Latin American Journal of Aquatic Research, 54(4): 543-562, 2026
DOI: 10.3856/vol54-issue4-fulltext-3631

Review Article

Microplastics in *Oreochromis niloticus* tilapia aquaculture: sources and effects

Edna Fabiola Castillo-Márquez[1], Benigno Ortiz-Muñiz[1], María del Refugio Castañeda-Chávez[1], Fabiola Lango Reynoso[1], Olaya Pirene Castellanos Onorio[2], Itzel Galaviz Villa[1] & Dalia Guadalupe Mendoza López[1]
[1]TecNM/Instituto Tecnológico de Boca del Río, Boca del Río, Veracruz, México
[2]TecNM/Instituto Tecnológico de Veracruz, Veracruz, México
Corresponding author: Benigno Ortiz (benigno.om@bdelrio.tecnm.mx)

ABSTRACT. Microplastic pollution poses an emerging risk to aquaculture systems and food security. Nile tilapia (*Oreochromis niloticus*), one of the most widely farmed freshwater species globally, can be exposed to these particles through water, feed, and aquaculture infrastructure. This systematic review aimed to synthesize the scientific evidence regarding the sources, characteristics, and effects of microplastics in tilapia aquaculture. The PRISMA 2020 guidelines were followed, and a literature search was conducted across Scopus, SpringerLink, Google Scholar, and ResearchGate for the period 2016-2025. Following the selection process, 34 studies were included in the qualitative synthesis. The results demonstrate that microplastics in *O. niloticus* are widespread globally, having been recorded in natural, aquaculture, and experimental systems. Fibers and fragments, composed mainly of polyethylene, polypropylene, and PET, predominate; these are associated with both external sources (wastewater, urban activities, and textiles) and internal sources (wear and tear of netting, pipes, equipment, and contaminated feed). Most studies document accumulation in the gastrointestinal tract, although particles have also been detected in the gills, liver, and muscle, suggesting a potential risk to human health. Furthermore, physiological effects such as digestive disturbances, oxidative stress, and reduced growth have been reported. Overall, the evidence confirms that microplastics are a significant contaminant in tilapia aquaculture and highlights the necessity to implement mitigation strategies and standardize assessment methodologies.

Keywords: *Oreochromis niloticus*; aquatic pollution; food security; physiological effects

INTRODUCTION

Microplastics (MPs), defined as plastic particles less than 5 mm in size (Ankita 2025), have become a widely distributed emerging contaminant in marine and freshwater ecosystems. These particles can be of primary origin, intentionally manufactured for industrial or domestic purposes, or secondary, derived from the fragmentation of larger plastics present in the environment (GESAMP 2015, Lusher et al. 2020). Their persistence and ability to adsorb chemical contaminants favor their dispersal and incorporation into the aquatic food chain (Zhang et al. 2019, Valencia-Castañeda et al. 2022).

Aquaculture represents one of the fastest-growing food production sectors worldwide and is a key source of protein for the human population (FAO 2018, Tidwell & Bright 2019). However, its close dependency

Associate Editor: Alvaro Bicudo

on natural water bodies and the intensive use of plastic materials in production facilities render the system vulnerable to MP contamination (Liu et al. 2019, Chen et al. 2021). In this context, it has been suggested that the presence of MPs can affect both the health of farmed organisms and the safety of the final product intended for human consumption (Li et al. 2021, Zhou et al. 2021).

Among farmed species, Nile tilapia (*Oreochromis niloticus* Linnaeus, 1758) stands out due to its significant economic importance, rapid growth rate, and wide global distribution, with annual production exceeding 4 million tonnes (FAO 2020). Recent studies have demonstrated that this species can ingest MPs and accumulate them in various tissues, primarily in the gastrointestinal tract; however, particles have also been detected in internal organs and muscle tissue, which raises potential implications for food safety (Aryani et al. 2021a, Martinez-Tavera et al. 2021).

Despite increased research on plastic contamination in fish, information on the sources, characteristics, and biological effects of MPs in Nile tilapia (*O. niloticus*) aquaculture remains fragmented and disparate. Consequently, this systematic review aims to synthesize the available scientific evidence on the presence of MPs in tilapia, identifying the primary sources of contamination and the reported effects on this species.

Microplastics in the aquaculture environment

MP contamination is ubiquitous within aquaculture environments and the resulting products, exerting a significant impact on the sector. This situation is exacerbated because aquaculture activities depend directly upon natural water bodies with which they are inextricably linked (Belton & Azad 2012, Ren et al. 2019). Within this context, MPs can enter farming systems through various pathways-both external and those inherent to the production process itself-thereby elevating the exposure of aquatic organisms (Fig. 1).

Sources of microplastics in the aquaculture environment

Sources of MPs in aquaculture can be categorized into those introduced from the external environment, including rivers, marine systems, terrestrial runoff, and the atmosphere, and those originating from in situ aquaculture processes, such as the aging and wear of plastic fishing gear, feed, and the packaging of aquaculture products (Wu et al. 2023). Among external sources, fluvial inputs represent a particularly significant contribution. Kumar et al. (2021) indicate that these water bodies receive MPs derived from industrial wastewater, anthropogenic activities, treatment plants, and agricultural practices.

Notably, textile industry discharges are a primary source of synthetic fibers in riverine environments. Furthermore, domestic wastewater is a substantial source of MPs (Gündoğdu et al. 2018), as laundering synthetic garments releases thousands of plastic fibers. For instance, polyester fleece fabrics can release up to 7,360 fibers m^{-2} L^{-1} during a single wash cycle, while other synthetic fibers, such as acrylic and nylon, also contribute varying quantities (Carney-Almroth et al. 2018). These MPs reach river systems via domestic wastewater; despite processing at wastewater treatment plants (WWTPs), a significant volume of MPs evades capture and disperses into natural ecosystems (Sun et al. 2019). Recent estimates suggest that between 22.1 and 133 million MPs are discharged daily through treated effluent (Ziajahromi et al. 2021). Given that rivers are inextricably linked to marine and freshwater ecosystems, MP pollution in these water bodies profoundly impacts aquaculture. Consequently, rivers must be recognized as a major vector of MP contamination for the sector.

Internal sources and management practices

Within the aquaculture sector, the production process itself serves as a direct source of contamination. The wear and tear and fragmentation of netting, buoys, ropes, pipes, feeders, and other ancillary plastic equipment, alongside the handling of supplies, feed, and packaging, result in a chronic release of MPs into culture systems. Several studies have demonstrated the presence of plastic particles of varying dimensions within aquaculture facilities and in the feed supplied to farmed organisms (Hanachi et al. 2019, Thiele et al. 2021). Multiple entry points for these residues have been identified, including infrastructure deterioration, the use of fishmeal, and the intake water used in production units (Cole et al. 2011, Hanachi et al. 2019, Thiele et al. 2021). The lack of rigorous biosecurity and hygiene protocols during various operations exacerbates this issue, posing a sustained risk to farmed species.

Research conducted in culture ponds confirms that suboptimal adherence to Best Management Practices (BMPs) contributes to elevated levels of plastic pollutants (Cai et al. 2013, Xu et al. 2022). This situation is exacerbated by the ongoing proliferation of plastic waste from human activities, which enters aquatic ecosystems and subsequently aquaculture systems through various effluents. Nonetheless, as aquaculture remains essential for global food security,

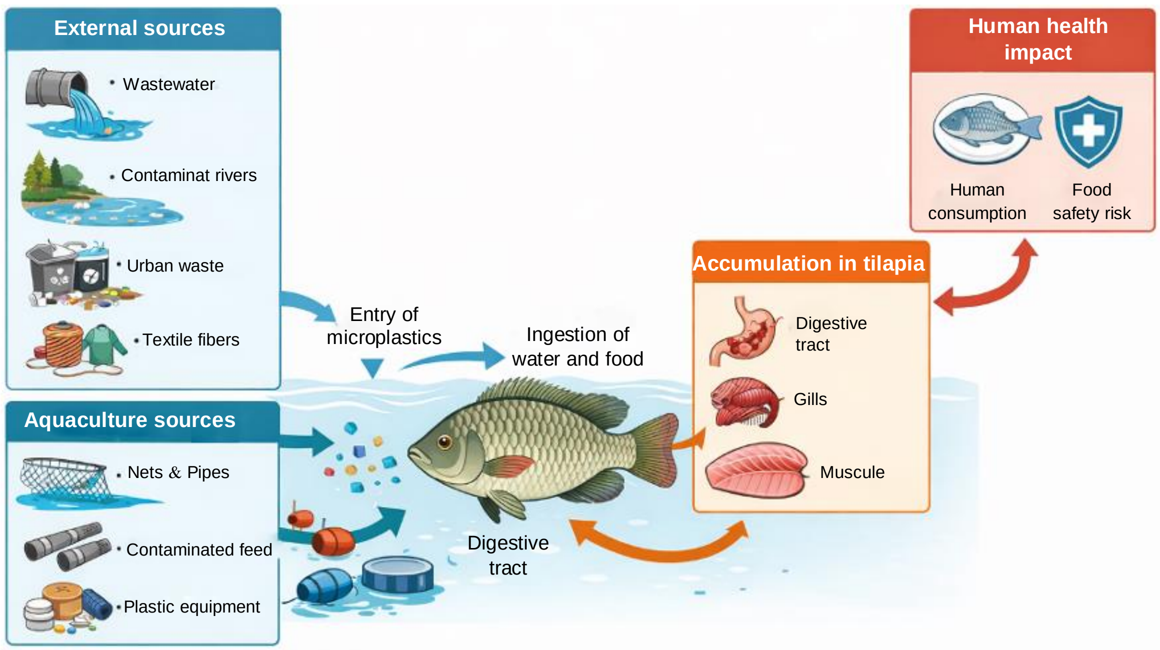

Figure 1. Entry routes and accumulation of microplastics in Nile tilapia (*Oreochromis niloticus*) aquaculture.

it is imperative to implement mitigation strategies that reduce MP prevalence and bolster the sector's sustainability.

