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Microplastics Pollution in Aquatic Environment: A Review of Abundance, Distribution, and Composition in the Egyptian Coastal Waters

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ABSTRACT

The continuous production and widespread use of synthetic plastics, along with the resulting waste, pose significant environmental challenges and threaten ecosystems. Microplastics (MPs) have emerged as a novel type of contaminants in aquatic environments, posing risks to both ecosystems and human health. Egypt is distinguished by the diversity of its aquatic environment. The Mediterranean Sea is globally recognized as a major hotspot for the accumulation of marine litter and plastic pollution. On the other hand, the Nile River is considered a major source of plastic pollution flowing into the eastern Mediterranean basin. In addition, the Red Sea Coast of Egypt is confronted with various anthropogenic stressors that contribute to the accumulation of plastic litter in the region, causing a significant threat to the sensitive and critical ecosystems found there. Despite the global documentation of MPs pollution, there is a lack of sufficient data on the extent of MPs and their interaction with other contaminants in the aquatic environment of Egypt. Monitoring and assessing the extent of MPs pollution in aquatic environments are crucial initial steps, providing a foundation for developing recommendations and policies to mitigate major marine pollutants. This study concerned with MPs pollution in the aquatic environment, with an aim to define the various types of MPs , their sources, fate, toxicity, characterization and impact on human health. In addition, it aimed to summarize the existing research conducted in the Egyptian aquatic environments, offering an overview of the current knowledge regarding the abundance and distribution of MPs in Egypt's aquatic ecosystems.

INTRODUCTION

A coastal zone is the interface between the land and water and includes rocky shores, dense mangrove forests, and muddy saltmarshes. It is essential to marine life and supports a large part of the world's living marine resources, certainly more than the open sea. Egypt has coastlines on the Mediterranean Sea and the Red Sea. It's noteworthy that half of Egypt's population resides in these coastal zones. The livelihoods in these areas are predominantly supported by traditional fishing methods, with some contribution from automation **(El-Serehy *et al*., 2012)**.

Egypt has a marine coastline of more than 4,500kms; 1,150kms on the Mediterranean Sea and around 1,850kms on the Red Sea, including those in the Gulf of Suez and the Gulf of Aqaba, in addition to 1530kms on the River Nile (Fig. 1). While such coastal areas have provided Egypt with a very rich source of marine and natural resources, the Egyptian Mediterranean coast (EMC) has long been a popular summer destination for locals, whereas the Red Sea resorts have primarily catered to

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foreign tourists. However, the northern coastline has been experiencing significant development in recent years, with modern infrastructure and resorts being built. EMC is categorized into four distinct regions: the northwest coastal sector, the Alexandria coastal sector, the Nile Delta coastal sector, and the easternmost sector **(Frihy & El-Sayed, 2013)**. The coexistence of diverse activities, ranging from industrialization, agricultural lands, and natural gas and oil production to tourist resorts and harbor operations, contributes to the introduction of a multitude of various pollutants into the marine environment along the EMC coast. This complex interplay of human activities underscores the potential environmental challenges and the need for comprehensive monitoring and management strategies **(Said *et al.*, 1993; Shreadah *et al.*, 2012)**.

Pollution along the Red Sea coast emanates from a mix of natural and human-related sources. Common contributors include industrial processes, petroleum industries, urban growth, tourism operations, fishing, shipping, resorts, and harbor activities. The diverse range of these activities highlights the complexity of pollution sources along the Red Sea, necessitating holistic strategies for an effective environmental management **(Abdel-Halim *et al.*, 2007; Masoud *et al.*, 2010; Shreadah *et al.*, 2011; Abo-El-Khair *et al.*, 2016)**. The Nile River is vital to Egypt, providing the primary freshwater resource essential for fulfilling nearly all drinking and irrigation water needs. The unregulated disposal of anthropogenic waste from various drains situated along the banks of the Nile has notably elevated the contamination of the Nile water to a critical level.

Fig. 1. Map indicates the Egyptian coasts and the studied areas

Emerging pollutants are defined as chemicals and compounds recently recognized as posing risks to the environment, ecosystems, and human health. Notably, many of these pollutants lack regulation under national or international legislation, amplifying the potential threat to our well-being. This category includes an array of substances, such as antibiotics, drugs, steroids, endocrine disruptors, hormones, industrial additives, chemicals, as well as microbeads and MPs **(Sousa *et al.*, 2018; Peña-Guzmán *et al.*, 2019)**.

