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# Human Health Risk Assessment from the Ingestion of Clarias gariepinus (Burchell, 1822) and Oreochromis niloticus (Linnaeus, 1758) Contaminated with Micro- (Nano) Plastics (MNPs) from River Ngadda, Borno State – Nigeria

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**ABSTRACT**

***Introduction*:** Freshwater fish inhabiting polluted rivers are capable of bio-accumulating microplastics (plastic fragments measuring less than 5 mm, and nanoplastics (particles with dimensions below 1 µm) in their gastrointestinal tracts and occasionally in edible tissues, depending on species, size, and feeding ecology. Consumption of MNP-contaminated fish therefore represents a potential pathway of human exposure. Although dietary intake estimates vary by region and consumption patterns, aquatic bio-resources are recognized exposure routes alongside inhalation and other food sources. This study assessed the human health risks associated with consuming *Clarias gariepinus* and *Oreochromis niloticus* contaminated with micro- and nanoplastics (MNPs) from the Ngadda River, Borno State, Nigeria.

***Materials and Methods***: *C. gariepinus* and *O. niloticus* were collected monthly from 6 stations over eight months. Samples were processed and analyzed for MNPs using Fourier Transform Infrared (FTIR) Spectroscopy and Gas Chromatography–Mass Spectrometry (GC–MS) at Yobe State University, Damaturu.

**Results**: Mean MNP abundance in *C. gariepinus* ranged from 0.24–0.39 pp/kg (Stations B–C), while *O. niloticus* ranged from 0.47–0.79 pp/kg. Estimated ingestion for children was 70.38–117.97 pp/week and 844.50–1415.65 pp/year. Adult exposure ranged from 211.13–353.91 pp/week and 2533.51–42426.95 pp/year.

***Conclusion***: *O. niloticus* exhibited higher bioaccumulation than *C. gariepinus*. Spatial variability reflected localized pollution sources. Dietary exposure levels for both children and adults were notable, highlighting the need for further studies on MNP retention and elimination in humans.

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## Introduction

Plastics from diverse sources pollute ecosystems, such as industrial plastic waste, domestic plastic waste, plastic waste from recreational areas, and plastic waste from the fishing industry. Plastic pollutants in aquatic ecosystems are classified as macroplastics, microplastics, and nanoplastics. This classification is based on the size of plastic pollutants. Macroplastics are large items of plastic origin that are > 25 millimetre (mm) in size, and mesoplastics range between 5 and 25 mm in size. Microplastics, on the other hand, are plastic particles with sizes with particle lengths spanning approximately 0.1 -



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5,000 µm along their maximum dimension, while nanoplastics generally occur within a size range of about 1 - 100 nanometers (nm) [1]. Among these plastic pollutants, micro and nanoplastics (MNPs) are the commonest found in aquatic organisms [1-6].

Micro- and nanoplastics (MNPs) have been detected in multiple anatomical compartments of fish, including the gills, digestive tract, and fin tissues. Notably, smaller freshwater species are frequently consumed whole, which may increase the likelihood of direct human exposure to these particles through dietary intake [7-8]. MNPs might be ingested by fish from their polluted environment, and in turn, the fish might also be consumed by humans, which might increase the potential for bioaccumulation and trophic transfer [9-12]. The ecotoxicity of MNPs in the ecosystem calls for the continuous monitoring of aquatic ecosystems to assess the levels of contamination.

Additionally, MNPs might interact with other persistent environmental pollutants in the ecosystem, particularly heavy metals, either by absorbing, sorbing, or attaching to these metals on their surfaces, which might increase their bioavailability and their subsequent chances of intake by biota [13-14]. Plastics, which are usually fragmented into MNPs in the environment as a result of several factors such as aging, fluctuating temperature, wind and water currents, and chemical reactions, are manufactured with chemical additives. MNPs may leach these harmful additives and carry toxic pollutants, posing risks such as endocrine disruption and inflammatory responses in human biological systems [2, 11, 15-17].

The ingestion of fish contaminated with MNPs raises several plausible human health concerns. Most ingested MNPs in fish are retained in the gastrointestinal (GI) tract, and fillets typically carry far fewer particles than viscera. Therefore, evisceration before cooking reduces exposure, whereas small species eaten whole (or dishes that include entrails) can increase the risk of human exposure. Risk also depends on local contamination sources (wastewater effluent, urban runoff) and fish feeding ecology; benthic and detritivorous species tend to ingest more particles. While current risk assessments suggest that MNPs in seafood make only a small contribution to total dietary exposure, the adverse effects of plastic additives and co-contaminants cannot be neglected [18, 19].

