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Assessment of the effect of exposure to microplastic on Nile tilapia fish

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Abstract

Microplastics are hazards to aquatic life. The concentration of microplastics (MPs) in aquatic ecosystems is increasing daily due to anthropogenic activities. Nile tilapia is a popular fish and is cultivated in many parts of the world to fulfil meat demands. However, the cultivation of Nile tilapia is affected by rising pollution levels. The review article contains data related to how microplastics affect Nile tilapia's health and reproductive behaviour so that adaptation and mitigation strategies can be done in a better way. The main purpose of this review article is to find out how rising concentrations of microplastics can harm fish organs, affect normal biological functioning, and cause behavioural abnormalities. The findings of this review article

Volume: 9, No: 2, pp.5164-5184
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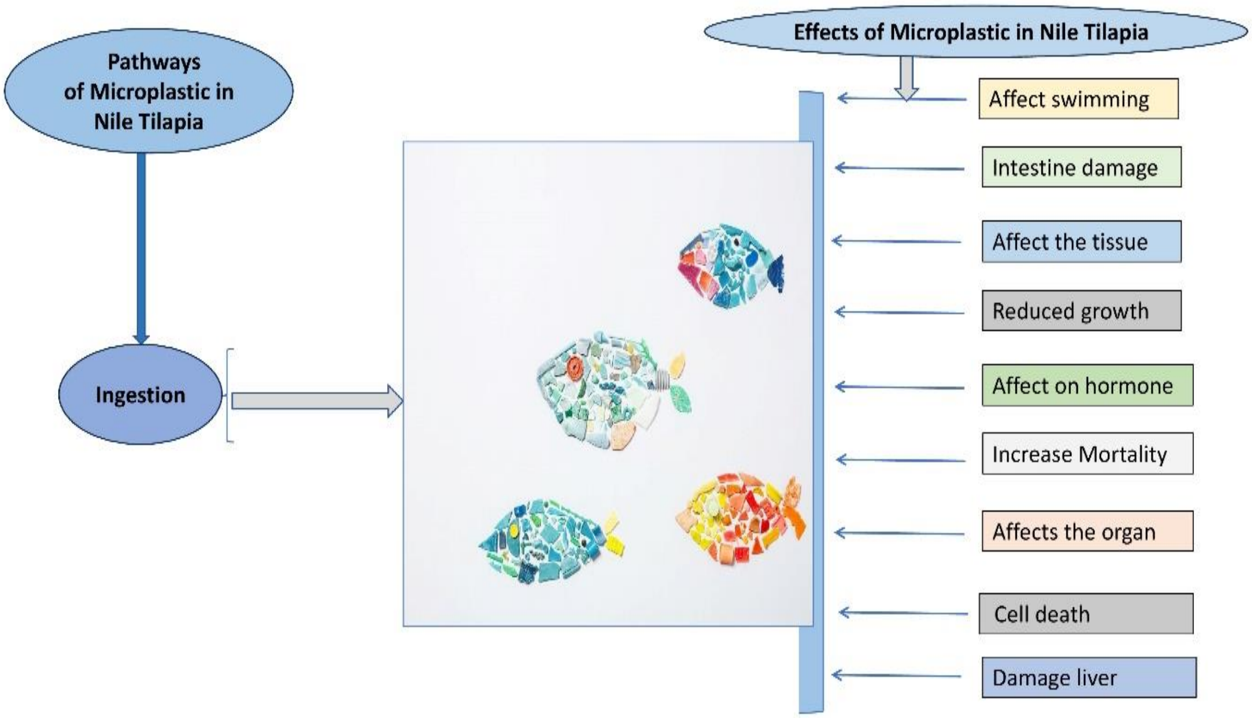
showed that the concentrations of MPs in different fish tissues have generally increased over time. It can lead to a decrease in the red blood cells, eosinophil percentages, haemoglobin levels, platelet counts, and percentages of hematocrit. After MP exposure, to microplastic, the biochemical markers increased considerably. Furthermore, exposure to MPs decreased the activity of acetylcholinesterase in the fish brain. Therefore there is a need to resolve this issue for further research and improved environmental protection measures.



