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MICROPLASTICS IN *Oreochromis niloticus*: AN ABUNDANCE STUDY AND HEALTH RISK ASSESSMENT AROUND THE GAJAH MUNGKUR RESERVOIR

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Abstract

Introduction: *More than 430 million tons of plastic waste are added globally each year, increasing the potential distribution of microplastics, particularly in aquatic environments. Microplastic contamination in the Gajah Mungkur Reservoir is thought to come from nearby textile factories and fish farming using plastic floating nets. This study differs from previous research that only identified microplastics in reservoir water by conducting an individual-based carcinogenic health risk assessment using primary data. This study aims to identify the characteristics of microplastics in Oreochromis niloticus (abundance of particle, shape, color, and polymer type) and assess the carcinogenic risks of the local community.* ***Methods:*** *This quantitative descriptive research used 9 Oreochromis niloticus samples from floating net cages and 30 respondents selected through purposive sampling techniques. Microplastics were identified using a stereomicroscope and FTIR. The Microplastic Carcinogenic Risk (MPCR) formula was applied. The research ran from November 2024 to March 2025.* ***Results and Discussion:*** *Microplastics in Oreochromis niloticus had an average abundance of 0.45 particles/gram, with the highest at 0.87 particles/gram. The estimated daily intake of microplastic particles in respondents shows an average result of 0.007730 particles/day. The average MPCR value of respondents is 1.86×10-6, indicating a carcinogenic risk level according to US EPA guidelines, although still within tolerable limits.* ***Conclusion:*** *The average respondent is at risk of carcinogenic microplastics but still within tolerance limits. Suggestions for the community are not to throw garbage and household waste into the rivers around the reservoir and to reduce single-use plastics.*

INTRODUCTION

Microplastic pollution has been a global problem for many years now. According to the United Nations Environment Programme (UNEP), the world's plastic waste continues to grow in number, with more than 430 million tons every year (1). A study in the Porong River in Sidoarjo, Indonesia found microplastic contamination with the highest total abundance of 222 particles/10 liters in water and 213 particles/100 gr in sediment with fiber (2). Another study at two outlet points of Gajah Mungkur Reservoir, Indonesia, also found microplastic contamination of 4 particles/100 liters and 8 particles/100 liters of water dominated by the film type (3). The abundance of microplastics in waters can bioaccumulate in the bodies of zooplankton, small fish, large fish, and other organisms that eat them (4). Subsequently, in this study, fish samples were used, which are directly linked to potential human exposure through the food chain. Furthermore, unlike other health risk assessment studies that generally rely on generalized population estimates, this research is based on primary data collected through direct interviews with respondents, including information on portion size, exposure duration, and individual body weight. The carcinogenic health risk

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is calculated individually for each respondent, providing a more specific, accurate, and contextually relevant risk estimation for the affected population.

Microplastic particles can enter the human body through oral (swallowing), which will then be absorbed by M cells (microfold cells) in Peyer's plaque in the absorption intestine, carried to lymphoid tissue by transcytosis, move to mucosal tissue, lymphatic system, and blood circulation through loose junction and carried in the blood to all parts of the body (5-6). Previous studies have shown evidence of microplastics in several parts of the human body, such as in 17 out of 22 (77%) blood samples, in 26 out of 34 breast milk samples (58 particles), and in the feces of 102 people (average 375.92 particles/g) (7–9). The accumulation of microplastics causes health problems such as colitis, immune disorders, neoplasia, and potentially cancer in long-term consumption (10-11). Plastic additives such as arsenic, chromium, cadmium, lead, and mercury are also carcinogenic, according to The International Agency for Research on Cancer (IARC) (12).

One of the largest inland waters in Indonesia, Gajah Mungkur Reservoir, is located in Wonogiri Regency, Central Java Province, with a catchment area of approximately 1,350 km^2 and an area of 8,800 hectares. This reservoir was built in the 1970s by damming the Bengawan Solo River, which was utilized by the surrounding community as a place for freshwater fish farming, especially tilapia floating net cages (13). In 1989, there were 45 floating net cages with a size of 6 × 6 meters with a depth of 3 meters for each plot. Currently, there are 70 cages with tilapia as the type of fish that has the highest production (14-15).