Laboratory studies have revealed that nanoplastics (NPs) can cross the intestinal barrier, disturb tight-junction proteins, increase permeability (“leaky gut”), and alter microbiota–host signaling, leading to inflammation and dysbiosis [20]. These mechanisms are consistent with broader reviews linking MNP exposure to oxidative stress, immune activation, and metabolic disturbances in mammalian systems [21, 22]. Importantly for human plausibility, microplastics (MPs) have been detected in human blood, indicating systemic bioavailability, and have been associated with changes in coagulation and inflammatory markers [23, 24]. Additionally, MNPs have also been found in human placentas, demonstrating translocation across biological barriers, although the health consequences remain uncertain [25, 26].

Similarly, MNPs are reported to exert a chemical – vector effect on biota as they contain additives (e.g., phthalates, bisphenols, brominated flame retardants, etc.) and can also sorb with different environmental contaminants (e.g., PAHs, PCBs, metals). When contaminated fish are ingested, these chemicals can contribute to internal exposure. The European Food Safety Authority’s (EFSA) earlier appraisal concluded that, for most consumers, MPs in seafood likely add only a small fraction to the existing dietary intake of such chemicals, but emphasized limited occurrence and bioavailability data, and highlighted NPs as a key uncertainty [18-19, 27]. The study is aimed at assessing the human health risk from the ingestion of *C. gariepinus* and *O. niloticus* contaminated with micro and nanoplastics (MNPs) from river Ngadda, Borno State, Nigeria

## Material and Methods

### *The Study Location*

The health risk assessment was carried out in Borno State, Nigeria, geographically situated



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between latitudes 10°N and 14°N and longitudes 11°31′E and 14°41′E. The climatic conditions of the state are characterized by long dry – hot and short wet seasons, with an average annual mean temperature of 31°C. The hottest period is March – April, with a maximum temperature of 37 – 40°C, while the coldest period is between December and January. The State has an average annual rainfall of approximately 500 –700 mm per annum [28-29]. Borno has a number of rivers, such as Koi-koi, Hawul, and Ngadda. The study was conducted on the Ngadda River.

River Ngadda is a freshwater system formed by the confluence of the Yedzaram and Gombole Rivers within the Sambisa Forest region. Following their junction, the unified channel continues downstream as River Ngadda, traversing multiple rural and urban settlements before discharging into Alau Dam. The river subsequently delineates a pronounced arcuate course around Maiduguri metropolitan area, shaping the hydrological landscape of the Maiduguri, Borno State Nigeria [28-33]. Additionally, there is another highly seasonal river in the town known as River Nggadabul which met at a confluence with River Ngadda behind Gidan Madara, Gwange and continuous to flow as River Ngadda. River Ngadda is one of the minor tributaries of the Lake Chad and is widely known for its commercial fishing activities with *C. gariepinus* and *O. niloticus* as the abundant fish species [32, 33]. A map of the Ngadda River in Borno State, Nigeria, is shown in **Figure 1**. A map of the study area is shown in **Figure 2 – 4**.


**Figure 1:** Map of Borno State, Nigeria Highlighting River Ngadda.





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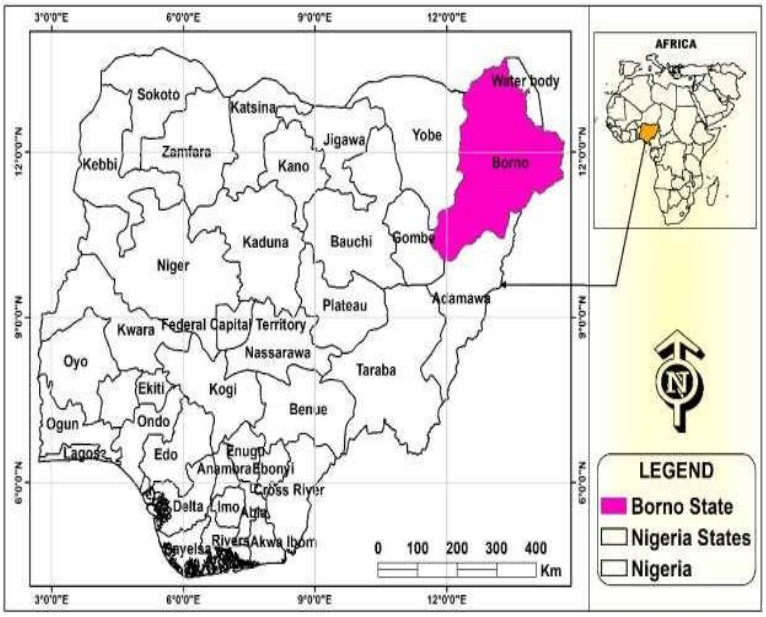