1. Introduction

Plastic has long-term persistence in the environment; therefore, it is considered a major environmental pollutant become a significant issue of the twenty-first century (Ahmad et al., 2023). Oceans throughout the world get a lot of plastic waste each year. According to estimates, within the last ten years, the total amounts of plastic have increased 50 times as compared to the past (Everaert et al., 2018). Previous studies predict that many types of plastics accumulate in the aquatic environment, including polystyrene, polyethene polyvinyl chloride. But some methods like, mechanical abrasion, UV light, hydrolysis, and biodegradation all reduce plastic materials into smaller polymers between 1 and 100 nm, known as nanoplastics" (NPs) and microplastics" (Gigault et al., 2018).

Volume: 9, No: 2, pp.5164-5184
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Microplastics (MPs) are plastic particles that result from the deterioration of plastic and have a size of less than 5 mm. According to Borges-Ramírez et al., 2020), microplastics will become more bioavailable to benthic biota, such as benthic fish that consume detritus, plants, and benthic invertebrates. A significant amount of microplastics in aquatic systems will become trapped in the substrate. Fish have varying levels of sensitivity to pollutants, but because of their extensive exposure and lengthy lifespans, they can serve as significant bioindicators of pollution (Okwuosa et al., 2019).

Fish meal is an essential component in fish feed that can be replaced with alternative protein sources to make it more cost effective (Arshad et al ., 2023). With 9% of global fish production, nile tilapia is the third most extensively cultivated fish species. (FAO, 2007). It is the primary species farmed in Brazil, where it accounts for 63.93% of total production (Peixe BR, 2023). Because of its remarkable flexibility, resilience to illness, quick growth, and effective feed conversion, this species is well-known in aquaculture around the world (Li et al., 2024). Commercial feed accounts for about 92% of the world's tilapia production, which is mostly dependent on it (Tacon, 2020). In aquatic organisms, microplastics have harmful effects, including intestinal mucosa absorption and blockages of the gastrointestinal tract (Jovanovic et al., 2018). Virgin microplastics are that are chemically inert don't directly harm fish. However, polyethene (PE) microbeads have been shown to enhance oxidative stress in shrimp (Niemcharoen et al., 2022). Some plastic polymers have the potential to interfere with aquatic species' reproductive systems and behave as endocrine disruptors.

Microplastics are becoming more and more common in a variety of habitats throughout the world. Therefore, it is a hazard not only for aquatic species but also to human food security and health. The detection of microplastic fragments in the faeces is a reliable indicator of human ingestion of microplastics (Schwabl et al., 2019). These particles have the ability to accumulate or be hazardous to those who have consumed them. Seafood intake serves as a possible source of exposure to microplastic for humans (Yuan et al., 2022). However, the factors that influence microplastic intake and accumulation are not well understood, and some fish have yet to be examined. Since fish constitute a vital supply of protein for humans, it is imperative to thoroughly assess the hazards posed by novel pollutants to fish populations and the security of aquatic food sources. Their reproductive performance can be impacted by a variety of biotic and abiotic factors as well as human-induced stresses such as eutrophication and pollution (Wang et al., 2020).

Research is still being conducted to demonstrate the ecotoxicological impacts of fish microplastic contamination, which might affect individual fish or a population as a whole (Castro-Castellon et al., 2021). The majority of microplastics are chemically inert and these are not toxic to fish (Jovanovic et al., 2018). However, they may enhance fish oxidative stress (Niemcharoen et al., 2022). Reduced growth may result from MPs consuming less amino acids than what is necessary for their species. Reduced dietary protein levels are feasible without impairing fish productivity, and diets with a balanced amino acid profile can improve feed protein consumption (Kaushik et al., 2010). The aim of this study is to conduct a thorough evaluation of MPs' effects on tilapia at different stages and organs (Nguyen et al., 2020).

Table 1: Represents the affect of Microplastic on Nile Tilapia adaptation and mitigation strategies to minimize its affects

	Effect	**Mitigation Strategies**	**Adaptation Strategies**	**References**
Physical Health	• Problems with the digestive system may arise from consuming microplastics. • Microplastics can cause interior damage and inflammation.	• Implement policies that will limit plastic manufacturing and use. • Improve trash management to keep plastic from entering water bodies.	• Improve filtration systems to reduce microplastic contamination. • Implement best practices for feeding and waste management in aquaculture facilities.	(Chen et al., 2022) (Schwabl et al., 2019)

Volume: 9, No: 2, pp.5164-5184
ISSN: 2059-6588(Print) | ISSN 2059-6596(Online)

