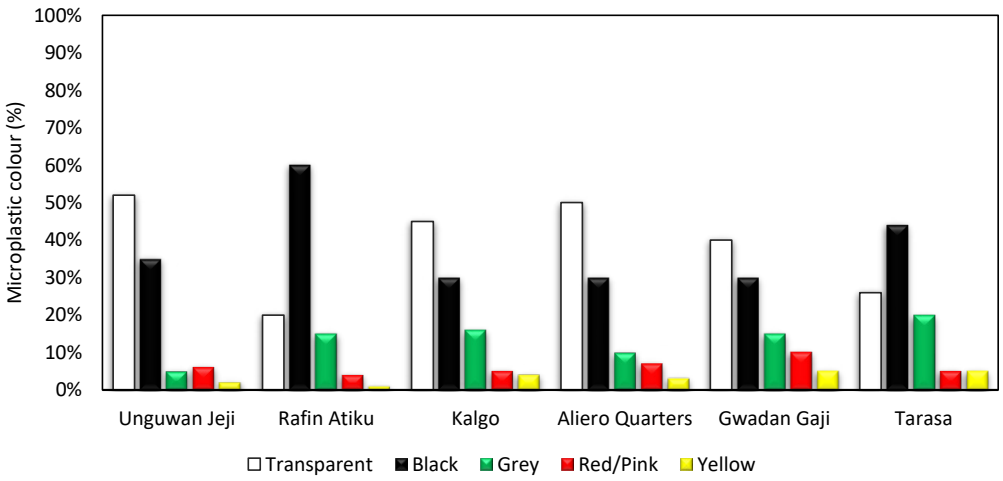

Fig. 4. Percentage of Microplastic Colour in Well Water Samples

Table 3. Absorbance Peak and Functional Groups of Polymers Identified in the Water Samples

Sample	Absorbance Peak	Functional Group	Polymer Type	Reference
Unguwan-Jeji	3697.31, 2456.31, 1203.93, 1636.30, and 1028.74	CH_3 stretch CH_2 C-C	PP, PE, PS, PET, and NY	(46)
Rafin-Atiku	3679.51, 2896.14, 1028.74, 2020.21, and 1051.10	CH_3, C-H stretch, and CH_3 bend	PE, PS, PET, and NY	(47)
Kalgo	2892.41, 2102.21, 1364.20, 1028.74, and 1051.10	CH_2, CH, and C_6H_6	PS, PET, and NY	(47)
Aliero-Quarters	2892.41, 2102.21, 1364.20, 1028.74, and 1941.94	CH_3, CH_2, C=OC, and the tetraphthalate group	PET and NY	(47)
Gwadan-Gaji	2292.31, 3332.24, 3321.05, 2892.41, and 2165.58	HNC_6, $H1_2$, C_4H_8, and COOH	NY, PET, PS, PE, and PP	(47)
Tarasa	3332.24, 2292.31, 2829.41, 2165.58, and 3321.05	O-H stretch COO=C=C bend alcohol	PP, PE, PS, PET, and NY	(47)

Note: PP: Polypropylene; PE: Polyethylene; PS: Polystyrene; PET: Polyethylene terephthalate; NY: Nylon.