A preliminary study on September 22, 2024, showed that 9 out of 10 public respondents liked Oreochromis niloticus to be consumed with a frequency of 1-2 times a week. Laboratory tests of one sample of farmed *Oreochromis niloticus* in Gajah Mungkur Reservoir at the same time also found microplastics in one tilapia sample with an abundance of 22 particles/100gr measuring 0.09 - 2.40 mm, fiber and filament types that could come from fishing nets and strings during the farming process. In addition, filamentous microplastics can be related to the presence of several textile industries around Gajah Mungkur Reservoir (16). In addition, based on the results of preliminary study interviews with floating net cage owners, plastic materials are indeed used in *Oreochromis niloticus* in Gajah Mungkur Reservoir. At the seeding stage, plastic containers and buckets are used to move and spread fish seeds from the seeding center. During the tilapia maintenance process, the nets that function as cultivation containers (fish cages) are soaked in reservoir water for a long time. Various sources of plastic pollution cause the emergence of potential for microplastic contamination in the vicinity of cages, suggesting the need for a health risk assessment for the surrounding community consuming farmed tilapia in the floating net cages of Gajah Mungkur Reservoir. This study aimed to identify the characteristics of microplastics in *Oreochromis niloticus* (abundance of particle, shape, color, and polymer type) and the carcinogenic risks of the local community due to microplastic contamination of farmed *Oreochromis niloticus* in Gajah Mungkur Reservoir, Wonogiri Regency.

METHODS

This research is quantitative descriptive by describing the identification of microplastic particle characteristics (abundance, shape, color, and polymer type), as well as the results of the calculation of carcinogenic health risks of people who consume *Oreochromis niloticus* in Gajah Mungkur Reservoir. The research lasted for 5 months, was in November 2024 - March 2025. This research has gone through an ethical test from the KEPK Faculty of Dentistry, University of Jember No.2885/UN25.8/KEPK/DL/2024.

Oreochromis niloticus Sample Collection

The *Oreochromis niloticus* samples used were 9 fish according to the number of 3 floating net cages (having the highest production, consumed by the surrounding community, and the cages have been built for at least 5 years). A total of 3 *Oreochromis niloticus* were taken in each cage, provided that the fish samples were 4-6 months old and weighed 300-500 grams (based on interviews with cage owners). *Oreochromis niloticus* samples were collected from cages located at three specific coordinates, namely: (i) Point 1 (7°51'42,072"S 110°54'40,41"E), (ii) Point 2 (7°52'1,464"S 110°54'33,9"E), (iii) Point 3 (7°52'0,99"S 110°54'33,882"E) (Figure 1).

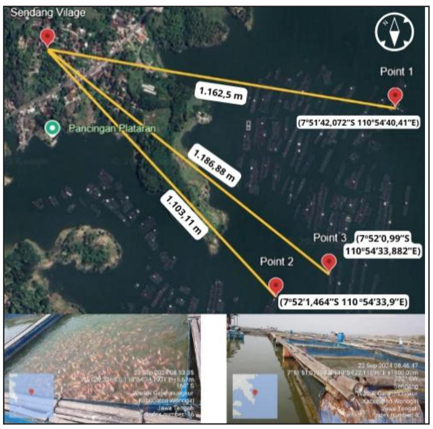

Figure 1. Location of Oreochromis niloticus Sampling in Floating Net Cages in Gajah Mungkur Reservoir

Oreochromis niloticus samples were taken with a small net and then dissected for meat. *Oreochromis niloticus* meat (100 grams) was put into a 100 ml sterile glass bottle and 70% alcohol liquid was added until the sample was submerged (17). The bottle was covered with bubble wrap and packed in cardboard boxes for microplastic identification through the Ecoton Gersik Laboratory service and microplastic polymer type testing through the Department of Materials and Metallurgy Engineering Laboratory service, Sepuluh Nopember Institute of Technology Surabaya. Stereomicroscope and Fourier Transform Infrared Spectroscopy (FTIR) are used to identify the abundance, shape, color, and type of microplastic polymers.