Growth and Survival	• Decreased rates of growth as a result of ingesting non-nutritive particles. • Higher death rates, particularly for young fish	• Cleanup Initiatives Organize water-related cleanup tasks. • Educate people on the consequences of plastic pollution.	• Breed Nile tilapia strains that are resistant to environmental stresses. • Restore natural habitats to boost the resilience of Nile tilapia populations.	(Ogunola et al., 2018) (Lei et al., 2018)
Reproduction	• Reduced success rate in reproduction as a result of physical strain and energy misallocation. • Microplastics could be passed down to children.	• Conduct studies to better understand the sources and effects of microplastics. • Regularly monitor microplastic levels i n aquatic conditions	• Provide dietary supplements to enhance health and resilience. • Protect the natural resources	(Karami et al., 2016) (Rochman et al., 2014)
Behavioral Changes	• Changed feeding habits, resulting in lower food intake and inadequate nutrition. • Changes in swimming patterns and predator avoidance behaviors.	• Educate the public about the effects of plastic pollution. • Organize cleaning procedures for water bodies.	• Implement optimal practices in feeding and waste management. • Restore natural habitats to boost the resilience of Nile tilapia populations.	(Temesgen et al., 2022) (Jabeen et al., 2017)
Toxicological Impact	• Microplastics can collect and release	• Conduct research to better	• Breed Nile tilapia strains that are	(Prata et al., 2019)

	hazardous contaminants, resulting in toxicity. • The accumulation of microplastics in tissues may affect organ function.	understand the sources and impacts of microplastics. • Monitor water bodies for microplastic levels to track progress.	resistant to environmental stresses. • Provide nutritional supplements to improve health and resilience.	(Hayati et al., 2020)

2. Microplastics in Aquatic Environments

Water and air are the two primary elements required for life, but modernization and anthropogenic activities can lead to an increase in the concentration of plastic. Plastic takes a very long time for nature to break down; it takes roughly 1000 years. Plastic pollution is a serious problem that impacts everyone on the planet and contributes significantly to climate change. It has been demonstrated that fish species in the River Thames, both freshwater and estuarine/marine, have been polluted with microplastics (Horton et al., 2018; McGoran et al., 2018). European smelt and European flounder were the first fish which showed signs of ingesting microplastic (McGoran et al., 2017).

2.1. Sources and types of microplastics

Several different types of habitats contain MPs, such as terrestrial, marine, and aquatic settings. Compared to marine environments, freshwater ecosystems have been receiving less attention when it comes to microplastic particle contamination (Lechner et al., 2014). This is especially true given that freshwater primarily rivers is the source of MPs that make their way into the ocean. It is therefore uncommon to find reports of MPs being transferred from rivers to beaches or open waters (Waseem et al., 2023). MPs in freshwater environments can have their distribution and quantity changed by humans and natural causes, including as dam releases and anthropogenic emissions (Eerkes-Medrano et al., 2015). Examples of these include storms and wind. MPs are divided into two categories according to where they come from. Primary MPs include scrubbers, scrubbers, and tiny fibers eliminated from the textile and clothing industries.

Remittances Review
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Secondary MPs are made when larger plastic objects break down in the environment as a result of weathering, heat, UV light, and oxidation processes, among other factors (Saha et al., 2021).