representative of the C-C group, shows PET, and an absorption at 1028.74 cm^{-1}characterizes C-H symmetrical stretching, suggesting the presence of NY. In samples from Rafin-Atiku, an absorption peak at around 3679.51 cm^{-1}, typical of CH_3, denotes PP. Another peak at 2896.14 cm^{-1}, characteristic of bending CH_2, is related to PS. Additionally, an absorption peak at 2020.21 cm^{-1}, representing the CH_3 group, reveals the presence of PET. Another peak at 1051.10 cm^{-1}, attributed to CH bending vibration, confirms the presence of NY. Samples from Kalgo displayed an absorption peak of 2892.41 cm^{-1}, assigned to the CH_2 stretching group, indicating PS. A peak at 2102.21 cm^{-1}, attributable to CH asymmetrical stretching, suggests the presence of PET. In addition, peaks at 1364.20 cm^{-1} and 1028.74 cm^{-1} represent C_6H_6, implying the possible presence of NY. The samples from Aliero-Quarters contained vibration peaks at 2992.41 cm^{-1} and 2102.21 cm^{-1}, characteristic of CH_3 and C=O, confirming PET. Further, a peak at 1914.94 cm^{-1}, assigned to the CH_3 stretching group, demonstrates the presence of NY. Samples from Gwadan-Gaji showed a prominent peak at 3332.24 cm^{-1}, attributable to C-H stretching, indicating NY. A peak at 3321.05 cm^{-1} represents CH_2 bending vibration, representing EPT. Furthermore, a peak at 2892.41 cm^{-1}, related to C_4H_8, suggests PS. There was also a peak at 2165.58 cm^{-1}, similar to HNC_6 symmetrical bending, revealing PP. Likewise, samples obtained from Tarasa exhibited characteristic peaks around 3332.24 cm^{-1}, assigned to the OH stretching vibration group, suggesting PP. Moreover, a peak at 2229.41 cm^{-1}, attributable to C-C stretching, indicates PS. The peak at 2829.41 cm^{-1}, associated with the C=O carboxylic group, demonstrates PET. Ultimately, the peak around 3321.05 cm^{-1} is attributed to C-H, implying the presence of NY. Fig. 5 depicts the spectra of the functional groups of polymers identified in the water samples.