Oreochromis niloticus Consumption Rate Data Collection

Oreochromis niloticus consumption level data used in this study included frequency of consumption, duration of consumption, and amount of consumption (grams) collected using a semi-quantitative Food Frequency Questionnaire. Thirty interview respondents resided in Sendang Village, the closest village to the reservoir and *Oreochromis niloticus* sampling point. Respondents were selected using a purposive sampling method, considering the specific characteristics required for health risk estimation, such as frequency of fish consumption and residence within the study area. This approach was chosen due to limited accessibility and the exploratory nature of the research, which aimed to gather initial insights into local exposure to microplastic-contaminated fish. The respondents were selected using the purposive sampling method with the condition that the respondents were 19-59 years old and consumed *Oreochromis niloticus* from the floating net cages of Gajah Mungkur Reservoir within the last 1 year.

Data Analysis

Calculation of microplastic abundance is used to determine the abundance of microplastics in each gram of *Oreochromis niloticus* meat using Formula 1(18).

$$Abundance\ of\ microplastic\ \left(\frac{particle}{gram}\right) = \frac{Count\ of\ microplastic\ particle\ (particle)}{Fish\ weight\ (gram)}$$ ....formula 1

The consumption of microplastic particles in the meat of Oreochromis niloticus farmed in Gajah Mungkur Reservoir can occur through oral or ingestion. The estimated daily intake can be calculated using Formula 2 (19,20):

$$EDI_{Ingestion} = \frac{Pji \times R \times F_E \times D_t}{Bw \times t_{avg}}$$ ....formula 2

Where $EDI_{Ingestion}$: estimated daily intake of microplastic particles (particles/kg × day); *Pji*: abundance of microplastic particles in *Oreochromis niloticus* meat (particles/gr); R: total consumption of *Oreochromis niloticus* per consumption (grams/day); F_E : number of days of exposure or consumption of *Oreochromis niloticus* (days/year); D_t: duration of exposure (years); Bw : human body weight (kg); t_{avg} : time period for carcinogenic effects (70 years × 365 days/year).

The lifetime health risk assessment of carcinogens was calculated using Formula 3 (20) and based on the Cancer Slope Factor (CSF) value. According to the US EPA guidelines the standard of carcinogenic risks or Microplastics Carcinogenic Risks (MPCR), acceptable carcinogenic health risk values are 10^{-6} to 10^{-4} (21). This standard is used to determine the carcinogenic health risk status of the respondents in this study.

$$MPCR = (EDI_{ingestion} \times CSF) \times \times 10^{-3}$$ (Formula 3)

Where MPCR: the risk of an individual experiencing carcinogen effects due to microplastic contamination; $EDI_{Ingestion}$: estimated daily intake of microplastics (calculated by Formula 2); *CSF*: cancer slope factor (vinyl chloride (PVC): 1.9 (22), polypropylene (PP): 0.24 (22), and ethylene oxide: 1,02) (23).

RESULTS

Microplastic Characteristics of Farmed *Oreochromis niloticus*

Sampling of *Oreochromis niloticus* was conducted on January 29, 2025, at 3 points of floating net cages of Gajah Mungkur Reservoir, Wonogiri Regency. The identification of the characteristics of microplastics consists of the abundance, shape, color, and type of polymer. The results of the calculation are presented in Table 1. The lowest abundance value was 0.08 particles/gram (S2 or Sample 2) taken at Point 1, while the highest abundance was 0.87 particles/gram (S1 or Sample 1) taken at Point 1. The average abundance of microplastics from 9 samples of this study was 0.45 particles/gram. The identification results that there are 4 forms of microplastics in *Oreochromis niloticus* meat samples, namely fiber (n = 240), film (n = 118), fragments (n = 27), and granules (n = 21) with a total of 406 particles. Fiber was the most common particle shape with a percentage of 59% found in 9 samples. Coloring is one of the stages in the process of making plastic or plastic-based goods in the industrial world. The color will remain attached to the product even though it has degraded into microplastic particles. The identification results of this study show that black is the most identified color with a total of 113 particles (27.8%) (Figure 2). In this study, only the sample with the highest microplastic content was carried out FTIR test to identify the type of polymer contained therein, namely Sample 1 (n = 87 particles). The FTIR test results presented in Figure 3 show that there are identified wave peaks, namely wave numbers 3,319.69 cm-1 (possible alcohol functional group compounds (-OH)), 2,161.28 cm^{-1} (possible alkyne functional group compounds (C≡C)), 1,636.29 cm^{-1} (possible aromatic functional group compounds (C=C)), and 583.38 cm^{-1} (compounds cannot be identified directly). There are 2 types of microplastic polymers identified as Polyethyleneimine (PEI) and Polyurethane (PU).