Equipment degradation as a source of microplastics

Other studies indicate that a wide array of infrastructure and equipment used in aquaculture facilities, including tanks, netting, buoys, pipes, hoses, aerators, feed bags, and handling tools, is prone to degradation through exposure to weathering and ultraviolet (UV) radiation, leading to the generation of MPs. Furthermore, facility maintenance and the frequent use of ropes, brushes, nets, and similar implements can release additional plastic fibers (Song et al. 2017), aligning with the findings of the FAO (2018), which warns that aquaculture gear, particularly within cage systems, inevitably introduces MPs due to prolonged immersion, wear and tear, and mechanical abrasion between materials such as nets, lines, and buoys. Similarly, Wright et al. (2021) estimate that ropes and braided filaments, widely used in aquaculture, can contain significant volumes of plastic, while Jorquera et al. (2022) link salmonid production to the release of MPs from feed bags, ropes, and floating polymers. Overall, the evidence suggests that most MPs associated with aquaculture originate from the structural breakdown of materials and equipment throughout the production cycle.

Microplastics in aquaculture feeds

Fish feed is a critical determinant of the efficacy of aquaculture operations. For intensive farming systems, a consistent supply of feeds formulated with precise nutritional profiles is essential (Muhib & Rahman 2023). Feed typically accounts for 60-80% of total production costs for tilapia; consequently, high prices and limited accessibility represent formidable challenges for fish farmers (Ragasa et al. 2022). Despite these constraints, feed remains a fundamental component, though manufacturers frequently face limitations regarding the quality of raw materials. In many instances, producers utilize low-value or discarded fish to manufacture fishmeal (Devi et al. 2024). Such fishmeal often originates from by-catch, discarded individuals, or processing waste and serves as a primary protein source (Cashion et al. 2017). Furthermore, microplastics can be introduced into Nile tilapia (*O. niloticus*) and other species through the inclusion of contaminated dried marine fish (Muhib & Rahman 2023), which represents a substantial proportion of the ingredients in commercial formulations (Hasan et al. 2022, Piyawardhana et al. 2022, Siddique et al. 2023).

Fishmeal represents a significant vector for MPs that may be incorporated into animal feed during formulation (Thiele et al. 2021, Yao et al. 2021). The presence of MPs has been documented in fishmeal, with concentrations of approximately polystyrene, highly oxidized polyolefins, and polyester (Castelvetro et al. 2021). Similarly, Hanachi et al. (2019) detected MPs in four distinct types of fishmeal and identified a positive correlation between MP content in the meal and levels detected in carp (Cyprinidae) farms.

It is posited that most MPs in fish feed originate from multiple vectors, including manufacturing plants and the transport and storage stages of raw materials (Yao et al. 2021, Siddique et al. 2023, Devi et al. 2024). Additionally, the deterioration of plastic components in processing machinery can release particles, while airborne plastic dust may precipitate onto ingredients. In aquaculture, the formulation of commercial feed involves blending various components to meet specific protein, lipid, and carbohydrate requirements (Craig & Helfrich 2017). These proportions vary according to the species and their developmental stage, specifically the starter, grower, or finisher (grow-out) phases. Finally, the consumption of MP-contaminated feed poses significant risks to both organism health and human safety as these particles bioconcentrate through the food chain (Devi et al. 2024).

Effects of microplastics on Nile tilapia

O. niloticus is widely distributed across rivers, lakes, estuaries, and large-scale culture ponds. Although capable of surviving in salinities up to 35, its optimal development occurs at values close to 29. As an omnivorous species, its diet comprises algae, diatoms, insect larvae, fish eggs, detritus, and fry (Idodo-Umeh 2003). However, this species is increasingly exposed to emerging anthropogenic pollutants associated with rapid industrialization and urbanization (Martinez-Tavera et al. 2021). In aquaculture systems, *O. niloticus* reaches sexual maturity between five and six months of age. Production is conducted through various grow-out techniques (ponds, floating cages, and recirculating aquaculture systems), characterized by the use of formulated diets with balanced protein, lipid, carbohydrate, vitamin, and mineral content; ingredients such as soya or fishmeal constitute the primary basis of these balanced feeds (FAO 2009).

The impact of MPs on aquatic organisms remains a subject of intense debate, regarding both their ecological consequences and their implications for human health. Some authors have suggested that MPs accumulate and are sequestered exclusively within the digestive tract of fish, which would theoretically limit the risk to consumers of species typically ingested whole (Lusher et al. 2017, COFI 2018). However, research such as that by Aryani et al. (2021a) demonstrates the contrary. In an experimental aquarium setting, juvenile tilapia exposed to polyethylene (PE) exhibited the bioaccumulation of MPs in the blood, gills, gonads, intestines, kidneys, stomach, and muscle tissue, suggesting that juvenile tilapia may experience systemic exposure to MPs, as these particles enter and are distributed via the bloodstream. The high concentrations of MPs detected, particularly in juvenile and grow-out fish, underscore the susceptibility of *O. niloticus* to this contaminant. Despite the essential role of tilapia in global human protein intake, studies addressing the effects and sources of MPs in tilapia aquaculture remain scarce. Table 1 summarises the recorded presence of MPs in Nile tilapia. The data presented herein may be constrained by the existing knowledge gap concerning the physiological responses of organisms to MPs within tilapia aquaculture systems (Cole et al. 2015, Lyu et al. 2020).

METODOLOGY OF ANALYSES

A systematic literature review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (Page et al. 2021) to identify studies concerning the presence, sources, and effects of MPs in *O. niloticus* aquaculture. The literature search was performed for the period 2016-2025 across international scientific databases, including Scopus, SpringerLink, ResearchGate, and Google Scholar, selected for their extensive coverage of environmental sciences, aquaculture, and toxicology.

The search strategy was designed to maximize the identification of relevant studies on microplastics in tilapia. Keyword combinations-including "microplastics", "tilapia", "*Oreochromis niloticus*", "aquaculture", "ponds", "freshwater pollution", "flesh", and "environmental contamination"-were employed using Boolean AND/OR operators. Search strings were tailored to the specific syntax of each database:

- Scopus: ("microplastics" OR "plastic pollution" OR "microplastic contamination") AND ("tilapia" OR "*Oreochromis niloticus*") AND ("aquaculture" OR "fish farming" OR "freshwater") AND (NOT "marine");
- SpringerLink: ("microplastics" AND "tilapia") OR ("microplastic contamination" AND "*Oreochromis niloticus*") OR ("ponds" AND "aquaculture");
- Google Scholar: "microplastics" AND ("tilapia" OR "*Oreochromis niloticus*") AND ("aquaculture" OR "tilapia" OR "flesh");
- ResearchGate: ("microplastics" AND "tilapia") AND ("freshwater" OR "aquaculture").

Table 1. Evaluation of the methodological quality and risk of bias of the included studies using a Likert scale.

Reference	Journal	Likert score
Biginagwa et al. (2016)	Journal of Great Lakes Research	4
Ding et al. (2018)	Environmental Pollution	5
Adeogun et al. (2020)	Challenges in Emerging Environmental Contaminants	1
Khan et al. (2020)	Toxics	3
Merga et al. (2020)	Science of The Total Environment	5
Tien et al. (2020)	Environmental Pollution	5
García et al. (2021)	Environmental Science and Pollution Research	4
Aryani et al. (2021b)	IOP Conference Series: Earth and Environmental Science	2
Al-Fatih (2021)	International Journal of Environmental Science and Technology	4
Lestari et al. (2021)	IOP Conference Series: Materials Science and Engineering	2
Martínez-Tavera et al. (2021)	Chemosphere	5
Oliva et al. (2021)	Revista Ambiente & Agua	3
Yusuf & Tahir (2021)	International Journal of Scientific and Research Publications	1
Dehm et al. (2022)	Environmental Monitoring and Assessment	4
Mai et al. (2022)	Vietnam Journal of Science and Technology	2
Zhou et al. (2022)	Environmental Engineering Research	3
Garcés-Ordóñez et al. (2022)	Science of The Total Environment	5
Hu et al. (2023)	Science of The Total Environment	5
Espiritu et al. (2023)	Marine Pollution Bulletin	5
Sefiloglu et al. (2024)	Environmental Sciences Europe	4
Muhib & Rahman (2024)	Environmental Science and Pollution Research	4
Siddique et al. (2024)	Ecological Indicators	5
Hapal et al. (2024)	AACL Bioflux	2
Lina (2024)	International Journal of Scientific Research	1
Aunurohim et al. (2024)	Environmental Advances	3
Demsie & Yimer (2024)	Environmental Science and Pollution Research	4
Wangboje & Adeghor (2024)	European Journal of Science, Innovation and Technology	1
Samuel et al. (2024)	Journal of Applied Life Sciences International	1
Kolandhasamy et al. (2025)	Fish Physiology and Biochemistry	3
Deswati et al. (2025a)	Journal of Ecological Engineering	2
Deswati et al. (2025b)	EKSakta	1
Dibaratun & Nabua (2025)	International Journal of Research and Innovation in Social Science	1
Manon et al. (2026)	Aquaculture	5

Studies were prioritized based on methodological clarity and the inclusion of impact assessments.