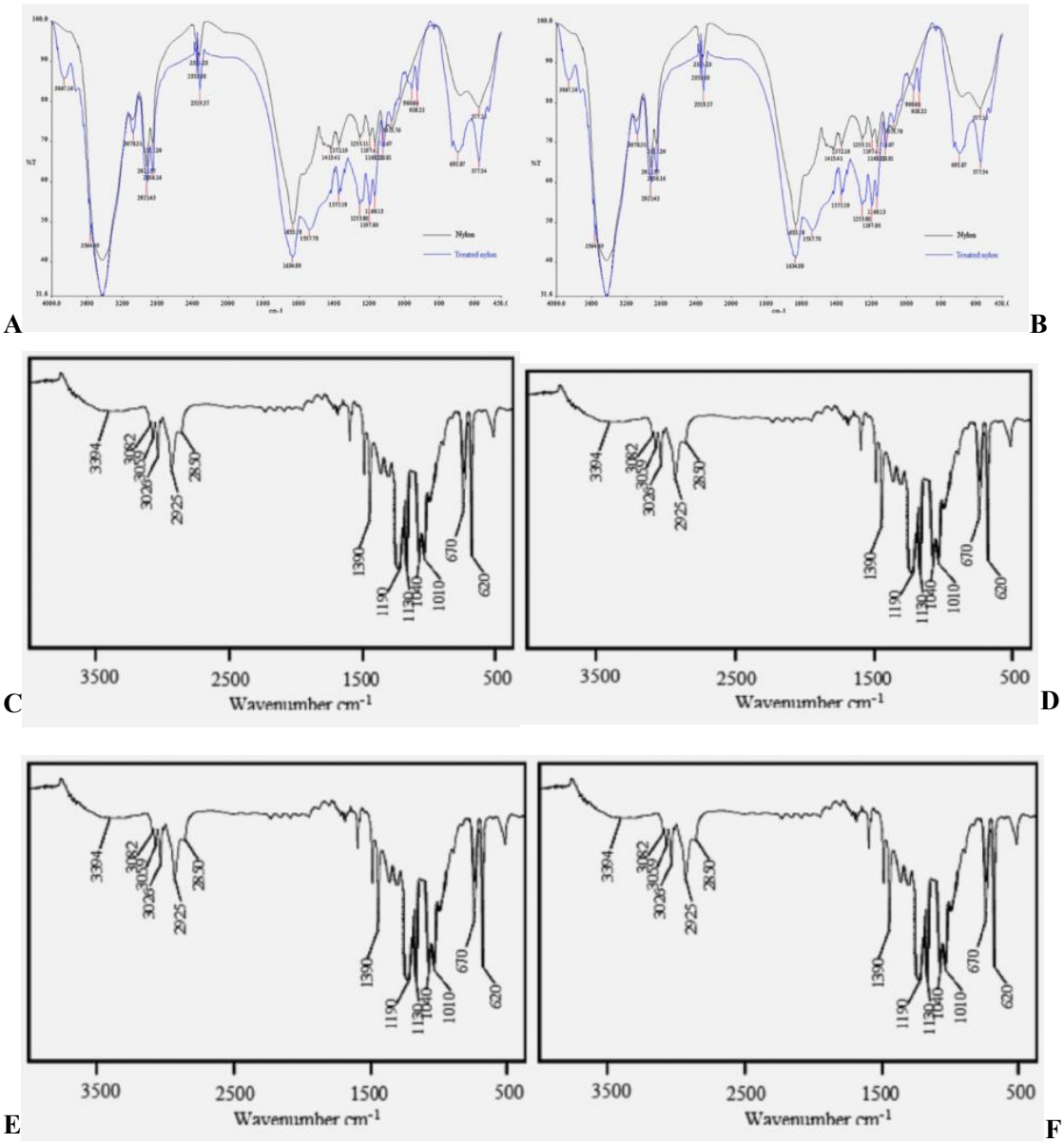

Fig. 5. Spectra of the Polymers in the Water Samples as Obtained by FTIR: **(A)** Unguwan-Jeji, **(B)** Rafin-Atiku, **(C)** Kalgo, **(D)** Aliero-Quarters, **(E)** Gwadan-Gaji, and **(F)** Tarasa. *Note*: FTIR: Fourier transform infrared spectroscopy

3.6. Distribution of Polymer Types in the Water

Fig. 6 shows the percentage distributions of polymer types in the water samples. NY (polyamide) was the dominant polymer (60.00%, 55.00%, 48.00%, 35.00%, 20.00%, and 10.00% in Kalgo, Tarasa, Unguwan-Jeji, Rafin-Atiku, Aliero-Quarters, and Gwadan-Gwaji, respectively), followed by PP (51.00%, 45.00%, 41.00%, 32.00%, 20.00%, and 18.00% in Gwadan-Gwaji, Rafin-Atiku, Aliero-Quarters, Unguwan-Jeji, Kalgo, and Tarasa). PE (17.00%, 15.00%, 14.00%, 10.00%, 8.00%, and 5.00% in Rafin-Atiku, Tarasa, Unguwan-Jeji, Kalgo, Aliero-Quarters, and Gwadan-Gwaji) and PS (9.00%, 8.00%, 6.00%, 5.00%, 5.00%, and 2.00% in Tarasa, Aliero-Quarters, Kalgo, Gwadan-Gwaji, Unguwan-Jeji, and Rafin-Atiku) were the other dominant polymers. In addition, PET (4.00%, 4.00%, 3.00%, 1.00%, 1.00%, and 1.00% in Kalgo, Aliero-Quarters, Tarasa, Unguwan-Jeji, Rafin-Atiku, and Gwadan-Gwaji) was the last dominant polymer.

Our findings conform to those of Selvam et al (48) and Shi et al (49), reporting polyamide as the most dominant polymer in groundwater in South India and northern China, respectively. However, the results contradict the findings of a systematic review by Lee et al (50), indicating PP and PE as dominant polymers in groundwater. Likewise, our data do not match those of studies conducted in Nigeria, notably those of Oni and Sanni (21) and Aliyu et al (22), reporting PP and PE as the most abundant polymers in groundwater, respectively. According to available literature, the current research is the first to report the dominance of polyamide in groundwater in Nigeria. The dominance of polyamide in the water further suggests that the groundwater receives the majority of microplastics from textile laundering, as well as waste from food packaging and electronics. According to Palmer (51), polyamides are commonly used in textiles, electrical/electronics, the automotive industry, carpets, kitchen utensils, and sportswear due to their high durability and strength. Similarly, the abundance of PP and PE indicates that the well water receives the majority of microplastics from textile laundering, photodegradation of larger plastic materials, food packaging, and automobile fuel tanks. PP is frequently utilized in textiles, biomedical, packaging, apparel, and automotive (52,53). The presence of PS and PET indicates that the well water also received some microplastics from medical, automobile, and electrical/electronic waste, as well as disposable cutlery, coffee cups, pens, pencils, trays, cases for compact disks, and digital video disks, among others (54,55). Thus, laundering activities, indiscriminate dumping of plastic materials (e.g., NY bags and plastic buckets), and food packaging are the primary sources of microplastics in the well water.