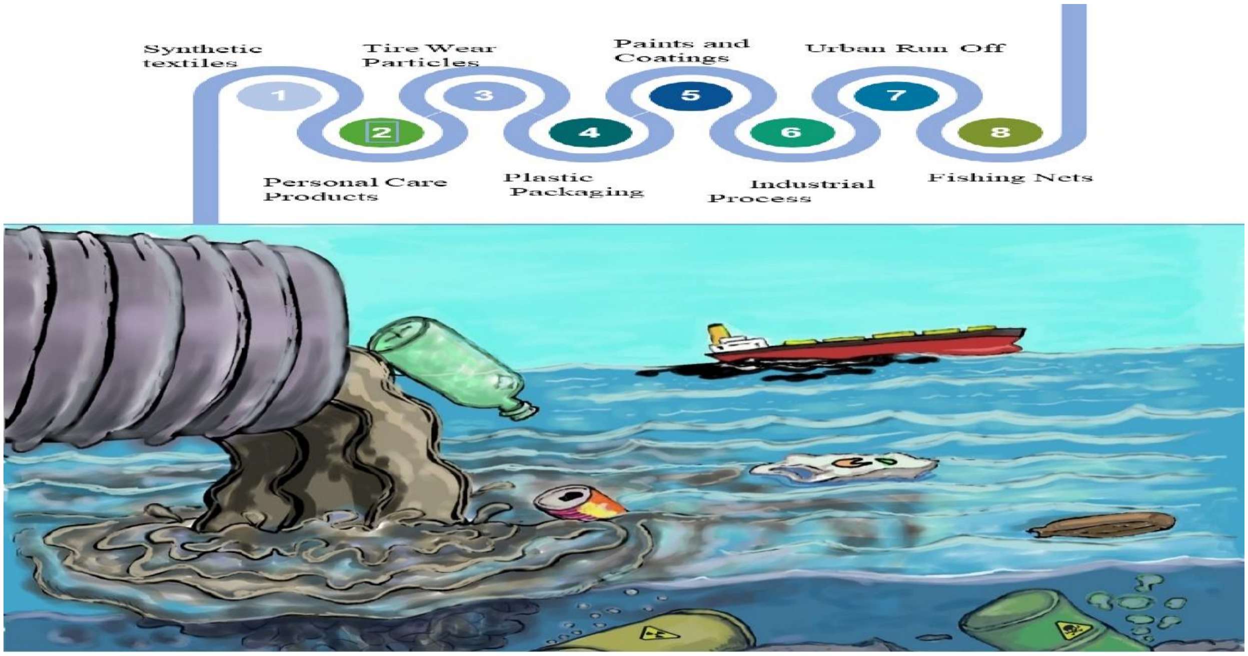

Fig 1: Represents the sources and types of microplastics

2.2. Pathways of microplastics into water bodies

However, the distribution of MPs in aquatic bodies is frequently diverse. Small sample quantities could therefore overlook waste that is present at the water's surface. Low MP densities may have been reported due to limited water volume filtered by net or sieve (Moore et al., 2011). The most important route for microplastics (MPs) to reach open waters is by riverine transport, and land-based discharges have the potential to be a significant source of MPs (Lam et al., 2020). Rivers act as reservoirs for concentrated MPs, which may have negative environmental consequences (Xu et al., 2020). Urban rivers can also be regarded as key areas of concern for MP pollution. Since most river sediments contain a high concentration of MP, they might act as an essential sink for MP deposition, retention, accumulation, and pollution (Nel et al., 2018).

Studies on the Amsterdam canal region suggest that sediments could serve as a sink for microplastics (MPs) and that particles floating in the water can be transported to the sea with other suspended particulates (Leslie et al., 2017). A portion of the plastic pollution that rivers

Volume: 9, No: 2, pp.5164-5184
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produce seems to settle in benthic or coastal sediments, especially in the slower-moving parts of the river. Not all of it seems to make its way into the open ocean. MP concentrations were 600,000 times higher in the Elbe River sediments on average than they were in the aqueous phase. Urban rivers may be a significant source of MP downstream (Moore et al., 2011)

Ingestion of microplastics through aquatic organisms

Microplastics are easily ingested by marine species due to their small size. Microplastics have been discovered in the stomachs of bivalves, zooplankton, mussels, shrimps, oysters, fish, copepods, and whales (Lusher et al. 2015). Ingestion of small plastic particles has been associated to mortality, pathological stress, reproductive difficulties, reduced enzyme synthesis, decreased development rate, and oxidative stress, putting organisms at considerable risk (Fosse et al., 2016). Furthermore, harmful compounds found in the nearby saltwater may be absorbed by microplastics and transferred into the food chain. According to studies, microplastics are being found at very high concentrations and in increasing quantities in rivers and lakes all over the world (Ferreira et al., 2016).