Inclusion and exclusion criteria

Studies were selected based on the following pre-defined criteria:

Inclusion criteria:

- Empirical research evaluating the presence, concentration, sources, or impacts of MPs in *O. niloticus*.
- Studies conducted within freshwater environments or aquaculture systems.
- Peer-reviewed articles published between 2016 and 2025.
- Publications in English or Spanish with available full-text access.

Exclusion criteria:

- Studies lacking empirical data (e.g. commentaries or editorials).
- Research focused exclusively on other aquatic species.
- Studies focusing solely on macroplastics (>5 mm).
- Articles where the full text was unavailable.
- Studies conducted exclusively in marine environments, with no relevance to freshwater tilapia systems.

Selection process

The identification, screening, eligibility, and inclusion phases were documented using a PRISMA flowchart (Fig. 2).

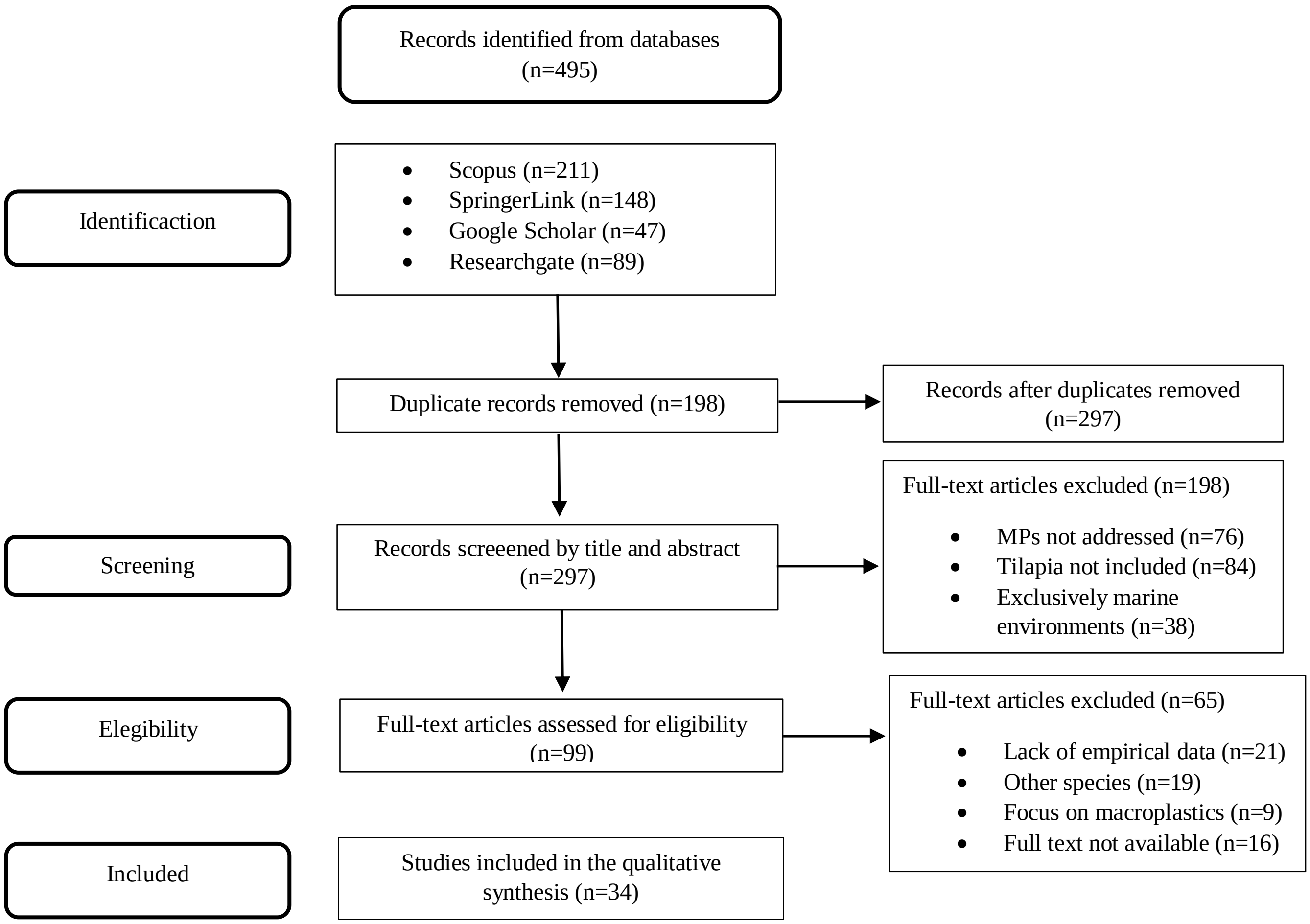

Figure 2. PRISMA 2020 flow diagram illustrating the identification, screening, eligibility, and inclusion process for the systematic review on microplastic (MP) contamination in Nile tilapia (*Oreochromis niloticus*) aquaculture.

Initially, 495 records were identified across the databases (Scopus: 211; SpringerLink: 148; Google Scholar: 47; ResearchGate: 89). After removing 199 duplicates, 296 records remained for initial screening of titles and abstracts. During this phase, 198 studies were excluded for failing to meet the inclusion criteria: not addressing MPs, excluding tilapia, or focusing exclusively on marine environments. Subsequently, 98 articles underwent full-text assessment. Of these, 65 studies were excluded due to a lack of empirical data, a focus on non-target species, analysis centered on macroplastics, or restricted full-text access. Finally, 33 studies met the eligibility criteria and were included in the qualitative synthesis.

Data extraction and analysis

For each selected study, data were extracted regarding: authorship, year of publication, geographic location, type of aquaculture system, sources and types of MPs, analytical identification methods, contamination levels, and reported biological effects on *O. niloticus*. Data extraction was performed independently by two reviewers; any discrepancies were resolved through discussion and consensus to ensure methodological consistency.

Methodological quality assessment: Likert scale

To assess the methodological rigor and potential risk of bias within the primary studies, a five-level Likert scale (Likert 1932) was developed and applied based on the editorial quality of the scientific journal in which each study was published. This approach facilitates a proxy estimation of the robustness of the editorial process, the rigor of peer review, and the reliability of findings using verifiable bibliometric indicators (Sarthou 2016, Rivero-Macias 2019).

Journal quality was evaluated using validated data from recognized databases, including Journal Citation Reports (JCR), Scopus (CiteScore), and SCImago Journal Rank (SJR). The Likert classification was defined by the following criteria: indexing status (JCR, Scopus, or non-indexed); impact factor (IF), where higher values reflect greater editorial rigor; CiteScore as an indicator of scientific visibility; and the journal quartile (Q1-Q4).

The Likert scale was interpreted as follows:

5 = Very high methodological quality (e.g. Q1 JCR journals).

4 = High quality.

3 = Medium quality.

2 = Low quality.

1 = Very low quality.

Each study was assigned to a category based on the bibliometric performance of the source journal, ensuring the risk-of-bias assessment was grounded in the publisher's established quality. The final Likert scores for each study are presented in Table 1.

The methodological quality analysis demonstrates that most included studies were published in journals indexed in Scopus or JCR, indicating a predominance of medium-to-high-quality evidence. A considerable number of studies achieved Likert scores of 4 and 5, corresponding to Q1-Q2 journals with established peer-review processes and robust analytical methodologies, thereby supporting the reliability of the results synthesized in this review. Conversely, some studies with scores of 2 and 3 were associated with journals of lower visibility or limited indexing, suggesting a potential risk of methodological bias and necessitating cautious interpretation of their findings.

Overall, the convergence of findings across studies of varying editorial quality reinforces the consistency of the available evidence. Nevertheless, it highlights the imperative to promote future research employing standardized methodologies, greater analytical transparency, and comparable protocols to mitigate the risk of bias and strengthen the scientific foundation regarding the presence and effects of MPs in *O. niloticus*.

Methodological quality of the included studies

The assessment of methodological quality using the Likert scale revealed a heterogeneous distribution in terms of editorial rigor and methodological soundness. The majority of studies fall within the medium-to-high quality categories, indicating that a substantial proportion of the evidence was published in indexed journals with rigorous peer-review frameworks.

A significant number of studies obtained scores of 4 and 5, reflecting high bibliometric visibility, which bolsters the overall reliability of the reported results. These studies typically employ more robust analytical methodologies, including confirmatory techniques such as Fourier Transform Infrared (FTIR) or Raman spectroscopy, and provide a more critical discussion of their limitations. However, the presence of studies classified as low or medium quality suggests a potential risk of bias that must be considered during data synthesis. Ultimately, the alignment of results across disparate editorial tiers indicates that MP contamination in tilapia is a consistent and widely documented phenomenon. However, methodological variability underscores the necessity for standardized analytical protocols in future research.

The 33 studies included in this systematic review demonstrate that MPs have been documented in *O. niloticus* across diverse geographic and production contexts, including natural ecosystems, aquaculture systems, and experimental conditions. The gathered evidence reveals that species exposure is consistent on a global scale, albeit with variations linked to the system type, contamination sources, and the methodologies employed. To facilitate a comparison of findings and identify general trends, Table 2 summarises the primary characteristics of the included studies, including geographic location, aquaculture system type, tissues analyzed, predominant polymers, identification techniques, sources, and reported effects.