3.7. Health Risks of the Water

Table 4 provides MPCF, risk index category, and estimated daily intake (EDI) of microplastics in the water samples. Gwadan-Gaji had the highest contaminated factor (5.10), followed by Rafin-Atiku (4.50), Aliero-Quarters (4.10), UnnguwaJeji (3.20), Kalgo (2.00), and Tarasa (1.80), respectively. With 3.136, Kalgo samples had the highest oral EDI, followed by Rafin-Atiku with 3.102 and Gwadan-Gaji with 3.039. In addition, samples from Kalgo and Rafin-Atiku jointly had the highest dermal EDI, followed by Unguwan-Jeji, Aliero-Quarters, and Gwadan-Gaji with 0.014 each. The microplastic contamination factor in all the water samples was above the recommended values, suggesting that regular consumption of water can pose health challenges. Additionally, the oral EDI of all the

Table 4. Microplastics Risks in the Water Samples

Sample	MPCF	Risk Category	EDI Oral	EDI Dermal
Unguwan-Jeji	3.20	Contaminated	2.897	0.014
Rafin-Atiku	4.50	Contaminated	3.102	0.015
Kalgo	2.00	Contaminated	3.136	0.015
Aleiro Quarters	4.10	Contaminated	2.886	0.014
Gwadan-Gaji	5.10	Contaminated	3.039	0.014
Tarasa	1.80	Moderately contaminated	2.723	0.013
	MPPLI = 3.06		RDI < 1	< 1

Note: MPCF: Microplastic contamination factor; EDI: Estimated daily ingestion; MPPLI: Microplastic pollution load index; RDI: Red dichromatic imaging or relative depth index.

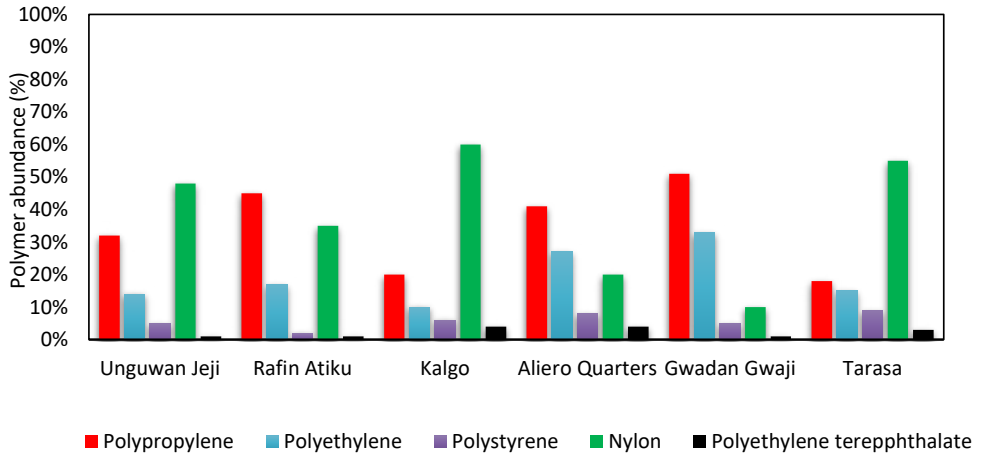

Fig. 6. Concentrations of Each Polymer Type in the Water

water samples exceeded the threshold, proving that the daily intake of water can cause health problems. Table 5 presents the risk index of polymers in the water samples. PET and PP, at all locations, recorded risk level II, PE and PS displayed risk level III, and NY recorded risk level IV, further proving that consuming the water regularly may pose low-to-high risks, with NY posing the highest risk.