**Figure 2:** Map of Nigeria Highlighting Borno State
**Source**: BORMLS [29].

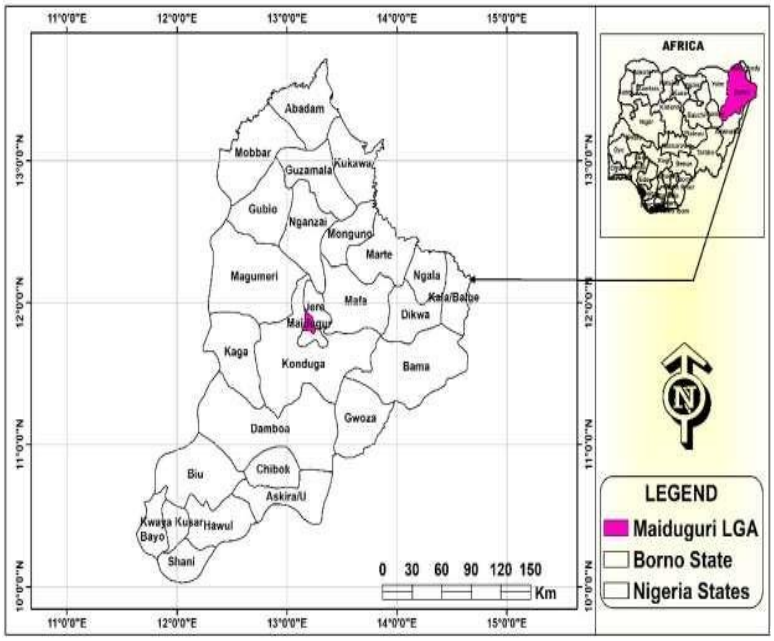


**Figure 3:** Map of Borno Highlighting Maiduguri Metropolis
**Source**: BORMLS [29].



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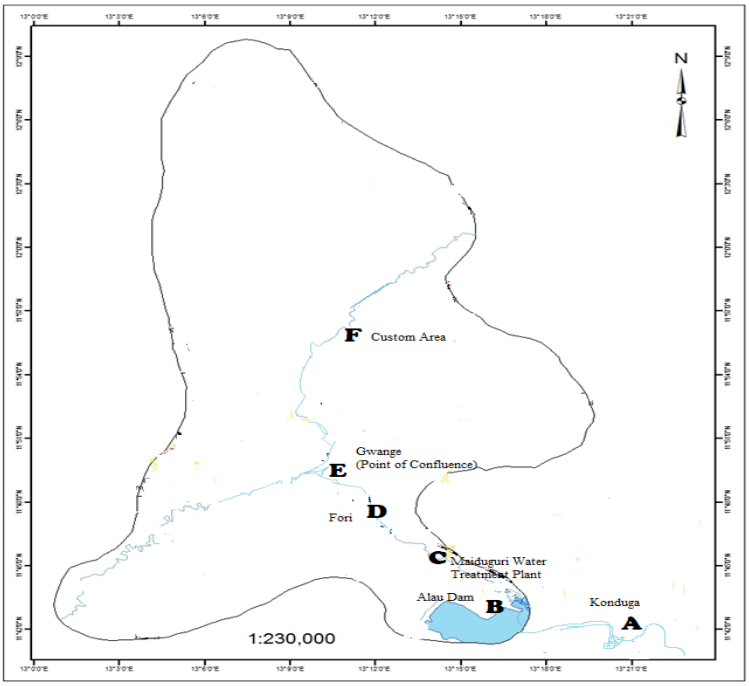


**Figure 4:** Map of Maiduguri and its Environs showing the Sampling Locations
**Source:** Sharah, [34].

***Fish sample collection***

Fish specimens (*C. gariepinus* and *O. niloticus*) were brought at the landing sites directly from the fishermen at the six different sampling stations monthly for 8 months as shown in **Figure 4** and **Table 1.** The samples were labelled, kept chilled on ice and delivered to the laboratory for additional analytical procedures as explained by Bwala, [32-33]. Four fish species were collected monthly at each sampling station for each species (4 fish × 8months × 6 stations = 192 fish for each species). A total of 384 fish were used in this study. The fish samples collected at each sampling station were authenticated and identified by a fish taxonomist at the Fisheries Department, University of Maiduguri (UNIMAID).