Based on the synthesis presented in Table 2, it is evident that the presence of MPs in tilapia is consistent across natural, aquaculture, and experimental systems, indicating that species exposure is widespread rather than isolated.

DISCUSSION OF RESULTS

Microplastic presence according to system type

Initial reports from African lakes demonstrated the presence of MPs in tilapia associated with urban waste, providing early evidence of species exposure in freshwater ecosystems (Biginagwa et al. 2016). Similar findings were observed in Ethiopia, where fibers and fragments derived from domestic waste were identified in Lake Ziway (Merga et al. 2020), and subsequently in Lake Hawassa, where a high prevalence was linked to

Table 2. Summary of presence, sources, and biological effects of microplastics (MPs) in *Oreochromis niloticus* aquaculture. FTIR: Fourier transform infrared spectroscopy, ATR-FTIR: attenuated total reflectance Fourier transform infrared spectroscopy, EVA: ethylene-vinyl acetate, HDPE: high-density polyethylene, LDPE: low-density polyethylene, PS: polystyrene, NY: nylon, PA polyamide, PE: polyethylene, PES: polyester, PET: polyethylene terephthalate, PMMA: polymethyl methacrylate, PP: polypropylene, PU: polyurethane, PVA: polyvinyl acetate, PVC: polyvinyl chloride, RY: rayon, SC: synthetic cellulose, PO: olefins, PAC: acrylics, GC: gas chromatography, MS: mass spectrometry.

Country /Region	Aquaculture system type	Tissue type	MPs ind^{-1}	MPs g^{-1}	Frequency of occurrence (5)	Shape	Dominant colours	Predominant polymer	Digestion protocols	Identification methods	Identified sources	Reported biological effects	Reference
Tanzania	Lake	Gastrointestinal tract	4	-	35%	-	-	PE, PU, PES, PE/PP, copolymer and silicone rubber	NaOH	ATR-FTIR	Urban waste	Alterations in digestive physiology or deleterious effects	Biginagwa et al. (2016)
China	Experimental aquarium	Intestine, gills, liver, brain	-	-	100%	Espheres	Green	PS	Conventional chemical digestion was not applied; fluorescent microspheres were utilized for direct tissue tracking.	Fluorescence stereomicroscope	Commercial polystyrene microbeads	Neurometabolic effects / Impact on the nervous system and metabolism	Ding et al. (2018)
Nigeria	Lagoon	Gastrointestinal tract	1-6		34%	-	-	Polymer identification not performed.	NaCl H_2O_2	Fluorescence stereomicroscope	Municipal water supply	Vectors for pathogen and environmental pollutant transfer	Adeogun et al. (2020)
Egypt	River	Gastrointestinal tract	7.5 ± 4.9	-	75.9%	Fibers, fragments, films, pellets, foams	Blue	PE, PET, PP	NaOH	ATR-FTIR	Anthropogenic activity	Entry into the human food chain	Khan et al. (2020)
Ethiopia	Lake	Gastrointestinal tract	-	-	22%	Fragments, fibers	Blue. white	PE, PP, AV	KOH	ATR-FTIR	Domestic waste	Entry into the human food chain	Merga et al. (2020)
Taiwan	River	Gastrointestinal tract	46	-	-	-	-	-	H_2O_2 digestión	FTIR	Anthropogenic activity	Pollutant vector	Tien et al. (2020)
Colombia	Aquaculture ponds	Gastrointestinal tract, gills, muscle	2.1 ± 1.26	-	44%	Fragments	-	PET, PES, PE	H_2O_2 digestión	μFTIR	*In situ* plastic infrastructure (nets, pipes, equipment)	Entry into the human food chain	Garcia et al. (2021)

Continuation

Country /Region	Aquaculture system type	Tissue type	MPs ind^{-1}	MPs g^{-1}	Frequency of occurrence (5)	Shape	Dominant colours	Predominant polymer	Digestion protocols	Identification methods	Identified sources	Reported biological effects	Reference
Indonesia	Experimental aquarium	Blood, gills, gonads, intestine, liver, muscle, stomach.	-	-	-	-	-	-	KOH at 10% H_2O_2 at 30%	Light microscope	Direct exposure	Environmental impact and threat to food security. Threat to fish survival / Reduced survival rates	Aryani et al. (2021b)
Indonesia	River/Floating cages	Gastrointestinal tract	970 maximum	-	-	Fragments, fibers, filaments	-	-	H_2O_2	Stereomicroscope	Contaminated water body	Entry into the human food chain	Al-Fatih (2021)
Indonesia	River	Gastrointestinal tract, gills	155,50 ± 61,96	Gastrointestinal tract 265.71 ± 133.34 gills 303.59 ± 293.09	-	Fibers, films	Transparent, blank, blue, red.	-	H_2O_2	Dissecting microscope	Contaminated water body	Potential ecotoxicological risk	Lestari et al. (2021)
Mexico	Reservoir-based aquaculture	Gastrointestinal tract	-	-	53.67%	Fibers,	Black, blue, red, white.	SC, PES, PA	KOH	μFTIR	Industrial, municipal and urban activities	Human health risks	Martinez-Tavera et al. (2021)
Guatemala	Lake	Gastrointestinal tract	9.71	-	96.92%	Lines, fibers	-	-	NaOH	Unidentified polymer	Wastewater discharges and anthropogenic activity	Risk of consumers	Oliva et al. (2021)
Indonesia	Lake	Gastrointestinal tract	7.8	-	-	Fibers y fragments	Blue, black, red, transparent	Polymer identification not performed	KOH	Stereomicroscopy	Anthropogenic activity	Entry into the human food chain	Yusuf & Tahir (2021)
Fiji	Aquaculture ponds	Gastrointestinal tract	2.7 ± 1.4	-	90%	Fibers	-	PP, PU, PVA, NY	KOH	ATR-FTIR	*In situ* plastic infrastructure (nets, pipes, equipment).	Bioaccumulation and trophic transfer	Dehm et al. (2022)
Vietnam	Aquaculture ponds	Gastrointestinal tract		0.6	100%	-	-	PE, PET, PP/PE, PET, PP, NY	H_2O_2	μFTIR	*In situ* plastic infrastructure (nets, pipes, equipment).	Chemical vector and food chain transfer	Mai, Thi, et al. (2022)

Continuation

Country /Region	Aquaculture system type	Tissue type	MPs ind^{-1}	MPs g^{-1}	Frequency of occurrence (5)	Shape	Dominant colours	Predominant polymer	Digestion protocols	Identification methods	Identified sources	Reported biological effects	Reference
China	Aquaculture ponds	Gastrointestinal tract, gills	10,01	-	87,50%	Fibers	blue	Olefins, acrylics, rayons, polyester, polyethylene, and polypropylene	-	Stereomicroscopy (photomicrographs)	Water column and commercial feed.	Intestinal damage, reproductive and behavioral alterations. Leaching of chemical additives (teratogenic and carcinogenic effects)	Zhou et al. (2022)
Colombia	Coastal Lagoon	Gastrointestinal tract	14	-	-	Fibers, fragments, films	White, transparent	PE, PP, HDPE	-	ATR-FTIR	Domestic sewage, fishing activities, infrastructure, and municipal solid waste.	Threat to lagoon ecosystems and artisanal fisheries' food security	Garcés-Ordóñez et al. (2022)
China	Biofloc systems	Liver, intestine, gills				Spheres	Green	PS	-	Stereomicroscopy	MPs introduced experimentally.	Nutritional composition (crude protein and lipids), hepatic accumulation.	Hu et al. (2023)
Philippines	River	Tracto gastrointestinal, gilis	0.3	-	80%	Fragments	-	PP, PE, PP/PE	KOH	Raman spectroscopy	Anthropogenic activity	Risk of trophic transfer, potential physiological impairment, and organismal stress	Espiritu et al. (2023)
Sweden	Recirculating Aquaculture Systems (RAS)	Muscle	0-3	0.14 ± 0.32	42%	-	Transparent, white and blue	PE, PP, PS y PMMA, PE y PS	KOH	Pyrolysis-GC-MS	RAS plastic components (tanks, pipes and biofilters).	Potential accumulation in edible tissue and food security risk	Sefiloglu et al. (2024)

Continuation

Country /Region	Aquaculture system type	Tissue type	MPs ind^{-1}	MPs g^{-1}	Frequency of occurrence (5)	Shape	Dominant colours	Predominant polymer	Digestion protocols	Identification methods	Identified sources	Reported biological effects	Reference
Bangladesh	Aquaculture ponds	Gastrointestinal tract, gills, muscle	12-46	0.8-3.5	100%	Fibers, fragments	Transparent, black, blue	PP y PET	H_2O_2	Microscopy and FTIR-ATR	Fragmentation of domestic and agricultural plastics	Feeding inhibition, growth retardation, and accumulation in the gut and liver	Muhib & Rahman (2024)
Bangladesh	Aquaculture ponds	Gastrointestinal tract	3-29	0.2-2.1	92-100%	Fibers, lines, fragments	Transparent, black, blue	PE, PP, PET	H_2O_2	Stereomicroscopy and FTIR	Aquaculture, agricultural, and domestic plastic waste from the surrounding farming environment	Internal organ accumulation, physiological stress in fish, and potential risk to human food security	Siddique et al. (2024)
Philippines	Aquaculture ponds	Gastrointestinal tract	35,44	-	35%	Fibers, fragments	White and black	Rayon and polyethylene	Physical separation and microscopic observation	Stereomicroscopy and FTIR	Pond plastic infrastructure and aquaculture inputs	Trophic transfer risk and contamination of aquaculture systems	Hapal et al. (2024)
Philippines	Reservoir - based aquaculture	Gastrointestinal tract	232	-	100%	Fibers, fragments, pellets, films	White, black, transparent, red, orange, green-blue.	PE, PES, PP, PA	H_2O_2 treatment with filtration and centrifugation	Optical microscopy	Synthetic clothing (textile laundering), fishing gear (nylon nets, lines), plastic bags, and packaging	Ecological risk: intestinal blockage, acute toxicity in fish, and bioaccumulation. Human risk: MP entry into the food chain and potential health impacts	Lina (2024)