Table 1. Abundance and Shape of Microplastic Particles in Oreochromis niloticus Meat

No	Location	Sample Code	Abundance of Microplastics (Particles/100 gram)	Microplastic Forms (Particles/100 gram)			
				Fiber	Film	Fragment	Granule
1		S1	87.00	52.00	31.00	4.00	0.00
2	Point 1	S2	8.00	8.00	0.00	0.00	0.00
3		S3	25.00	13.00	11.00	1.00	0.00
4		S4	36.00	30.00	0.00	2.00	4.00
5	Point 2	S5	37.00	16.00	6.00	2.00	13.00
6		S6	76.00	16.00	57.00	3.00	0.00
7		S7	62.00	52.00	4.00	6.00	0.00
8	Point 3	S8	11.00	4.00	2.00	5.00	0.00
9		S9	64.00	49.00	7.00	4.00	4.00
Total			**406.00**	**240.00**	**118.00**	**27.00**	**21.00**
Average			**45.11**	**26.67**	**13.11**	**3.00**	**2.34**
Percentage (%)			**100.00**	**59.00**	**29.00**	**6.65**	**5.17**

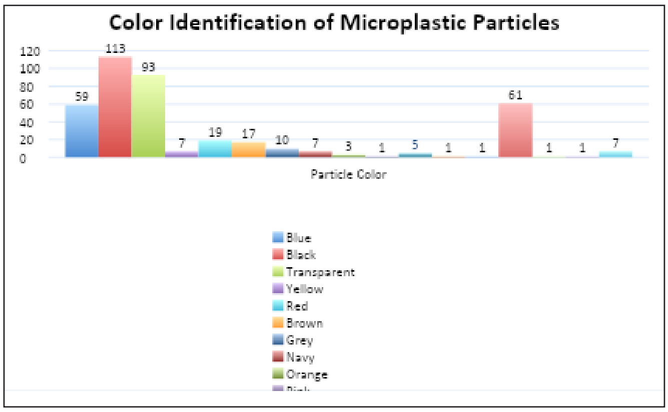

Figure 2. The Color of Microplastic Particles

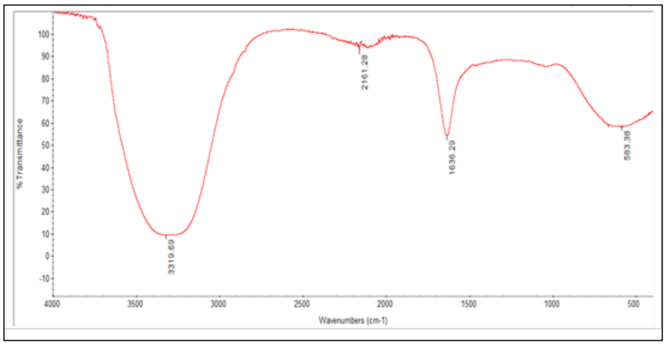

Figure 3. FTIR Test Results of Microplastic Polymers

Table 2. Respondent Characteristics and Community Consumption Levels

Indicator	Mark			
	Min	Median	Mean	Max
Respondent Characteristics				
Age (Years)	19.0	42.5	40.6	59.0
Body Weight (Kg)	39.0	57.2	59.3	90.0
Level of Public Consumption				
Duration of exposure (years)	10.0	33.0	31.7	50.0
Frequency of consumption (days/ year)	1.0	78.0	84.0	208.0
Amount of consumption (grams/day)	0.1	7.0	9.8	45.7