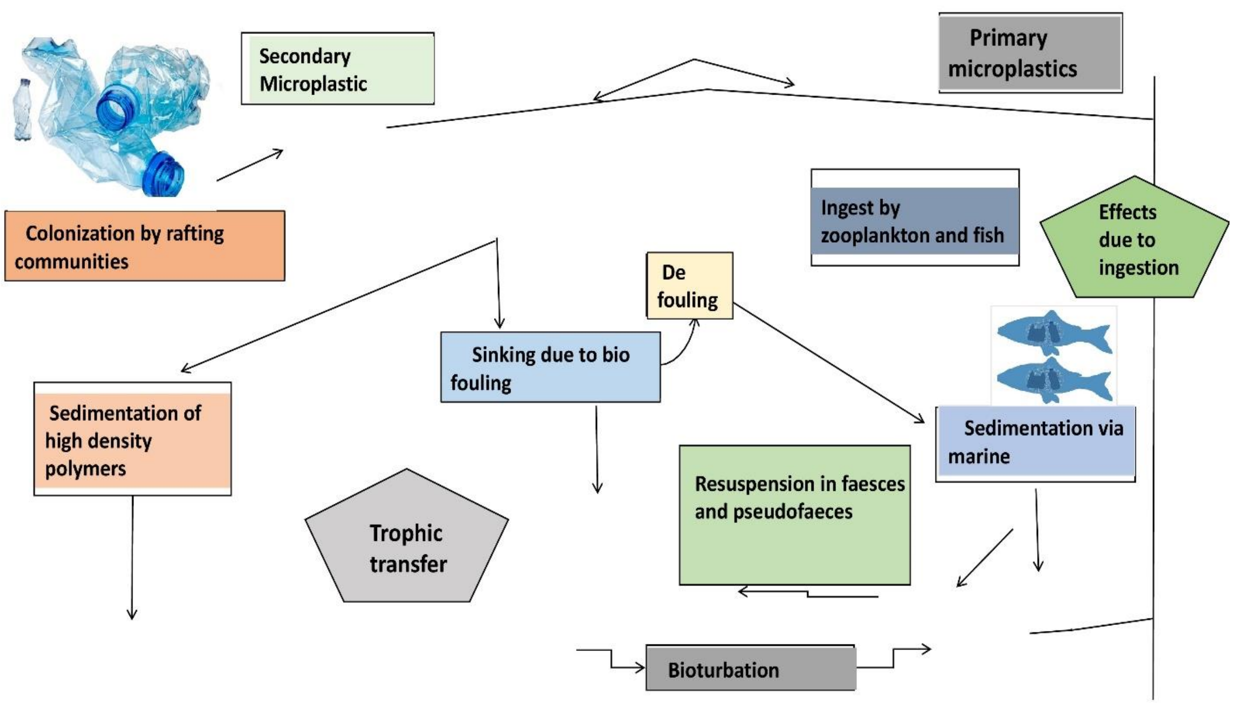

Fig 2: Represents the ingestion of microplastic by Nile Tilapaia

3. Health Impacts of Microplastics on Nile Tilapia

Numerous studies have shown that marine life may absorb microplastics, therefore it can be harmful to tissues, and act as carriers of infections (Qiao et al., 2019). Microplastics have the ability to have a wide range of negative impacts, including reduced immune response, cancer, altered reproductive function, and deformities in both people and animals. Microplastic pollution of the oceans poses a risk to human health as well as economic issues. Multiple toxic effects of MPs include alteration of energy metabolism, oxidative stress inflammation, neurotoxicity, intestinal damage, and behavioural abnormalities (Barboza et al., 2018).

3.1. Gastrointestinal Impact

Analyzing fish reduces the geographical and temporal variation that would otherwise be found when undertaking one-time assessments of other matrices because microplastics can remain in fish guts for several days (Ather et al). Therefore, it would be insufficient to comprehend the larger biological and environmental processes impacting fish ingestion of microplastics by focusing exclusively on environmental data from the particular time point and place at which fish were caught (Grigorakis et al., 2017). Prior research has indicated that ingestion is strongly influenced by fish features and exposures. Environmental contaminants caused disruptions to the organization of the gut microbial community and altered the function of intestinal neurotransmitters' regulatory neurons. MPs may stay in the digestive tract after being consumed by fish, or they may be eliminated or absorbed into other bodily tissues (Tanaka and Takada, 2016). MPs mostly gathered in fish guts (Lei et al., 2018). The buildup of MPs can impede the gut's ability to digest food and induce satiety, which can impair growth and lower survival rates. MPs may also affect the activity of fish digestive enzymes (Wen et al., 2018b).