**Table 1:** Sampling Stations.

| S/N | STATION | LOCATION | GPS COORDINATE |
|---|---|---|---|
| 1 | A | Konduga village (Sabon Gari), Konduga LGA | 11° 38’ 46.24” N<br>13° 25’ 00.35” E |
| 2 | B | Alau Dam, Konduga LGA | 11° 43’ 27.04” N<br>13° 17’ 00.25” E |
| 3 | C | Behind Water Treatment Plant (WTP), Jere LGA | 11° 47’ 28.1’’ N<br>13° 11’ 33.8’’ E |
| 4 | D | Fori ward, Jere LGA | 11° 48’ 10.2’’ N<br>13° 10’ 18.9’’ E |
| 5 | E | Gwange (Point of Confluence), Jere LGA | 11° 49’ 49.2’’ N<br>13° 09’ 31.3’’ E |
| 6 | F | Custom Area, Maiduguri Metropolitan Council (MMC) | 11° 51’ 29.8’’ N<br>13° 11’ 01.0’’ E |

***Extraction and Evaluation of MNPs in the Fish Samples***

The fish specimens were subsequently prepared for dissection under controlled laboratory conditions. Prior to use, all dissection instruments, glassware, and working surfaces were thoroughly


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rinsed with distilled water to minimize the risk of external contamination. The external surfaces of each specimen were also gently washed with distilled water to remove adhering debris and potential contaminants, as explained by Kılıç [35]. The gastrointestinal tract, gill tissues, and muscle samples were aseptically excised from each specimen following a ventral dissection. An incision was made beneath the opercular region and extended longitudinally to the anal aperture to allow complete organ removal. Excised tissues were preserved in ethanol prior to chemical digestion. Organic matter degradation was subsequently performed using a 10% sodium hypochlorite (NaClO) solution prepared at a 1:3 (v/v) dilution with deionized water, as explained by Collard *et al.* [16] and Campbell *et al.* [2]2 with no modification. Filters were carefully transferred into sterile Petri dishes for subsequent microscopic analysis. For fish specimens weighing less than 5.0 g, the entire gastrointestinal tract (GIT), gills, kidneys, and liver were excised, finely sectioned using sterile dissection scissors, and subjected to complete chemical digestion. In specimens exceeding 5.0 g, the GIT, gills, kidneys, and liver were longitudinally opened and rinsed with ethanol to facilitate removal of surface contaminants and to enhance reagent penetration, particularly due to the thicker digestive epithelium characteristic of larger individuals. Thereafter, the tissues were digested in 30 mL of a nitric acid–sodium hypochlorite solution ($HNO_3$:NaClO; 1:10 v/v). Where residual organic matter persisted following the initial digestion, additional digestion cycles were performed to ensure complete breakdown of biological material, a procedure commonly required for larger gastrointestinal tracts and associated organs [16]. Following chemical digestion, the processed samples were subjected to sequential ultrafiltration using 50 µm and 30 nm mesh filters. The retained fractions were carefully transferred into separate glass Petri dishes and rinsed with 95% methanol. Subsequently, the samples were oven-dried at 100 °C overnight to ensure complete evaporation of the solvent prior to further analysis, as explained by Campbell *et al.* [2]. Once the samples were dry, the plastic particles were enumerated under a microscope.

The processed samples were placed in sterile Petri dishes for FT-IR and GC – MS analysis of both microplastics and nanoplastics at Yobe State University (YSU), Damaturu.

***Fourier Transform Infrared (FT-IR) Spectroscopy, Gas Chromatography Mass Spectroscopy (GC-MS) and Microscopic Analysis***

The extracted plastic particles were characterized using FT-IR and GC–MS to identify the polymer composition and quantify the microplastics and nanoplastics, respectively. FT-IR analysis of the microplastic samples was conducted with a spectrophotometer fitted with a single-bounce attenuated total reflectance (ATR) attachment. Nanoplastic characterization was carried out by injecting the treated samples into a GC–MS system (Agilent Technologies 7890B GC interfaced with a 5977A MSD). Polymer identification was achieved by comparing the absorbance spectra of the samples with the reference libraries installed in both the FT-IR and GC–MS instruments. Finally, the analyzed samples were subjected to further microscopic examination.

***Ethical Considerations/Approval***

All field and laboratory procedures involving the sampled *C. gariepinus* and *O. niloticus* species were conducted in accordance with internationally accepted guidelines for the care and use of experimental animals. The study protocol was reviewed and approved by the Postgraduate Departmental Coordinator, Department of Ecology, Faculty of Sciences of the Abubakar Tafawa Balewa University (ATBU), with the recommendation of the Departmental Health Research and Animal Ethics Committee of the ATBU. Additionally, handling, sampling, and euthanasia were performed using humane methods to minimize stress and suffering, and all efforts were made to reduce the number of animals used while ensuring the scientific validity.

**Statistical Analysis**

The collected data were first arranged and processed using Microsoft Excel (2013 version).