Estimated Daily Intake of Microplastic Particles in the Community Around the Reservoir

Respondents in this study consisted of 13 men (43.3%) and 17 women (56.7%). On average, respondents consumed *Oreochromis niloticus* with an amount of 9.8 grams in one day of consumption (presented in the Table 2). The highest amount of respondents' consumption was 45.7 grams in a single consumption, namely in 3 people (10%). The majority of respondents (76.7%) processed *Oreochromis niloticus* by frying. The calculation of the estimated daily intake of microplastics was carried out using formula 2. The value of *Pji* was obtained from the average microplastic abundance of 9 samples, namely 0.45 particles/gram. The value of T_{avg} is obtained from the default value of T_{avg} in the Environmental Health Risk Analysis Guidebook of the Directorate General of PP and PL (2012), which is 70 years × 365 days (25,550 days) (19). The results of the calculation of the estimated intake of microplastic particles in the community around the reservoir are presented in Table 3. The average estimated intake of microplastics from 30 respondents is 0.007730 particles/kg × day. This means that it is estimated that the average respondent has a microplastic intake of 0.007730 particles per day for every kilogram (kg) of the respondent's body weight.

Table 3. Estimated Daily Intake of Microplastic Particles As A Carcinogenic Health Risk

No	Consumption Portion / R (Gram/day)	Consumption Frequency/ F_e (Day/year)	Consumption Period/ D_t (Years)	Body Weight/ B_w (Kg)	Estimated daily intake / $EDI_{Ingestion}$ (Particles/kg × day)	Carcinogenic Health Risk/ MPCR	Risk Level according to US EPA 2011
1	5.4	78	50	51.04	0.007210	1.73 × 10-6	Risky, still within tolerance limits
2	8.6	78	34	57.00	0.007024	1.69 × 10-6	Risky, still within tolerance limits
3	0.8	12	40	39.16	0.000180	4.32 × 10-8	Very low risk
4	11.4	208	40	55.00	0.030449	7.31 × 10-6	Risky, still within tolerance limits
5	0.8	12	40	50.48	0.000140	3.35 × 10-8	Very low risk
6	5.4	78	30	71.94	0.003069	7.37 × 10-7	Very low risk
7	5.4	78	20	64.48	0.002283	5.48 × 10-7	Very low risk
8	5.4	78	20	60.00	0.002453	5.89 × 10-7	Very low risk
9	22.9	208	10	51.00	0.016419	3.94 × 10-6	Risky, still within tolerance limits
10	1.3	12	45	39.00	0.000325	7.80 × 10-8	Very low risk
11	0.8	12	10	90.00	0.000020	4.70 × 10-9	Very low risk
12	0.8	12	30	59.90	0.000088	2.12 × 10-8	Very low risk
13	22.9	78	15	89.00	0.005292	1.27 × 10-6	Risky, still within tolerance limits
14	8.6	78	40	68.65	0.006861	1.65 × 10-6	Risky, still within tolerance limits
15	8.6	78	10	46.00	0.002560	6.14 × 10-7	Very low risk
16	28.6	208	50	58.00	0.090232	2.17 × 10-5	Risky, still within tolerance limits
17	22.9	208	50	76.55	0.054693	1.31 × 10-5	Risky, still within tolerance limits
18	14.3	208	10	50.91	0.010280	2.47 × 10-6	Risky, still within tolerance limits
19	8.6	78	30	63.93	0.005526	1.33 × 10-6	Risky, still within tolerance limits
20	8.6	78	32	60.07	0.006273	1.51 × 10-6	Risky, still within tolerance limits
21	17.1	78	15	50.00	0.007065	1.69 × 10-6	Risky, still within tolerance limits
22	0.8	12	50	70.00	0.000126	3.02 × 10-8	Very low risk
23	0.8	12	15	48.00	0.000055	1.32 × 10-8	Very low risk
24	8.6	78	35	57.45	0.007174	1.72 × 10-6	Risky, still within tolerance limits
25	45.7	208	45	73.90	0.101978	2.45 × 10-5	Risky, still within tolerance limits
26	1.3	12	50	50.00	0.000282	6.76 × 10-8	Very low risk
27	2.7	12	50	57.00	0.000494	1.19 × 10-7	Very low risk
28	1.3	12	20	45.00	0.000125	3.01 × 10-8	Very low risk
29	0.1	1	20	71.00	0.000001	1.30 × 10-10	Very low risk
30	22.9	208	45	55.00	0.068510	1.64 × 10-5	Risky, still within tolerance limits
Ave-rage	**9.8**	**84**	**31.7**	**59.30**	**0.007730**	**1.86 × 10-6**	**Risky, still within tolerance limits**
Min	**0.1**	**1**	**20**	**71.00**	**0.000001**	**1.30 × 10-10**	**Very low risk**
Max	**45.7**	**208**	**45**	**73.90**	**0.101978**	**2.45 × 10-5**	**Risky, still within tolerance limits**