Continuation

Country /Region	Aquaculture system type	Tissue type	MPs ind^{-1}	MPs g^{-1}	Frequency of occurrence (5)	Shape	Dominant colours	Predominant polymer	Digestion protocols	Identification methods	Identified sources	Reported biological effects	Reference
Indonesia	Floating cages	Muscle, gastro-intestinal tract	muscle 576 digestive tract 724	muscle0.46 digestive tract 0.58	100%	Fibers	Blue, black	PA, nylon	H_2O_2	Stereomicros-copy and FTIR	Degraded aquaculture netting and cordage	Direct risk to consum-ers and po-tential health im-pacts	Aunurohim et al. (2024)
Ethiopia	Lake	Gastrointestinal tract	-	-	86.66 %	Frag-ments, fi-bers,	White, yellow, transpar-ent, blue, black, green.	PS, PP, LDPE, HDPE, NY, PMMA, EVA	KOH	FTIR	Antropo-genic activ-ity	Entry into the human food chain	Demsie & Yimer (2024)
Nigeria	River	Gastrointestinal tract	0.67-2.50			Fragments Filaments Foams Pellets Fibers		PE	H_2O_2	FTIR	Not explic-itly speci-fied	Potential food secu-rity risk	Wangboje & Adeghor (2024)
Nigeria	Aquaculture ponds	Gastrointestinal tract	1.44 ± 0.7	-	-	Fibers, fragments, pellets, films	Blue, black, white, red, green	PE, PP	KOH	ATR-FTIR	Domestic discharges, mismanaged plastic waste, and local fishing activities	Potential risk to fish health and, by exten-sion, to hu-man food security	Samuel et al. (2024)
India	Estanques acuícolas	Gastrointestinal tract, gilis	PVC: 4,8 ± 2,7 gastrointestinal tract; 6,6 ± 2,07 gilis PE: 5,6 ± 2,6 gastrointestinal tract; 5,8 ± 0,84 gilis		100%	Fragments		PE, PVC	Controlled labora-tory chemical di-gestion (enzy-matic/chemical for MP release)	Microscopic ob-servation, histo-logical tissue analysis and oxi-dative enzyme assay.	Experi-mental die-tary expo-sure (MP-enriched feeding)	Growth re-duction and homeostatic alterations	Ko-landhasamy et al. (2025)
Indonesia	Biofloc systems	Digestive sys-tem, gills, mus-cle	0-9 particles ind^{-1}	0-0,25 particles g mus-cle^{-1}; up to 9 g intestines^{-1}	100%	Fragments and fibers	Transpar-ent, black, blue	PE, PA, PET	NaCl solution (density separa-tion)	ATR-FTIR	Plastic de-bris in bio-flocs, exper-imental in-put	High eco-logical risk (PLI 1.386-2.038; PHI >120,000); MP-free bi-ofloc re-duces risk	Deswati et al. (2025a)

Continuation

Country /Region	Aquaculture system type	Tissue type	MPs ind^{-1}	MPs g^{-1}	Frequency of occurrence (5)	Shape	Dominant colours	Predominant polymer	Digestion protocols	Identification methods	Identified sources	Reported biological effects	Reference
Indonesia	Biofloc systems	Digestive system, gills, muscle	Maximum accumulation in the esophagus: 39.2 ± 6.87 particles/g	Intestines: 8.08 ± 0.15; esophagus: 10.4 ± 0.12 (Treat. A); flesh: 3.86 ± 0.28; gills: 4.96 ± 0.14	-	Fragments and fibers	White, black	PE, PVC, PA	Biofloc system with heterotrophic bacteria (*Bacillus* spp., *Pseudomonas* spp.) for MP degradation; organ analysis post-exposure	ATR-FTIR	Aquaculture equipment (PVC hoses, nets, feed pellets), and external environmental pollution	Oesophageal accumulation via mucosal retention; medium-to-high ecological risk (PHI = 166.69, PLI = 1.01-1.66, PERI = 21.49); digestive alterations and potential toxicity	Deswati et al. (2025b)
Philippines	Lake	Gastrointestinal tract	21 MPs in 18 tilapias (~1.17 MPs $fish^{-1}$)	-	-	Films and fibers	-	PE, PP, PET, Nylon	KOH	Stereomicroscopy and FTIR	Synthetic textiles, plastic packaging, fishing nets, and domestic wastewater	Ecological risks (impact on fish health, water quality degradation) and potential human risks (oxidative stress, DNA damage, and metabolic disorders)	Dibaratun & Nabua (2025)
Bangladesh	Aquaculture ponds	Gills, gastrointestinal tract, muscle	-	-	100%	Fibers	black	PE (followed by PES and PP)	KOH H_2O_2	FTIR	Culture water, commercial feed, and deteriorated equipment and facilities	Internal abrasions, obstructions, behavioral impairments, nutrient malabsorption, reproductive failure, and risk of trophic transfer	Manon et al. (2026)

intensive anthropogenic activities (Demsie & Yimer 2024).

In Indonesia, lacustrine studies confirmed the presence of fibers and fragments associated with direct human activity, reinforcing the premise that lentic water bodies act as sinks for plastic pollution (Yusuf & Tahir 2021). In the Philippines, recent research in lakes documented MPs linked to textiles, packaging, and fishing nets, demonstrating the combined influence of domestic and artisanal fishing sources (Dibaratun & Nabua 2025).

In Latin America, Lake Amatitlán in Guatemala showed a high prevalence of MPs, confirming the accumulation of particles in urban reservoirs (Oliva-Hernández et al. 2021). In Mexico, evidence from inland systems used for aquaculture suggests significant exposure; in a reservoir associated with industrial, municipal, and urban activities, a high prevalence of MPs was reported in tilapia, with a predominance of fibers and dark coloration. Polymers such as synthetic cellulose, polyester, and polyamide were identified by μFTIR, reinforcing concerns about their potential as emerging contaminants with implications for human health and product safety (Martinez-Tavera et al. 2021). Similarly, the Ciénaga Grande de Santa Marta in Colombia exhibited the presence of PE and PP associated with domestic wastewater discharges, fishing activities, and aquaculture infrastructure (Garcés-Ordóñez et al. 2022).

In lotic systems, tilapia is exposed to MPs transported by currents and effluent discharges. In Egypt, the Nile River exhibited a high diversity of particles associated with human activities (Khan et al. 2020). In contrast, in Taiwan, the Fengshan River showed concentrations associated with urban pressure (Tien et al. 2020). Indonesian studies in urban rivers reported high abundances and morphological diversity, indicating persistent aqueous pollution (Al-Fatih 2021, Lestari et al. 2021).

In the Philippines, riverine studies detected fragments dominated by PE and PP linked to anthropogenic activities (Espiritu et al. 2023). In West Africa, research in Nigerian rivers confirmed the presence of MPs associated with domestic waste and fishing activities (Samuel et al. 2024, Wangboje & Adeghor 2024). Furthermore, in Nigerian urban lagoons, MPs have been reported to act as vectors for pollutants and pathogens, reinforcing their ecological relevance (Adeogun et al. 2020).

In aquaculture systems, evidence indicates that MP contamination does not stem exclusively from the external environment. In Colombia, polymers derived from nets, pipes, and equipment were detected, demonstrating that aquaculture infrastructure can act as a significant secondary source (Garcia et al. 2021). Similar results were observed in Fiji, where identified polymers were directly associated with materials from the culture facilities (Dehm et al. 2022).

In Asia, studies in ponds across Vietnam and China confirmed the influence of both feed and the water column on MP prevalence (Mai et al. 2022, Zhou et al. 2022). Research in Bangladesh has shown that domestic and agricultural waste contribute to the accumulation of MPs in farmed fish, leading to physiological effects and potential food safety risks (Siddique et al. 2023, Muhib & Rahman 2024, Siddique et al. 2024). In the Philippines, studies in ponds and reservoirs reported high abundances linked to textiles, packaging, and fishing gear (Hapal et al. 2024, Lina 2024).

Recent investigations in Bangladesh have confirmed the widespread presence of MPs in ponds, with a predominance of PE and polyester fibers associated with culture water, feed, and infrastructure, indicating a potential risk to human health (Manon et al. 2026). In recirculating aquaculture systems (RAS), MPs were detected in tilapia muscle, confirming that even in controlled environments, contamination can occur.

In RAS, MPs were detected within the muscle tissue of tilapia, suggesting that system components may contribute to contamination and pose a direct risk to consumers (Sefiloglu et al. 2024). In Indonesia, research conducted in floating net cages confirmed the accumulation of substances associated with nylon nets and ropes, indicating the influence of aquaculture infrastructure (Aunurohim et al. 2024).