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Statistical analyses were subsequently performed with the Statistical Package for the Social Sciences (SPSS), version 26.0. All statistical inferences were tested at a significance level of 5% ($p < 0.05$). Descriptive statistics (mean and standard deviation) were employed to describe the dataset.

***Abundance of Plastic Particles in Fish***

The abundance of plastic particles in fish is estimated as

Abundance of p. p in fish $= \frac{\sum p.p}{\sum fw}$ as cited in Sanabil, Hadi & Zummah, [36].

Where $\sum p.p$ – summation of plastic particles in the fish species

$\sum fw$ – total weight of the sampled fish (*C. gariepinus* was weighted to have a mean weight of 0.231 ± 0.12 kg whereas *O. niloticus* was found to weight 0.078 ± 0.081 kg)

***Assessment of Human Health Risks from the Dietary Intake of MNPs Contaminated Fish***

The human health risk assessment from the ingestion of contaminated fish from the study area was estimated using the European Food Safety Authority (EFSA) postulated formula and the Food and Agricultural Organization (FAO) recommended daily dose of fish consumption: children (1 – 12 years) - 100 g/week and adults (≥ 18 years) - 300 g/week [27, 37-38]. The Food and Agriculture Organization (FAO) estimated the per capita fish consumption in Nigeria as 11.39 kg/year, equivalent to 11390 g/year (corresponding to 219.04 g/week) [38].

The estimated human intake of plastic particles from the contaminated fish species was estimated based on EFSA and FAO recommendations on the total mean of the number of plastic particles in fish, the two commercially important species of fish. Human risk assessment was estimated using the formula as proposed by ESFA [18, 27] below:

**Human Plastic Particles Intake per week** $= C_{pp} \times F^{w}$

**Human Plastic Particles Intake per Year** $= C_{pp} \times F^{w} \times N^{w}$

**Human Plastic Particles Intake per week per Capita** $= C_{pp} \times F^{w/ca}$

**Human Plastic Particles Intake per year per Capita** $= C_{pp} \times F^{y/ca}$

Where:

**$C_{pp}$** – Mean plastic particles in fish tissues (pp/g)

**$F^{w}$** - Recommended fish consumption per week (g/week)

**$N^{w}$** - Weeks of the year (52 weeks)

**$F^{w/ca}$** - Fish consumption per week per capita (g/week/capita)

**$F^{y/ca}$** - Fish consumption per year per capita (g/year/capita)

## Results

***Average Plastic Particles in the Fish Species***

The results of the average MNPs in the fish species, as shown in **Figure 5,** indicate that *O. niloticus* has the highest abundance of plastic particles across all stations in the study area. The results further indicate that the average abundance of MNPs in *C. gariepinus* ranged from 0.24 – 0.39 pp/kg (in stations B and C, respectively), whereas in *O. niloticus,* it ranged from 0.47 – 0.79 pp/kg in stations B and C, respectively).





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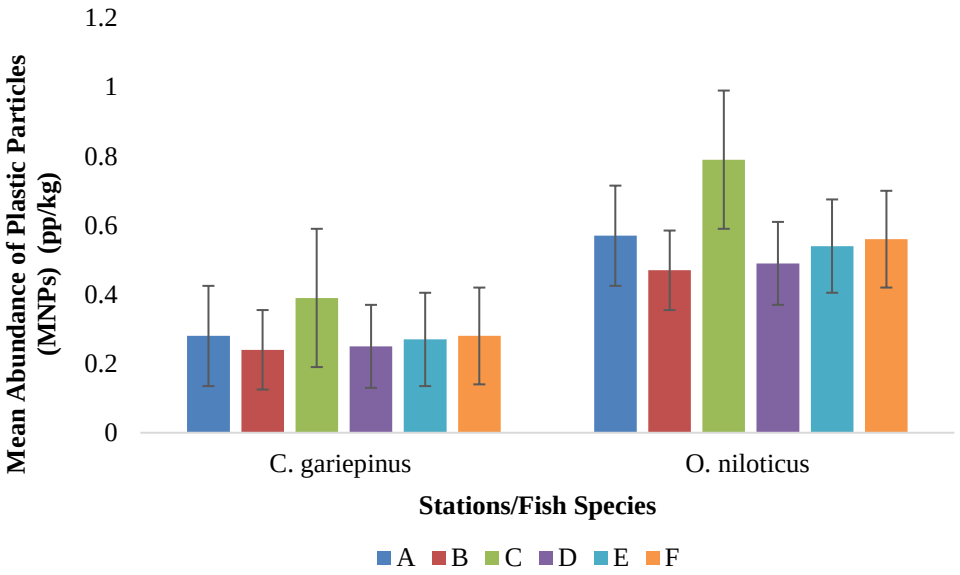