3.2. Reproductive Health Implications

MPs can affect the fish's reproductive stress, which disrupts hormonal levels. The seminiferous tubules that connect the testicular lumen to the testicle's basement wall make up the testes of tilapia fish. Comparing the seminiferous tubules' diameter to those of the control one when exposed to a concentration of MPs from commercial feeding alone, there was no discernible change (Karami et al., 2016). On the other hand, the tubular diameter is dramatically is decreased

Remittances Review
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at higher MP concentrations. The diameter of the fish's seminiferous tubules can be increased by probiotics (Rochman et al., 2014). According to reports, MPs interfere with the steroid production pathway causing endocrine dysfunction. Additionally, MPs have been shown to cause reproductive stress by increasing apoptosis levels and histological alterations in testes, delaying female gonadal maturation, decreasing fecundity, and decreasing the levels of testosterone and estradiol in females (Wan et al., 2019). Long-term population stability and the health of entire aquatic ecosystems are affected by fish reproductive success. Moreover, exposure to MP pollution might cause oxidative stress and have a detrimental effect on male tilapia fertility (Qiang and Cheng, 2021).

3.3. Physiological effects

chemical additives in MPs, especially those employed as plasticizers and/or retarders, have a negative impact on human health. According to research, MPs and their additives may provide a risk for obesity (Kannan et al., 2021) and cause endocrine problems, neurotoxicity, hepatotoxicity, cancer, and reproductive toxicity (Prata et al., 2020). Because of the tiny MP particle size, large specific surface area, and worries about exposure to the toxic chemical additive added, these chemicals derived from plastic polymers have a higher chance of infiltrating people's bodily fluids (such as sweat, stomach, intestine, and lung fluid) that are exposed (i.e., the higher biological availability) (Ageel et al., 2022).

3.4. Behavioural changes

Fish ingestion of MPs is largely determined by their feeding habits. Some fish swallow MPs mistakenly, others might ingest MPs due to their likeness to natural prey. This depends on the fish's capacity to find food with their senses, catch and consume it, and process the nutrients via their bodies and systems (Jabeen et al., 2017). The adaptable, omnivorous Nile tilapia eat a wide range of food sources, including as smaller fish and fish eggs, as well as phytoplankton, zooplankton, detritus, invertebrates and periphyton (Temesgen et al., 2022). As a result of their diversified eating patterns, Nile Tilapia are more likely to consume MPs because they eat a wide range of food in the water column (Garcia et al., 2020). In addition, planktivorous fish—like Nile Tilapia are known to consume a lot of water to filter food, and they may inadvertently

Remittances Review
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Volume: 9, No: 2, pp.5164-5184
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swallow MPs or other non-food objects. Therefore, their intestines are twisted and lengthy, which enables them to gather MPs (Yin et al., 2022).

Fig 3: Represents the behavioral changes in Nile tilapia due to microplastic

3.5.Tissue and cellular-level impacts

Reactive oxygen species are produced at higher concentrations of MPs, which harm the tissues and ultimately cause cell death. By oxidizing the cell's lipid, protein, and DNA components, these harmful compounds lead to oxidative stress at the cellular level. This unbalance causes inflammation, which in turn causes cell death (Ullah et al., 2024). Fish that experience oxidative stress in their reproductive system become infertile as a consequence of reproductive system failure. Numerous studies have demonstrated that the hypothalamic-pituitary-gonadal axis functions less effectively when there is oxidative stress brought on by harmful elements in the fish's body system. This leads to problems that rely on hormone activity, such as deficient cell development and limited growth. Thus, gonadotropin hormone, production is decreased as a result of hypothalamic dysfunction brought on by hazardous chemicals (Hayati et al., 2020).

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hypothalamic dysfunction brought on by hazardous chemicals. The synthesis of testosterone, steroids and estradiol is also reduced in conjunction with the gonadotropin-releasing levels, which affects gamete cell growth in the testes. The testes are regarded as endocrine organs that not only create gametes but also steroids. The number and shape of the cells that produce sperm in the testes are similarly impacted by oxidative stress. Additionally, it destroys the structure of the seminiferous tubules and prevents spermatogenesis, which hinders fertilization (Hayati et al., 2020).