Analyzed organs and associated biological effects

Experimental studies provide evidence regarding ingestion mechanisms and biological impacts. Trials using fluorescent microspheres demonstrated their internal distribution, along with neurological and metabolic effects (Ding et al. 2018). Subsequent investigations evidenced accumulation across multiple tissues, including blood, gills, gonads, intestines, liver, muscle, and stomach, suggesting risks to fish survival (Aryani et al. 2021a). In experimental biofloc systems, hepatic accumulation and nutritional alterations were observed (Hu et al. 2023). Other trials demonstrated reduced growth performance and homeostatic disruptions following dietary exposure to MPs (Kolandhasamy et al. 2025).

Recent investigations into biofloc technology (BFT) indicated that microbiological management may reduce both accumulation and the ecological risk associated with MPs, suggesting a potential mitigation approach for aquaculture (Deswati et al. 2025a,b).

Microplastic types and predominant polymers

Studies consistently identify a predominance of fibers and fragments, pointing towards synthetic textiles, netting, and urban waste as primary sources. The most frequent polymers identified include PE, polypropylene (PP), and PET materials commonly utilized in packaging and consumer goods, indicating that contamination levels mirror global plastic production and usage trends.

Nevertheless, this review also highlights significant methodological limitations. Most studies employ disparate reporting units, digestion protocols, and identification methods, which hinder direct comparison. Furthermore, most research focuses on the gastrointestinal tract, while few evaluate edible tissues or chronic effects, thereby limiting the assessment of the actual risk to the consumer.

Practical implications for aquaculture management

Drawing upon the findings of the synthesized research, the following technical measures are proposed to mitigate the prevalence and transfer of MPs within tilapia aquaculture systems:

a) Phased replacement of plastic infrastructure: the gradual implementation of netting, ropes, and structural components manufactured from alternative materials with superior abrasion resistance, or stabilized recycled polymers, is recommended to reduce the chronic release of fibers and fragments during operational activities. Furthermore, using thicker geomembranes or high-durability protective coatings can significantly reduce mechanical fragmentation.

b) Water supply contamination control: aquaculture systems utilizing surface water should incorporate fine physical filtration stages or prolonged sedimentation before system entry, particularly in regions subject to high urban or industrial pressure. In RAS, integrating fine-mesh or drum filters, supported by rigorous periodic maintenance, is essential.

c) Feed assessment as a contamination vector: given evidence of MPs in formulated diets, implementing quality control protocols is recommended. These should include periodic feed analysis via FTIR or Raman spectroscopy, especially when utilizing recycled ingredients or industrial by-products.

d) BFT as a mitigation strategy: experimental studies indicate that well-managed biofloc systems can facilitate particle sedimentation or retention. It is recommended to optimize the carbon-to-nitrogen ratio, maintain adequate aeration, and conduct controlled sediment flushing to reduce MP accumulation within the culture environment.

e) Systematic monitoring of farmed fish: the periodic evaluation of MPs in tissues, specifically muscle, the gastrointestinal tract, and gills, should be incorporated into aquaculture biosecurity and safety programs. Such monitoring enables the early detection of contamination sources and facilitates necessary adjustments to production protocols.

f) Plastic waste management in production units: robust internal protocols must be established for the collection, storage, and appropriate disposal of damaged netting, packaging, and other plastic inputs to prevent in situ fragmentation or environmental release.

In the scientific domain, it is imperative to promote research employing robust and comparable methodologies focused on trophic transfer, long-term sublethal effects, and accumulation in edible tissues. Finally, environmental and health authorities should integrate MP management into aquaculture regulations and standardized benchmarks to ensure product safety and the long-term sustainability of the sector.

CONCLUSIONS

The evidence synthesized in this review demonstrates that MP contamination in *O. niloticus* aquaculture is a widespread and consistent issue across different countries, systems, and culture conditions. Particles, primarily fibers and fragments, originate from both external sources-such as domestic discharge, urban waste, and industrial activity-and the aquaculture process itself, including the attrition of nets, pipes, ropes, and equipment. Tilapia are highly susceptible to exposure, with confirmed MP presence in the gastrointestinal tract, gills, liver, and, in several studies, muscle tissue; this implies a potential public health risk and suggests active bioaccumulation.

Furthermore, experimental and field studies report physiological effects encompassing intestinal damage, oxidative stress, metabolic alterations, and potential reproductive repercussions, indicating that MPs may compromise fish health and productive performance. Although the methodological quality of the evaluated studies was heterogeneous, research published in high-impact journals concurs that MPs are an emerging contaminant of increasing relevance within aquaculture, requiring immediate action to mitigate their presence and associated effects.

Credit author contribution

E.F. Castillo-Márquez: conceptualization, methodology, formal analysis and writing-original draft; B. Ortiz-Muñiz: funding acquisition, project administration, conceptualization, supervision, validation, review and editing; M.R. Castañeda-Chávez: methodology, validation, supervision; F. Lango Reynoso: methodology, data curation and formal analysis; O.P. Castellanos Onorio: methodology and review; I. Galaviz-Villa: review; D.G. Mendoza López: formal analysis, data curation and review. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support provided by the TecNM (Project 21974.25-P) and the SECIHTI grant (4001712).

REFERENCES

Adeogun, A.O., Ibor, O.R., Khan, E.A., et al. 2020. Detection and occurrence of microplastics in the stomach of commercial fish species from a municipal water supply lake in southwestern Nigeria. Environmental Science and Pollution Research, 27: 31035-31045. doi: 10.1007/s11356-020-09031-5

Al-Fatih, A.N.F. 2021. Identifikasi mikroplastik pada sistem pencernaan ikan Nila (*Oreochromis niloticus*) di Kali Pelayaran Kabupaten Sidoarjo. Environmental Pollution Journal, 1: 3. doi: 10.58954/epj.v1i3.63

Ankita, 2025. Microplastics: Current status in the environment and human health risks: a comprehensive review. International Journal of Environmental Sciences, 11: 426-438. doi: 10.64252/wn613j96

Aryani, D., Khalifa, M.A., Herjayanto, M., et al. 2021a. Correlation of water quality with microplastic exposure prevalence in tilapia (*Oreochromis niloticus*). E3S Web of Conferences, 324: 03008. doi: 10.1051/e3sconf/202132403008

Aryani, D., Khalifa, M.A., Herjayanto, M., et al. 2021b. Penetration of microplastics (polyethylene) to several organs of Nile tilapia (*Oreochromis niloticus*). IOP Conference Series: Earth and Environmental Science, 715: 012061. doi: 10.1088/1755-1315/715/1/012061

Aunurohim, A., Raufanda, M.S., Saptarini, D., et al. 2024. Microplastic contamination in the flesh and gastrointestinal tract of Nile tilapia (*Oreochromis niloticus*) reared in floating net cages at Lake Ranu Grati, Pasuruan, East Java, Indonesia. Environmental Advances, 17: 100587. doi: 10.1016/j.envadv.2024.100587

Belton, B. & Azad, A. 2012. The characteristics and status of pond aquaculture in Bangladesh. Aquaculture, 358-359: 196-204. doi: 10.1016/j.aquaculture.2012.07.002

Biginagwa, F.J., Mayoma, B.S., Shashoua, Y., et al. 2016. First evidence of microplastics in the African Great Lakes: Recovery from Lake Victoria Nile perch and Nile tilapia. Journal of Great Lakes Research, 42: 146-149. doi: 10.1016/j.jglr.2015.10.012

Cai, C., Gu, X., Ye, Y., et al. 2013. Assessment of pollutant loads discharged from aquaculture ponds around Taihu Lake, China. Aquaculture Research, 44: 795-806. doi: 10.1111/j.1365-2109.2011.03088.x

Carney-Almroth, B.M., Åström, L., Roslund, S., et al. 2018. Quantifying shedding of synthetic fibers from textiles; a source of microplastics released into the environment. Environmental Science and Pollution Research, 25: 1191-1199. doi: 10.1007/s11356-017-0528-7

Cashion, T., Le Manach, F., Zeller, D., et al. 2017. Most fish destined for fishmeal production are food- grade fish. Fish and Fisheries, 18: 837-844. doi: 10.1111/faf.12209

Castelvetro, V., Corti, A., Bianchi, S., et al. 2021. Microplastics in fish meal: Contamination level analyzed by polymer type, including polyester (PET), polyolefins, and polystyrene. Environmental Pollution, 273: 115792. doi: 10.1016/j.envpol.2020.115792

Chen, G., Li, Y. & Wang, J. 2021. Occurrence and ecological impact of microplastics in aquaculture ecosystems. Chemosphere, 274: 129989. doi: 10.1016/j.chemosphere.2021.129989

Cost of Funds Index (COFI). 2018. Microplastics in fisheries and aquaculture: A summary of FAO's study. [https://openknowledge.fao.org/items/605c182b-6263-4e58-be7f-d9e5aafbf532]. Reviewed: January 8, 2026.

Cole, M., Lindeque, P., Fileman, E., et al. 2015. The impact of polystyrene microplastics on feeding, function and fecundity in the marine copepod *Calanus helgolandicus*. Environmental Science & Technology, 49: 1130-1137. doi: 10.1021/es504525u

Cole, M., Lindeque, P., Halsband, C., et al. 2011. Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin, 62: 2588-2597. doi: 10.1016/j.marpolbul.2011.09.025

Craig, S. & Helfrich, L.A. 2017. Understanding fish nutrition, feeds, and feeding. [http://hdl.handle.net/10919/80712]. Reviewed: January 10, 2026.