Health Risk Assessment of Communities Around the Reservoir due to Microplastic Contamination in Farmed *Oreochromis niloticus*

However, both polymers do not have Cancer Slope Factor (CSF) values, so the carcinogenic health risk calculations were done with those related to both polymers. Polypropylene (PP) is a polymer that will be used because it is often found in *Oreochromis niloticus* (42). The Cancer Slope Factor (CSF) value used was Polypropylene (PP) polymer because the microplastic polymers identified in the study (Polyethyleneimine (PEI) and Polyurethane (PU)) did not have a (CSF) value. The CSF value of Polypropylene (PP) polymer based on the publication of the United State of Environment Protection Agency (USEPA) is 0.24 (22). The results of the health risk calculation in Table 4 show that the average carcinogenic health risk value or Microplastic Carcinogenic Risk (MPCR) is 1.86×10^{-6}.

According to the US EPA guidelines, the provision of carcinogenic risks or Microplastics Carcinogenic Risks (MPCR) that can be accepted or tolerated in the range between 1×10^{-6} to 1×10^{-4}, which means that when someone has an MPCR value in that range, they are at risk of being exposed to carcinogenic disorders from risk agents, but still within tolerance limits (21). The risk level is very low when having an MPCR value of less than 1×10^{-6}. However, when it has an MPCR value of more than 1×10^{-4}, then the risk level cannot be tolerated. Based on the results of the calculation of carcinogenic risk in Table 4, the average respondent has an MPCR value that is at a risky level but still tolerable.

DISCUSSION

Microplastic Characteristics of Farmed *Oreochromis niloticus*

The presence and abundance in the flesh of farmed fish are influenced by internal factors (fish size and farming process) and external factors (such as polluted environment) (24). A study measuring the morphometry of farmed *Oreochromis niloticus* in Buah Jakung Village, Serang Regency, Banten, showed that tilapia had a mouth opening of up to 2 cm (25). This condition allows microplastics with a size of 1 - 5 mm to enter the body and digestive system and be stored in Oreochromis niloticus meat (24). During the cultivation process, plastic products also affect microplastics in the body of farmed fish (24,26). This condition was also found in the *Oreochromis niloticus* cultivation process in the floating net cages of Gajah Mungkur Reservoir, which requires the fish farming net to be submerged in reservoir water for a long time.

The activity of washing synthetic clothing at the household level either using a washing machine or directly into the river, as well as the use of personal care products contributes to microplastic contamination of the aquatic environment and fish bodies (27-28). Research analyzing the presence of microplastics in the Gajah Mungkur Reservoir's surface water found several textile industries near the reservoir (16).