The complexity of these pollutants, especially MPs, necessitates a proactive and comprehensive approach to mitigate their effects and protect the well-being of both the environment and human populations. Plastic pollution has become a global problem, with its prevalence increasing across all ecosystems, especially in the oceans. More than 360 million tons of plastic are produced every year, with an estimated 19- 23 million tons of plastic waste leaks into aquatic ecosystems, polluting lakes, rivers and seas **(Jambeck *et al.*, 2015; UN Environment, 2019; UNEP, 2022)**.

This review focused on the contamination of aquatic environments by microplastics (MPs), aiming to identify different types of MPs, their origins, pathways, toxicity, characterization, and their potential impact on biota and human health. Furthermore, the study seeked to consolidate and present findings from previous research conducted in the Egyptian aquatic ecosystems, providing a comprehensive overview of the current understanding of the prevalence and distribution of MPs in these environments.

1. Plastics: Definition and types

Generally, plastic materials refer to a compound of polymer plus additives that has the capabilities of being shaped or molded into a valuable product. Commonly, plastics have a high stiffness/ modulus and a lack of reverse elasticity, allowing them to be distinguished from rubbers or elastomers **(GESAMP, 2015)**. These additives include inorganic fillers like silica and carbon that strengthen the material, plasticizers to make the material flexible, thermal and ultraviolet stabilizers, flame retardants and colorants. The most prevalent additives found in the environment include phthalates, bisphenol A (BPA), nonylphenols (NP), and brominated flame retardants (BFR) **(Hermabessiere *et al.*, 2017)**.

Plastics can be divided into different types according to different classification standards. For example, according to the different types of polymer materials, different types of plastic are produced globally, but the market is dominated by 6 classes of plastics: polyethylene (PE, high and low density), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS, including expanded EPS), polyurethane (PUR) and polyethylene terephthalate (PET). According to the difference in strength and toughness, they are divided into thermosets and thermoplastics. Thermoplastics are a class of polymers that can be softened and melted by the application of heat, and can be processed in the heat-softened state including PET, PE, PVC, PP , PS, polylactic acid (PLA), among others **(Chatterjee & Sharma, 2019; Chamas *et al.*, 2020)**. While, thermosets, are highly crosslinked covalent network polymers, generally provide outstanding mechanical properties, chemical and heat resistance, and dimensional stability. Thermosets have found extensive variety of applications ranging from kettle handles and surface coatings to auto bodies. However, since thermosets are cured through the formation of irreversible chemical bonds, they cannot be reprocessed or recycled upon failure, they include epoxy resin and phenolic resin, among others **(Liu *et al.*, 2022a)**.

Plastics can be broadly classified as standard plastics, commodity plastics, engineering plastics, and high performance plastics. Important classes of plastics exist under each of these categories. For example, PE, PS, PP, and PVC can all be categorized as commodity plastics. According to the different types of raw materials of synthetic plastics, they are divided into petroleum-based plastics and bio-based plastics **(Nanda *et al.,* 2023)**. The main raw materials for synthetic petroleum-based plastics come from petroleum products, and are polymer substances obtained by artificially adding or polycondensing different substances **(Okolie *et al.,* 2023)**. Common ones are PE, PP, PS, PET and PUR. Synthetic petroleum-based plastics are difficult to be used by microorganisms through biofilms due to their excessive molecular weight and hydrophobicity; in addition, these synthetic plastics have covalent bonds such as carbon-carbon bonds that are difficult to be broken and unfavorable biodegradable groups such as the benzene carboxylic group **(Suman *et al.,* 2020; Okolie *et al.,* 2023)**. Therefore, these polymers that are continuously produced and continue to enter the environment are difficult to be degraded under natural conditions, bringing almost irreversible damage to nature. It has been found that petroleum-based degradable plastics can be degraded by different pathways, including fungal degradation **(Sánchez, 2020)**, degradation by various bacteria against different substrates, and photocatalytic oxidative degradation **(Venkataramana *et al.,* 2021; Yang *et al.,* 2023)**, and enzymatic biodegradation **(Zurier & Goddard, 2021)**.