Dehm, J., Volau, M., Ledua, E., et al. 2022. Occurrence of microplastics within a freshwater aquaculture system in the Pacific Islands, Viti Levu, Fiji. Environmental Monitoring and Assessment, 194: 624. doi: 10.1007/s10661-022-10305-3

Demsie, A.F. & Yimer, G.T. 2024. Occurrence of microplastics in commercial fish species from the Ethiopian rift valley's Lake Hawassa, Ethiopia. Environmental Science and Pollution Research International, 31: 48641-48649. doi: 10.1007/s11356-024-34432-1

Deswati, D., Syafrizayanti, S., Tetra, O., et al. 2025a. Study on the dynamics of microplastics in the biofloc system for Nile tilapia (*Oreochromis niloticus*) aquaculture. Journal of Ecological Engineering, 26: 270-284. doi: 10.12911/22998993/201204

Deswati, D., Zein, R., Novsimapera, G., et al. 2025b. The evaluation of microplastic reduction in biofloc aquaculture for sustainable Nile tilapia cultivation. Eksata, 26: 329-343. doi: 10.24036/eksakta/vol26-iss03/609

Devi, S.S., Jayan, S. & Kumar, A.B. 2024. Microplastic assessment in aquaculture feeds: Analyzing polymer variability across commercial fishfeeds from three continents. Journal of Hazardous Materials, 479: 135621. doi: 10.1016/j.jhazmat.2024.135621

Dibaratun, N.P. & Nabua, E.B. 2025. Unveiling microplastics in tilapia (*Oreochromis niloticus*) from Lake Lanao and assessing community awareness: Basis for IEC and I'm development. International Journal of Research and Innovation in Social Science, 9: 754-763 doi: 10.47772/IJRISS.2025.90500062

Ding, J., Zhang, S., Razanajatovo, R.M., et al. 2018. Accumulation, tissue distribution, and biochemical effects of polystyrene microplastics in the freshwater fish red tilapia (*Oreochromis niloticus*). Environmental Pollution, 238: 1-9. doi: 10.1016/j.envpol.2018.03.001

Espiritu, E.Q., Rodolfo, R.S., Evangelista, S.M.J., et al. 2023. Microplastics contamination in the fishes of selected sites in Pasig River and Marikina River in the Philippines. Marine Pollution Bulletin, 187: 114573. doi: 10.1016/j.marpolbul.2023.114573

Food and Agriculture Organization (FAO). 2009. *Oreochromis niloticus*. In: Cultured aquatic species fact sheets. [https://www.fao.org/fishery/docs/DOCUMENT/aquaculture/CulturedSpecies/file/es/es_niletilapia.htm]. Reviewed: December 18, 2025

Food and Agriculture Organization (FAO). 2016. The state of world fisheries and aquaculture: Contributing to food security and nutrition for all. [https://www.fao.org/3/a-i5555e.pdf]. Reviewed: December 14, 2025

Food and Agriculture Organization (FAO). 2018. The state of world fisheries and aquaculture 2018 - Meeting the sustainable development goals. [https://www.fao.org/3/i9540en/I9540EN.pdf]. Reviewed: December 16, 2025

Food and Agriculture Organization (FAO). 2020. El estado mundial de la pesca y la acuicultura 2020. Versión resumida. La sostenibilidad en acción. FAO, Rome.

Garcés-Ordóñez, O., Saldarriaga-Vélez, J.F., Espinosa-Díaz, L.F., et al. 2022. Microplastic pollution in water, sediments and commercial fish species from Ciénaga Grande de Santa Marta lagoon complex, Colombian Caribbean. Science of The Total Environment, 829: 154643. doi: 10.1016/j.scitotenv.2022.154643

Garcia, A.G., Suárez, D.C., Li, J., et al. 2021. A comparison of microplastic contamination in freshwater fish from natural and farmed sources. Environmental Science and Pollution Research, 28: 14488-14497. doi: 10.1007/s11356-020-11605-2

Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) 2015. Sources, fate and effects of microplastics in the marine environment: a global assessment. GESAMP, London.

Gündoğdu, S., Çevik, C., Ayat, B., et al. 2018. How microplastics quantities increase with flood events? An example from Mersin Bay, NE Levantine coast of Turkey. Environmental Pollution, 239: 342-350. doi: 10.1016/j.envpol.2018.04.042

Hanachi, P., Karbalaei, S., Walker, T.R., et al. 2019. Abundance and properties of microplastics found in commercial fish meal and cultured common carp (*Cyprinus carpio*). Environmental Science and Pollution Research, 26: 23777-23787. doi: 10.1007/s11356-019-05637-6

Hapal, E., Reyes, A., Vera-Cruz, E., et al. 2024. Identification and characterization of microplastics in freshwater fishponds and marine cages in Baler, Aurora, Philippines. AACL Bioflux, 17: 1963-1982.

Hasan, J., Islam, S.M.M., Alam, M.S., et al 2022. Presence of microplastics in two common dried marine fish species from Bangladesh. Marine Pollution Bulletin, 176: 113430. doi: 10.1016/j.marpolbul.2022.113430

Hu, X., Meng, L.J., Liu, H.D., et al. 2023. Impacts of Nile tilapia (*Oreochromis niloticus*) exposed to microplastics in bioflocs system. Science of The Total Environment, 901: 165921. doi: 10.1016/j.scitotenv.2023.165921

Idodo-Umeh, G. 2003. Freshwater fishes of Nigeria (taxonomy, ecology notes, diet and utilization). Idodo Umeh, Benin.

Iheanacho S.C., Ikwo, N., Igwezw, N.O., et al. 2018. Effect of different dietary inclusion levels of melon seed (*Citrullus lanatus*) peel on growth, hematology and histology of *Oreochromis niloticus* juvenile. Turkish Journal of Fisheries and Aquatic Sciences, 18: 377-384. doi: 10.4194/1303-2712-v18_3_03

Iheanacho, S., Ogueji, O., Igberi, C., et al. 2019. Suitability of discarded cashew nut (*Anacardium occidentale*) meal as replacement of soybean meal (*Glycine max*) in the diet of juvenile African catfish *Clarias gariepinus* (Burchell, 1822). Indian Journal of Fisheries, 66: 76-84. doi: 10.21077/ijf.2019.66.3.89214-10

Jorquera, A., Castillo, C., Murillo, V., et al. 2022. Physical and anthropogenic drivers shaping the spatial distribution of microplastics in the marine sediments of Chilean fjords. Science of The Total Environment, 814: 152506. doi: 10.1016/j.scitotenv.2021.152506

Khan, F.R., Shashoua, Y., Crawford, A., et al. 2020. 'The plastic Nile': First evidence of microplastic contamination in fish from the Nile River (Cairo, Egypt). Toxics, 8: 22. doi: 10.3390/toxics8020022

Kolandhasamy, P., Singha, S., Bhattacharya, S., et al. 2025. Ingestion and the toxicological effects of virgin polyethylene (PE) and polyvinylchloride (PVC) microplastics in commercial freshwater fish, tilapia (*Oreochromis niloticus*). Fish Physiology and Biochemistry, 51: 180. doi: 10.1007/s10695-025-01596-7

Kumar, R., Sharma, P., Manna, C., et al. 2021. Abundance, interaction, ingestion, ecological concerns, and mitigation policies of microplastic pollution in riverine ecosystem: A review. Science of The Total Environment, 782: 146695. doi: 10.1016/j.scitotenv.2021.146695

Lestari, P., Trihadiningrum, Y., Firdaus, M., et al. 2021. Microplastic pollution in Surabaya River water and aquatic biota, Indonesia. IOP Conference Series: Materials Science and Engineering, 1143: 012054. doi: 10.1088/1757-899X/1143/1/012054

Li, Y., Chen, G., Xu, K., et al. 2021. Microplastics environmental effect and risk assessment on the aquaculture systems from south China. International Journal of Environmental Research and Public Health, 18: 1869. doi: 10.3390/ijerph18041869

Likert, R. 1932. A technique for the measurement of attitudes. Archives of Psychology, 22: 55-55.

Lina, E. 2024. Microplastics in tilapia fish (*Oreochromis niloticus*) cultured at Magat Dam reservoir. International Journal of Science and Research, 13: 835-841. doi: 10.21275/SR24703113853

Liu, X., Yuan, W., Di, M., et al. 2019. Transfer and fate of microplastics during the conventional activated sludge process in one wastewater treatment plant of China. Chemical Engineering Journal, 362: 176-182. doi: 10.1016/j.cej.2019.01.033

Lusher, A., Hollman, P.C.H. & Mendoza-Hill, J. 2017. Microplastics in fisheries and aquaculture: Status of knowledge on their occurrence and implications for aquatic organisms and food safety. FAO, Rome.

Lusher, A.L., Bråte, I.L.N., Munno, K., et al. 2020. Is it or isn't it: The importance of visual classification in microplastic characterization. Applied Spectroscopy, 74: 1139-1153. doi: 10.1177/0003702820930733

Lyu, W., Chen, Q., Cheng, L., et al. 2020. Microplastics in aquaculture systems and their transfer in the food chain. In: He, D. & Luo, Y. (Eds.). Microplastics in terrestrial environments: Emerging contaminants and major challenges. Springer International Publishing, Berlin, pp. 357-382.