**Figure 5**: The Average Abundance of MNPs in *C. gariepinus* and *O. niloticus* from the Study Area.

***Human Health Implication from the Consumption of Fish Exposed to Plastic Particles***

The results of human health risk from the consumption of contaminated *C. gariepinus* from the study area, as shown in **Table 2**, revealed that Station B had the lowest average level of contamination, whereas Station C recorded the highest levels of MNPs contamination. The results also indicate that children are likely to ingest 23.46 – 39.32 pp/week, which corresponds to 281.50 – 471.88 pp/year (in Stations B and C, respectively). The results further revealed that adults might ingest 70.38 – 117.97 pp/week, which corresponds to 2671.92 – 4478.96 pp/year/capita (in Stations B and C, respectively).

**Table 2:** Human Exposure to MNPs from the Consumption of Contaminated *C. gariepinus* from the Study Area.

| Stations | P.P intake per week (pp/week) | | P.P intake per year (pp/year) | | P.P intake per week per capita (pp/week/capita) | | P.P intake per year per capita (pp/year/capita) | |
|---|---|---|---|---|---|---|---|---|
| | children | Adult | children | adult | Children | Adult | Children | Adult |
| A | 28.35 | 85.04 | 340.17 | 1020.50 | 31.05 | 62.09 | 1614.37 | 3228.73 |
| B | 23.46 | 70.38 | 281.50 | 844.51 | 25.69 | 51.38 | 1335.96 | 2671.92 |
| C | 39.32 | 117.97 | 471.88 | 1415.65 | 43.07 | 86.14 | 2239.48 | 4478.96 |
| D | 24.63 | 73.88 | 295.54 | 886.61 | 26.97 | 53.95 | 1402.57 | 2805.14 |
| E | 26.81 | 80.42 | 321.67 | 965.02 | 29.36 | 58.72 | 1526.61 | 3053.23 |
| F | 27.91 | 83.73 | 334.92 | 1004.77 | 30.57 | 61.13 | 1589.49 | 3178.98 |

The results of human health risk from the consumption of contaminated *O. niloticus* from the study area, as shown in **Table 3**, reveal that children are likely to ingest 46.92 – 78.65 pp/week, which corresponds to 51.38 – 86.13 pp/week/capita (in Stations B and C, respectively). The results further revealed that adults might ingest 140.75 – 235.94 pp/week, which corresponds to 1689.01 – 2831.30 pp/year (in Stations B and C, respectively). The results further suggest that *O. niloticus* from the study area had a higher potential for bio-magnification and bio-transfer of MNPs than *C. gariepinus* from the study area.



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**Table 3:** Human Exposure to MNPs from the Consumption of Contaminated *O. niloticus* from the Study Area.

| Stations | P.P intake per week (pp/week) | | P.P intake per year (pp/year) | | P.P intake per week per capita (pp/week/capita) | | P.P intake per year per capita (pp/year/capita) | |
|---|---|---|---|---|---|---|---|---|
| | children | Adult | children | adult | | children | Adult | children |
| A | 56.69 | 170.08 | 680.33 | 2040.99 | 62.09 | 124.18 | 3228.73 | 6457.47 |
| B | 46.92 | 140.75 | 563.00 | 1689.01 | 51.38 | 102.77 | 2671.91 | 5343.84 |
| C | 78.65 | 235.94 | 943.77 | 2831.30 | 86.13 | 172.27 | 4478.96 | 8957.92 |
| D | 49.26 | 147.77 | 591.07 | 1773.22 | 53.95 | 107.89 | 2805.14 | 5610.28 |
| E | 53.61 | 160.84 | 643.35 | 1930.05 | 58.72 | 117.43 | 3053.23 | 6106.45 |
| F | 55.82 | 167.46 | 669.85 | 2009.54 | 61.13 | 122.27 | 3178.98 | 6357.95 |

The results of the human health risk from the ingestion of both fish species from the study area, as shown in **Table 4,** indicate that children ingest 70.38 – 117.97 pp/week and 844.50 – 1415.65 pp/year (in Stations B and C, respectively). MNPs from the consumption of both contaminated *C. gariepinus* and *O. niloticus* caught in the study area. Adult exposure to MNPs via the consumption of contaminated *C. gariepinus* and *O. niloticus* from the study area ranged from 211.13 – 353.91 pp/week and 2533.51 - 42426.95 pp/year (in Stations B and C, respectively).