The microplastic particles identified in this study have four forms: fiber, fragments, films, and granules. Fiber is the most particle form, namely 240 particles (59%). The dominance of the fiber particle form can occur due to the use of plastic nets during the *Oreochromis niloticus* cultivation process in the floating net cages of Gajah Mungkur Reservoir, Wonogiri Regency. The cage net is degraded due to friction, seawater waves, and ultraviolet light, which eventually breaks into fiber form (29). Fiber particles can also come from textile industry waste, yarn, and fishing lines (30). This statement aligns with the results of a study analyzing the presence of microplastics in the surface water of Gajah Reservoir, where several textile industries are located around the reservoir (16).

The results showed that there were 17 colors of microplastic particles, with the five most colors, namely black (113 particles /27.8%), transparent (93 particles /24.9%), clear (61 particles /15.0%), blue (59 particles /14.5%), and red (19 particles /4.7%). Black fiber microplastics generally come from clothing fibers, ropes, and fishing gear, such as nets and fishing strings, which are degraded by natural or human activities (especially capture water) (29). Black and blue are the colors of the nets used in tilapia aquaculture in the floating net cages of Gajah Mungkur Reservoir, Wonogiri Regency.

This research sample identified two types of microplastic polymers: polyethyleneimine (PEI) and polyurethane (PU). However, neither polymer has cancer slope factor (CSF) values, so the carcinogenic health risks were calculated with polymers related to them, namely polypropylene (PP). Polypropylene (PP) polymers have properties that are less resistant to, so in the production of a product, such as nets and fishing lines, requires additional ingredients to improve their quality where Polyethyleneimine (PEI) and Polyurethane (PU) polymers when added can produce Polypropylene (PP) polymers that are stronger, have higher tensile and heat resistance (31-32). Black fiber microplastics are usually polyethylene (PE) and polypropylene (PP) polymers, which are generally the building blocks of plastic products such as packaging, ropes, and fishing nets (29).

Estimated Daily Intake of Microplastic Particles in the Community Around the Reservoir

The results of interviews with 30 respondents on January 19, 2025, showed that the factor that influences the level of consumption of tilapia in the community is ease of access. People buy *Oreochromis niloticus* from their neighbors, owners, or managers of floating net cages in Gajah Mungkur Reservoir. In addition, people also sometimes buy cooked *Oreochromis niloticus* at food stalls around the reservoir. This gives the community easy access to farmed *Oreochromis niloticus*, which may increase their consumption (33).

The calculation of the estimated daily intake of microplastics in this study shows that the community around the reservoir has an average estimated daily intake value of 0.007730 microplastic particles per day for every kilogram (kg) of respondent body weight. For example, a respondent who weighs 70 kg is estimated to consume 0.541 particles/day or 3.79 particles/week of microplastic particles from *Oreochromis niloticus*. Microplastic particles from fish can be minimized by removing parts of the fish's digestive tract, such as the intestines and stomach, especially for medium to large fish because these body parts are not eaten directly by humans. The fish's digestive tract is where the process of food absorption and accumulation of microplastic particles occurs (34). In addition, gills can also contain microplastics, although the amount is usually less than in the digestive organs (25,35). A study comparing the number of microplastic particles in 18 samples of raw fish with 18 samples of deep-fried fish showed a decrease in the number of particles in each type of fish and that the oil used to fry fish contained more microplastic particles with an average increase of 27 particles in 3 samples (36). Thus, the intake of microplastic particles can also be reduced by not reusing the leftover fish frying oil.

Health Risk Assessment of Communities Around the Reservoir due to Microplastic Contamination in Farmed *Oreochromis niloticus*

The average respondent is at risk of carcinogenic microplastics but still within tolerance limits. Despite remaining within the established EPA tolerance limits ($\sim 1\times10^{-6}$), the average respondent's carcinogenic microplastic exposure may still pose significant long-term health risks, as recent evidence from the past five years highlights the potential dangers of chronic, low-dose accumulation (37). Recent reviews highlight that microplastics can serve as vectors for adsorbed carcinogenic chemicals (PAHs, BPA), leading to estimated lifetime cancer risks above the EPA threshold (e.g., $1.1–1.3\times10^{-5}$ for adults and children). In vitro and animal studies show increased inflammatory mediators and early tumor signaling in breast and skin cells after prolonged microplastic exposure (38).