Table 2: Represents the effect of Microplastic on Nile Tilapia Cell and tissues

Tissue/ Cellular Level	Effects	Severity	Implications	References
Gills	It can cause cell death and lead to Increased mucous secretion.	Moderate to severe	• Impaired breathing • Decreased oxygen intake • Increased susceptibility to infection.	(Temesgen et al., 2022)
Liver	Microplastics can harm fish livers by causing inflammation and disrupting liver function.	Moderate	• Poor detoxification • Possible liver injury • Disturbed metabolic processes.	(Garcia et al., 2020)
Intestine	It can cause inflammation and physical blockages.	Moderate	• Reduced nutrient absorption • Inflammation • Compromised intestinal barrier function.	(Ageel et al., 2022)
Muscle	Microplastic can lead to muscle fiber degeneration and cause cell death	Mild to Moderate	• Reduced swimming ability • Muscle weakness • Harmful impacts on growth and survival	(Horton et al., 2018)
Kidney	Microplastic can cause glomerular and tubular degeneration	Moderate	• Impaired excretory function • Potential kidney damage, and • Disrupted osmoregulation.	(Qiao et al., 2019)
Cellular level	It can cause DNA damage, cause nuclear abnormalities	Moderate to Severe	• Oxidative stress • Increased cell death • Genetic damage	(Hayati et al., 2020)

Volume: 9, No: 2, pp.5164-5184
ISSN: 2059-6588(Print) | ISSN 2059-6596(Online)

4. Mitigation and adaptation strategies

The need for plastic is increasing day by day, but there should be strict restrictions on it so that its effect can be minimized on aquatic as well as on human populations. A catastrophe happens when microplastics contaminate the water supply system it can pose serious risks to human livelihoods, and public health and welfare. Therefore, it is very necessary to explore the mitigation and adaptation strategies so that preventive measures can be taken in a better way. Many solutions have been developed at different levels to decrease and manage plastic waste to minimize the negative impacts caused by plastic pollution (Ogunola et al., 2018).

Mitigation strategies include minimising the use of plastic and reusing it by recycling. There should be a proper disposal system for plastic products to prevent them from reaching water bodies. There must be strict regulations on plastic use and improved waste management systems. For adaptation, clean water must be used in fish farms, and regular monitoring of water quality can be done to detect microplastics. Additionally, researchers should focus on the cultivation of tilapia species which are more resistant to pollutants (Prata et al., 2019).

5. Summary

Microplastics have adverse impacts on wildlife and disrupt natural food webs. The most promising options for eventually bioremediating environmental plastics are microorganisms. Plastics degrade into smaller particles known as MPs, or tiny particles. Particles smaller than 5 mm are the result of this degradation process. Benthic fish, which consume benthic invertebrates, as well as other sediment-dwelling and benthic biota can consume microplastic easily (Borges-Ramírez et al., 2020). MPs can be found in a variety of habitat types, including aquatic, marine, and terrestrial environments. Freshwater ecosystems have received significantly less attention about MP contamination than marine settings. This is particularly true because MPs entering the ocean originate in freshwater, specifically rivers. Reports of MPs being moved from rivers to beaches or open waters are consequently rare. The distribution and quantity of MPs in freshwater habitats are subject to change due to both natural and man-made factors (Schwabl et al., 2019).

At 9% of the world's output, Nile tilapia is the third most farmed fish species worldwide. Tilapia farming is expanding rapidly to meet the demands of both local and foreign markets. These days, tilapias are the second most popular group of farmed fish in the world, behind carp. In 2007, the amount of farmed tilapia produced worldwide which is cultivated in at least 85 countries surpassed 2.5 million tons. Nonetheless, because of its economic significance as one of the most significant farmed fish species worldwide, Nile tilapia is, by far, the most extensively cultivated tilapia species (FAO, 2007). The gradual breakdown of big plastic particles found in the environment gives rise to MPs. They started out as fishing nets, home objects, plastic disposables, and resin ingredients. MPs are currently the most prevalent type of non-biodegradable pollution on Earth. Multiple MPs can accumulate in freshwater. MPs can cause neurological dysfunction, hepatic stress, and hepatic stress (McGoran et al., 2017).

Therefore, assessing the impact of microplastic exposure on Nile tilapia is important for improving the aquatic ecosystem. Biomarkers should be used for assessing pollution stress and ecological changes because biochemical characteristics are recognized as important bioindicators for measuring the impact of various contaminants in fish (Prata et al., 2019). By compiling the data from different articles this review article concluded that microplastic contamination can affect the fish's growth, affect reproductive behaviour disrupt the hormonal level and affect the overall health. By highlighting these effects, it can help to minimize the effect of microplastic on the Nile tilapia. Protecting Nile tilapia from microplastic is important not only for their survival but it can also fulfil the food demand. Further research is needed to minimize microplastic pollution and its harmful effects on aquatic life.

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