Mai, H., Nhi, N.T.T., Uyen, B.T.T., et al. 2022. Baseline assessment of microplastic concentration in different freshwater bodies and in local fish of Bac Ninh province. Vietnam Journal of Science and Technology, 60: 63-72. doi: 10.15625/2525-2518/17394

Manon, Md.R.K., Hoque, Md.S., Alam, Md.A., et al. 2026. Microplastic pollution in aquaculture species: Quantification and characterization in tilapia and pangas. Aquaculture, 610: 742922. doi: 10.1016/j.aquaculture.2025.742922

Martinez-Tavera, E., Duarte-Moro, A.M., Sujitha, S.B., et al. 2021. Microplastics and metal burdens in freshwater tilapia (*Oreochromis niloticus*) of a metropolitan reservoir in Central Mexico: Potential threats for human health. Chemosphere, 266: 128968. doi: 10.1016/j.chemosphere.2020.128968

Merga, L.B., Redondo-Hasselerharm, P.E., Van den Brink, P.J., et al. 2020. Distribution of microplastic and small macroplastic particles across four fish species and sediment in an African lake. Science of The Total Environment, 741: 140527. doi: 10.1016/j.scitotenv.2020.140527

Muhib, M.I. & Rahman, M.M. 2023. Microplastics contamination in fish feeds: Characterization and potential exposure risk assessment for cultivated fish of Bangladesh. Heliyon, 9: e19789. doi: 10.1016/j.heliyon.2023.e19789

Muhib, Md.I. & Rahman, Md.M. 2024. How do fish consume microplastics? An experimental study on accumulation pattern using Nile tilapia (*Oreochromis niloticus*). Environmental Science and Pollution Research, 31: 39303-39317. doi: 10.1007/s11356-024-33782-0

Ogunji, J.O., Iheanacho, S.C., Mgbabu, C.N., et al. 2021. Housefly maggot meal as a potent bioresource for fish feed to facilitate early gonadal development in *Clarias gariepinus* (Burchell, 1822). Sustainability, 13: 921. doi: 10.3390/su13020921

Oliva-Hernández, B.E., Santos-Ruiz, F.M., Muñoz-Wug, M.A., et al. 2021. Microplastics in Nile tilapia (*Oreochromis niloticus*) from Lake Amatitlán. Ambiente & Água - An Interdisciplinary Journal of Applied Science, 16: e2754. doi: 10.4136/ambi-agua.2754

Onyeneke, R.U., Amadi, M.U., Iheanacho, S.C., et al. 2020. Consumption of different forms of fish in Abakaliki metropolis of Ebonyi State, Nigeria. African Journal of Food, Agriculture, Nutrition and Development, 20: 15523-15537. doi: 10.18697/ajfand.90.19175

Page, M.J., McKenzie, J.E., Bossuyt, P.M., et al. 2021. Declaración PRISMA 2020: Una guía actualizada para la publicación de revisiones sistemáticas. Revista Española de Cardiología, 74: 790-799. doi: 10.1016/j.recesp.2021.06.016

Piyawardhana, N., Weerathunga, V., Chen, H.S., et al. 2022. Occurrence of microplastics in commercial marine dried fish in Asian countries. Journal of Hazardous Materials, 423: 127093. doi: 10.1016/j.jhazmat.2021.127093

Ragasa, C., Osei-Mensah, Y.O. & Amewu, S. 2022. Impact of fish feed formulation training on feed use and farmers' income: Evidence from Ghana. Aquaculture, 558: 738378. doi: 10.1016/j.aquaculture.2022.738378

Ren, C., Wang, Z., Zhang, Y., et al. 2019. Rapid expansion of coastal aquaculture ponds in China from Landsat observations during 1984-2016. International Journal of Applied Earth Observation and Geoinformation, 82: 101902. doi: 10.1016/j.jag.2019.101902

Rivero-Macias, M.E. 2019. El enfoque basado en proceso en la gestión editorial de las revistas científicas. Humanidades Médicas, 19: 637-658

Samuel, O.O., Olamide, O.O. & Kazeem, G.O. 2024. Investigation of microplastics contamination in African catfish *Clarias gariepinus* and Nile tilapia *Oreochromis niloticus* fish species in Owe River, Ile-Oluji, Ondo State, Nigeria. Journal of Applied Life Sciences International, 27: 29-46. doi: 10.9734/jalsi/2024/v27i2639

Sarthou, N.F. 2016. Key points of discussion in scientific research evaluation: Peer review, bibliometrics and relevance. Revista de Estudios Sociales, 58: 76-86. doi: 10.7440/res58.2016.06

Sefiloglu, F.Ö., Brits, M., König-Kardgar, A., et al. 2024. Quantitative analysis of microplastics in Nile tilapia from a recirculating aquaculture system using pyrolysis-gas chromatography-mass spectrometry. Environmental Sciences Europe, 36: 172. doi: 10.1186/s12302-024-00987-6

Siddique M.A.M., Hossain, I., Sunji, Md.M.R., et al. 2024. Characterization, source identification and hazard index assessment of ingested microplastics in farmed tilapia *Oreochromis niloticus*. Ecological Indicators, 158: 111334. doi: 10.1016/j.ecolind.2023.111334

Siddique, M.A.M., Tahsin, T., Hossain, I., et al. 2023. Microplastic contamination in commercial fish feeds: A major concern for sustainable aquaculture from a developing country. Ecotoxicology and Environmental Safety, 267: 115659. doi: 10.1016/j.ecoenv.2023.115659

Song, Y.K., Hong, S.H., Jang, M., et al. 2017. Combined effects of UV exposure duration and mechanical abrasion on microplastic fragmentation by polymer type. Environmental Science & Technology, 51: 4368-4376. doi: 10.1021/acs.est.6b06155

Sun, J., Dai, X., Wang, Q., et al. 2019. Microplastics in wastewater treatment plants: Detection, occurrence and removal. Water Research, 152: 21-37. doi: 10.1016/j.watres.2018.12.050

Thiele, C.J., Hudson, M.D., Russell, A.E., et al. 2021. Microplastics in fish and fishmeal: An emerging environmental challenge? Scientific Reports, 11: 2045. doi: 10.1038/s41598-021-81499-8

Tidwell, J.H. & Bright, L.A. 2019. Freshwater aquaculture. Encyclopedia of Ecology, 1: 91-96. doi: 10.1016/B978-0-12-409548-9.10618-9

Tien, C.J., Wang, Z.X. & Chen, C.S. 2020. Microplastics in water, sediment and fish from the Fengshan River system: Relationship to aquatic factors and accumulation of polycyclic aromatic hydrocarbons by fish. Environmental Pollution, 265: 114962. doi: 10.1016/j.envpol.2020.114962

Valencia-Castañeda, G., Ruiz-Fernández, A.C., Frías-Espericueta, M.G., et al. 2022. Microplastics in the tissues of commercial semi-intensive shrimp pond-farmed *Litopenaeus vannamei* from the Gulf of California ecoregion. Chemosphere, 29: 134194. doi: 10.1016/j.chemosphere.2022.134194

Wangboje, O.M. & Adeghor, K.A. 2024. Baseline Investigation of microplastic levels in the Nile tilapia (*Oreochromis niloticus*, Linnaeus, 1758) from River Okhuo, Benin City, Nigeria. European Journal of Science, Innovation and Technology, 4: 335-345.

Wright, L.S., Napper, I.E. & Thompson, R.C. 2021. Potential microplastic release from beached fishing gear in Great Britain's Region of highest fishing litter density. Marine Pollution Bulletin, 173: 113115. doi: 10.1016/j.marpolbul.2021.113115

Wu, H., Hou, J. & Wang, X. 2023. A review of microplastic pollution in aquaculture: Sources, effects, removal strategies and prospects. Ecotoxicology and Environmental Safety, 252: 114567. doi: 10.1016/j.ecoenv.2023.114567

Xu, M., Xu, R.Z., Shen, X.X., et al. 2022. The response of sediment microbial communities to temporal and site-specific variations of pollution in interconnected aquaculture pond and ditch systems. Science of The Total Environment, 806: 150498. doi: 10.1016/j.scitotenv.2021.150498

Yao, C., Liu, X., Wang, H., et al. 2021. Occurrence of microplastics in fish and shrimp feed. Bulletin of Environmental Contamination and Toxicology, 107: 684-692. doi: 10.1007/s00128-021-03328-y

Yusuf, M.A. & Tahir, A. 2021. Study of the abundance and characteristics of microplastic contamination in the fish of capture results of fishermen in the Lake Towuti Waters, East Luwu, South Sulawesi. International Journal of Scientific and Research Publications, 11: 699-704. doi: 10.29322/IJSRP.11.07.2021.p11593

Zhang, S., Ding, J., Razanajatovo, R.M., et al. 2019. Interactive effects of polystyrene microplastics and roxithromycin on bioaccumulation and biochemical status in the freshwater fish red tilapia (*Oreochromis niloticus*). Science of The Total Environment, 648: 1431-1439. doi: 10.1016/j.scitotenv.2018.08.266

Zhou, A., Sun, D., Wang, C., et al. 2022. Characteristics and differences of microplastics ingestion for farmed fish with different water depths, feeding habits and diets. Journal of Environmental Chemical Engineering, 10: 107189. doi: 10.1016/j.jece.2022.107189

Zhou, A., Zhang, Y., Xie, S., et al. 2021. Microplastics and their potential effects on the aquaculture systems: A critical review. Reviews in Aquaculture, 13: 719-733. doi: 10.1111/raq.12496

Ziajahromi, S., Neale, P.A., Telles-Silveira, I., et al. 2021. An audit of microplastic abundance throughout three Australian wastewater treatment plants. Chemosphere, 263: 128294. doi: 10.1016/j.chemosphere.2020.128294

Received: March 17, 2026; Accepted: June 29, 2026