The use of Polypropylene (PP) as a reference in the health risk analysis in this study is based on the dominance of this type of polymer in the analyzed fish samples. However, this approach has limitations because it does not consider other types of polymers that fish may ingest, such as polyethylene (PE) or polystyrene (PS), which can have different toxicological profiles. Differences in physical and chemical characteristics between polymers can affect the human body's bioavailability, toxicity, and interaction mechanisms. Therefore, the risk estimation results in this study need to be interpreted carefully, and further studies that comprehensively evaluate the risks of different types of polymers are needed to obtain a more accurate picture of the risks.

Microplastic particles that enter the human body through oral (ingestion) will be absorbed by M cells (microfold cells) in Peyer's plaque in the absorption intestine, carried to lymphoid tissue by transcytosis, move to mucosal tissue, lymphatic system, and blood circulation through loose junction and carried in the blood to all parts of the body (5-6). The microplastic particles will accumulate in cells and tissues of the digestive tract, respiratory system, reproductive system, nervous system, liver, kidney, and spleen organs (39). Furthermore, after entering the target organs, microplastic particles interact directly with body cells and tissues that will form reactive oxygen species due to oxidative stress (39-40).

Body cells interacting with microplastics will experience changes in their regular activity, triggering a multi-step carcinogenesis process, generally passing through the stages of loss of apoptotic capacity and inhibiting cell growth, which then develops into precancerous cells. Precancerous cells become very strong and can escape the body's immune system. They require a particular process of genetic mutation to enter the carcinogenetic stage. The development of cancer cells can be driven by dysregulation of cell proliferation, which is related to the different cellular effects of exposure to microplastic particles (39-40).

The carcinogenic potential of microplastics can occur due to the use of additives in plastic manufacturing, such as arsenic, chromium, cadmium, lead, and mercury, which are carcinogenic, according to The International Agency for Research on Cancer (IARC) (12). Microplastics also often contain harmful chemicals such as plastic additives (e.g. phthalates and bisphenol A) that can be released into the body (41). Long-term exposure to microplastics can result in pathological changes such as liver damage, as well as inflammatory responses and increased oxidative stress that increase the risk of liver cancer (42).

This study has several limitations that should be acknowledged. First, the sample size for fish specimens and human respondents was relatively limited due to logistical and resource constraints during data collection. While the sample size aligns with those used in similar exploratory studies, it may limit the generalizability of the findings. Second, respondents were selected using purposive sampling, which may introduce selection bias and affect the representativeness of consumption patterns in the broader population. Lastly, the health risk assessment was based on Polypropylene (PP) as a proxy polymer type, given its dominance in the analyzed samples. One type of polymer (Polypropylene) used as a reference in health risk assessment does not yet represent the potential toxicity variation of other types of microplastics that fish may ingest. Although this approach is supported by literature, the toxicological profiles of other polymer types were not included, which may influence the comprehensiveness of the risk estimation. Future research with larger, randomized samples and expanded polymer analyses is recommended to enhance the robustness of the findings.

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CONCLUSION

The average abundance of microplastics in *Oreochromis niloticus* is 45.11 particles/100 grams of fish meat, which is dominated by fiber and red. Polyethyleneimine (PEI) and Polyurethane (PU) are the types of polymers identified. The mean value of Microplastic Carcinogenic Risk (MPCR) in the community around the reservoir was 1.86×10^{-6}, which means that the average respondent was at risk of exposure to carcinogenic microplastics but was still within the tolerance limit. People can remove all parts of the fish's stomach and digestive organs before consumption, and do not reuse oil that has been used for frying to reduce the intake level of microplastic particles. The community is also expected not to throw garbage and household waste into the rivers around the reservoir and to reduce the use of single-use plastics.

AUTHORS' CONTRIBUTION

AWN: Conceptualization, Methodology, Data Collection, and Writing- Original draft preparation. GN: Validation, Writing- Reviewing, and Final Manuscript Editing. DIA: Validation and Writing-Reviewing.

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