Similarly, the human MNPs intake per week per capita indicates that children ingest 77.08 – 258.40 pp/week/capita and 4007.88–6718.44 pp/year/capita (in Stations B and C, respectively) of MNPs from the contaminated fish species, while adults were exposed to 154.15–258.40 pp/week/capita and 8015.76–13436.89 pp/year/capita (in Stations B and C, respectively) of MNPs from the consumption of both contaminated *C. gariepinus* and *O. niloticus* in the study area.

**Table 4:** Human Exposure to MNPs from the Consumption of Both *C. gariepinus* and *O. niloticus* from the Study Area.

| Stations | P.P intake per week (pp/week) | | P.P intake per year (pp/year) | | P.P intake per week per capita (pp/week/capita) | | P.P intake per year per capita (pp/year/capita) | |
|---|---|---|---|---|---|---|---|---|
| | **Children** | **Adult** | **Children** | **Adult** | **Children** | **Adult** | **Children** | **Adult** |
| A | 85.04 | 255.12 | 1020.50 | 3061.49 | 93.14 | 186.27 | 4843.10 | 9686.20 |
| B | 70.38 | 211.13 | 844.50 | 2533.51 | 77.08 | 154.15 | 4007.88 | 8015.76 |
| C | 117.97 | 353.91 | 1415.65 | 42426.95 | 129.2 | 258.40 | 6718.44 | 13436.89 |
| D | 73.88 | 221.65 | 886.61 | 2659.84 | 80.92 | 161.84 | 4207.71 | 8415.42 |
| E | 80.42 | 241.26 | 965.02 | 2895.07 | 88.08 | 176.15 | 4579.84 | 9159.68 |
| F | 83.73 | 251.19 | 1004.77 | 3014.31 | 91.70 | 183.40 | 4768.47 | 9536.93 |

## Discussion

This study reveals the different levels of bio-transfer and the potential bio-magnification or bio-amplification potentials of micro- and nanoplastics (MNPs) from two commercially important freshwater fish species (*C. gariepinus* and *O. niloticus*) from the Ngadda River. The findings indicate that *O. niloticus* had higher levels of plastic particle contamination than *C. gariepinus*, with the highest abundance recorded at Station C (0.79 pp/kg). This is consistent with the study conducted by Barboza *et al.* [39], who reported species-specific variations in microplastic uptake, often linked to feeding strategy, habitat, and trophic level. Nile Tilapia (*O. niloticus*) are known to be omnivorous filter feeders, increasing their likelihood of ingesting suspended plastics 40, while African Catfish (*C. gariepinus*) display more benthic and predatory feeding behavior, which may reduce but not eliminate exposure [40-41].

The spatial differences observed, with higher MNP concentrations at Station C, suggest localized contamination hotspots potentially linked to anthropogenic pressures, such as effluent discharge from the Maiduguri Water Treatment Plant (WTP), urban runoff, or artisanal fishing activities. Similar spatial heterogeneity has been reported in other freshwater ecosystems, where stations closer to





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industrial and domestic effluents recorded higher MNP loads in fish tissues [42-43]. This underscores the role of watershed-level plastic pollution sources in shaping the bioaccumulation dynamics [44].

Human exposure assessments based on the ingestion of these fish species indicate a considerable intake of MNPs, particularly among children. In *C. gariepinus*, children were estimated to ingest 23.46–39.32 pp/week, whereas in *O. niloticus*, the ranges were significantly higher (46.92–78.65 pp/week). Adults also showed elevated exposure, with annual intake values ranging from 1689.01–2831.30 pp/year through *O. niloticus* consumption. These findings are consistent with those of dietary exposure models by Cox *et al*. [45], who estimated that the ingestion of contaminated seafood could result in the bio-transfer of MNPs particles in humans. Although the specific health risks (carcinogenic and non-carcinogenic risks) remain uncertain, the magnitude of exposure observed in this study cannot be ignored.

Furthermore, the estimated per capita weekly intake of MNPs exceeded the levels documented in comparable studies from Asia and Europe [46-47]. This discrepancy may be attributed to differences in fish ecology and human consumption habits in the study area, where fish is a staple protein source, especially among vulnerable groups such as children and pregnant women [48]. The high-frequency consumption of small-to medium-sized freshwater fish increases cumulative exposure compared to occasional seafood intake in Western populations [49].

The ecotoxicological implications of chronic ingestion of MNPs include potential disruption of gastrointestinal barrier function, immune responses, and microbiome balance [20, 50]. Both *in-vivo* and *in-vitro* assays indicate that MNPs can translocate across the intestinal epithelium, accumulate in secondary organs, and trigger oxidative stress pathways [23, 51-52]. The findings further showed that *O. niloticus* recorded the highest levels of contamination; thus, human populations that consume this species might be at a greater risk of systemic exposure to micro- and nanoplastics and their associated chemical additives.