Although the health risks of microplastics are not well understood, researchers opine that human exposure to microplastics can cause oxidative stress and DNA damage, as well as inflammation and its associated health risks, including endocrine disruption, carcinogenicity, and developmental toxicity, among others (56,57). Moreover, microplastics can carry pathogens and toxic elements or compounds, such as metals (28,56). Although the current study did not evaluate the heavy metal content of the well water, a recent study of well water quality in Birnin Kebbi by Yahaya et al (58) reported World Health Organization non-permissible concentrations of lead, iron, cadmium, chromium, and pH in the water. The same researchers detected abnormal levels of microorganisms, including *Bacillus* species (bacteria), *Escherichia coli* (bacteria), *Staphylococcus aureus* (bacteria), *Aspergillus niger* (fungi), *Mucor racem*osa (fungi), and *Paecilomyces variotti* (fungi), in the water. This further indicated that the well water in Birnin Kebbi might not be safe for consumption, suggesting a potential correlation between microplastic contamination and water quality parameters in the study area. Nonetheless, further research is needed to confirm this issue. This result is consistent with that of Shi et al (49), highlighting the potential risks of microplastics in groundwater in northern China. Our results also corroborate the findings of Aliyu et al (22), representing a medium-to-high risk of microplastics in drinking water, including groundwater.

4. Limitations of the Study

Although this study suggested the possible sources of microplastics in the water based on microplastic shapes, colours, and polymers, it had one limitation; the particular responsible industries, facilities, or activities were not investigated, which was primarily due to financial constraints and the complex scope the study would have assumed.

5. Conclusion

Well water from the Rafin-Atiku, Gwadan-Gwaji, Unguwan-Jeji, Aliero-Quarters, and Tarasa areas in Birnin Kebbi, Nigeria, was found to contain microplastics, with wells in Kalgo exhibiting the highest concentrations. Fibers, fragments, foams, and pellets were the predominant microplastic shapes in the water, respectively. The most prevalent polymer type in the water was polyamide (NY), followed by PP, PE, PS, and PET. Regarding risk analysis, samples from the Gwadan-Gaji area posed the highest risk, having the highest contamination factor, while Tarasa presented the least risk. Additionally, NY, recording risk level IV (high risk), posed the greatest risk among microplastic polymers in the water. The oral EDI of microplastics from all the water exceeded the recommended threshold. Based on the findings, there is a pressing need for microplastic pollution control in the city. Indiscriminate dumping of plastic materials in the metropolis should be discouraged, and efforts to recover and recycle plastic should be promoted to prevent plastic materials from entering the environment. Moreover, wastewater, particularly from fabric laundry, home sludge, and farming practices, should undergo treatment before being discharged. Although the probable sources of microplastics in the water were outlined based on the dominant shapes and polymers of the microplastics extracted, specific sources were not investigated in this study. Thus, it is recommended that future studies focus on the mentioned objective.

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Table 5. Polymer Risk Index of Polymers in the Water

Location	Polyethylene Terephthalate	Polypropylene	Polyethylene	Polystyrene	Nylon
Unguwan-Jeji	10.0	32.0	154.0	235.0	7200.0
Rafin-Atiku	10.0	45.0	187.0	187.0	5250.0
Kalgo	40.0	20.0	110.0	282.0	9000.0
Aleiro Quarters	40.0	41.0	297.0	376.0	3000.0
Gwadan-Gaji	10.0	51.0	363.0	235.0	1500.0
Tarasa	30.0	18.0	165.0	423.0	8250.0
Risk level	II	II	III	III	IV

Note: I = very low risk, II = low risk, III = moderate, IV = high, and V = very high. *Source*. (26).

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Competing Interests
The authors declare they have no competing interests.

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

Data Availability Statement
All data generated or analyzed during this study are included in this published article.

Declaration of Generative Artificial Intelligence and Artificial Intelligence-Assisted Technologies in the Writing Process
During the preparation of this work, the researchers used ChatGPT in order to correct grammatical errors and make sentences flow. After using this tool, they reviewed and edited the content as necessary. The researchers take full responsibility for the content of the publication.

Ethical Approval
xxx

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