Additionally, the role of MNPs as vectors for several environmental contaminants further complicates risk assessment. MNPs can adsorb environmentally persistent organic compounds (POPs), aromatic hydrocarbon derivatives (PAHs), and metallic trace contaminants from aquatic environments, potentially enhancing toxicity once ingested [22, 52]. Consequently, ingestion of contaminated fish could result in not only particle effects but also chemical exposure, a dual pathway supported by previous findings in both marine and freshwater contexts [37, 53]. The relatively higher MNP load in *O. niloticus* suggests a greater vector potential for toxicants than that in *C. gariepinus*.

Similarly, the findings raise concerns due to the reported presence of MNPs in human biological samples, including blood [23], stool [54], and placenta [25]. This evidence confirms that dietary exposure results in systemic absorption, strengthening the relevance of current dietary risk estimates. In particular, in developing regions where riverine fish remain a dietary cornerstone, exposure levels such as those reported here may pose cumulative risks over time [55-56].

The comparison between children and adults further highlights their age-related vulnerability. Children demonstrated proportionally higher per-capita exposure, consistent with prior studies suggesting that children, because of their comparatively smaller body mass combined with greater food intake per unit of their body weight, they tend to experience higher relative exposure to contaminants present in food [57]. Nutrition is crucial for growth and development, and such exposures may have long-term health implications, including developmental toxicity and endocrine disruption from plastic-associated chemicals [58-59].

Uncertainties persist regarding MNPs dose–response relationships, toxicodynamics, toxicokinetics, and thresholds for adverse effects in humans. Therefore, this study recommends the need for longitudinal studies aimed at establishing tolerable daily intake values by regulatory bodies. Integrative research combining field studies, exposure modeling, and toxicological assessments will critical for refining human health risk assessments [60-61].



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## Conclusion

The study revealed the average levels of MNP contamination in two commercially important freshwater fish species (*C. gariepinus* and *O. niloticus*) and indicated that *O. niloticus* had a higher bioaccumulation potential than *C. gariepinus* in the study area. The observed spatial variability was due to localized pollution sources, whereas human exposure assessment revealed significant dietary intake levels for both children and adults. The observed exposure rates exceeded previously reported values in several regions, reflecting the dietary reliance on freshwater fish in the study area.

The ecotoxicological effects of MNPs on biota, such as oxidative stress, immune activation, and chemical co-exposure, raise legitimate public health concerns. Children were identified as a particularly vulnerable group, showing higher per capita intake, which may predispose them to long-term health risks.

The study recommends further studies on the retention and elimination rates of MNPs in mammals, particularly humans, due to the current lack of understanding of these processes in the GI tracts of these organisms. A systematic study would provide insights into how MNPs interact with biological systems, potentially informing safety assessment assays and applications.

## Abbreviations

µm Micrometer
A.T.B.U Abubakar Tafawa Balewa University
E.F.S.A European Food Safety Authority
F.A.O Food and Agricultural Organization
FI-IR Fourier Transform Infrared Spectroscopy
GI Gastrointestinal
GS-MS Gas Chromatography - Mass Spectrometry
mm Millimeter
MNPs Micro- & Nanoplastics
MPs Microplastics
NESREA National Environmental Standards & Regulations Enforcement Agency
nm Nanometer
NPs Nanoplastics
pp/kg Plastic Particles Per Kilogram
pp/week Plastic Particles Per Week
pp/year Plastic Particles Per Year
UNIMAID University of Maiduguri
WTP Water Treatment Plant
YSU Yobe State University

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## Conflict of Interests

The author(s) declared no potential conflicts of interest

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## Ethical Considerations

The study followed internationally accepted animal care guidelines and received ethical approval from the Department of Ecology, Abubakar Tafawa Balewa University. Humane procedures were used to minimize stress and reduce the number of specimen.

## Code of Ethics

The study adhered to established ATBU and international standards governing animal welfare, scientific integrity, and responsible conduct of ecological and public health research. All investigators complied with approved ethical protocols, ensured transparency in data collection and analysis, and upheld principles of accountability and professionalism throughout the study. The study design incorporated the principles of reduction, refinement, and responsible use of biological resources to ensure ethical and scientifically sound practice.

## Authors' Contributions

**Bwala, M.N** – writing, original draft preparation, methodology, formal investigation and analysis in the project

**Ezra, A.G** – Conceptualization, validation, editing, project administration and supervision

**Nayaya, A.J** – Conceptualization, validation and





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supervision

**Buba, T**. – Conceptualization, editing, validation and supervision



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