Bio-based plastics, derived wholly or partially from biomass sources, represent an environmentally friendly alternative due to their renewable nature. Examples of common bio-based plastics include polylactic acid (PLA), polyhydroxyalkanoate (PHA), and polybutylene succinate (PBS) **(Atiwesh *et al.,* 2021)**. Biopolymers are not always biodegradable, for example, PBS, bio-polyethylene (bio-PE), and others are difficult to biodegrade. Biodegradable plastics are generally considered as biodegradable petroleum-based plastics and biodegradable bio-based plastics. What we usually call bio-based plastics is a kind of biopolymer. Biopolymers can be divided into unmodified biopolymers and modified biopolymers. Unmodified biopolymers such as starch, cellulose and lignin, which are naturally occurring unmodified biopolymers; their modified variants thermoplastic starch, cellulose acetate and lignin-based polymers, are modified biopolymers **(Pooja *et al.,* 2023)**. In function of their size, plastic fragments can be classified in macro- and mesoplastics (> 5mm), microplastics (MPs < 5mm) and nanoplastics (NPs, with a range size from 1nm to 1mm) **(Mariano *et al.,* 2021)**.

Despite the various advantages in daily use, the consumption of plastic materials increases environmental pollution due to their low biodegradability, inappropriate use, and inefficient disposal. The exposure of plastic derivatives in the environment promotes physical, chemical, and biological degradation processes leading to the accumulation of small plastic fragments both in the terrestrial and aquatic ecosystems, i.e., freshwater **(Eerkes-Medrano *et al.,* 2015)**, air **(Prata, 2018)**, foodstuff **(Kwon *et al.,* 2020)**, soil **(Li *et al.,* 2020)**, and sediments **(Yang *et al.,* 2021)**. The global increase in plastic consumption increased the production of MPs.

2. Microplastics pollution

2.1 Emission sources (Generation)

Microplastics are any polymeric matrix (insoluble in water) or synthetic solid plastic particle, possessing regular or irregular shapes and size ranging from 1µm to

5mm **(Frias & Nash, 2019)**. They are released into the environment as primary or secondary MPs **(Cole *et al.*, 2011; Friot & Boucher, 2017; Wang *et al.*, 2019)**. Primary MPs are plastics that are manufactured to be of a microscopic size **(Cole *et al.*, 2011; Wang *et al.*, 2021)**. They are generated in a certain way for the first time, such as MPs in cosmetics or plastic particles and resin particles as industrial raw materials, etc. **(Browne *et al.*, 2011; Gong & Xie, 2020)**. Primary MPs are likely to enter the aquatic environment through household sewage discharge or pellets used for airblasting or spillage of plastic resin powders **(Gregory, 1996)**. Another notable source of primary MPs, is sedimented MPs from personal care or the application of sewage sludge containing synthetic fibers or household products to land **(Horton *et al.*, 2017; Akdogan & Guven, 2019)**.

Secondary MPs are formed from larger plastic fragments after decomposition into smaller particles via physical, chemical and/or biological processes **(Sundt *et al.*, 2014; Auta *et al.*, 2017; Wang *et al.*, 2021)**. Environmental conditions, like temperature and sunlight, as well as the size and density of plastic materials affect the degradation rate of macroplastics (> 5mm) **(Auta *et al.*, 2017)**. Exposure to ultraviolet (UV) radiation catalyzes the photooxidation of plastics. Weathering is the primary process for breaking down plastics **(Arthur *et al.*, 2009)**. Moreover, sunlight-induced photo degradation can cause bond cleavage, thus leading to degradation and oxidation of plastics **(Andrady, 2011; Cole *et al.*, 2011; Wagner *et al.*, 2014)**. Plastic particles are also prone to breakage by mechanical forces, such as abrasion, turbulence and fluctuation **(Barnes *et al.*, 2009)**. Furthermore, the degradation rate of macroplastics slows down remarkably, when the external environment changes such as at very deep ocean depths with low oxygen content and haline conditions in the low energy marine environment of the benthic zone, **(GESAMP, 2015; Wang *et al.*, 2018b)**. Thus, to determine the exact source of secondary MPs in the environment, the source of macroplastics (> 5mm) and related degradation processes in different environments should first be elucidated. Different sources of MPs cause them to occur in diverse forms such as fibers, pellets, and fragments in environmental samples **(Klein *et al.*, 2015)**.

Fibers are the most common form reported **(Browne *et al.*, 2011)**, likely due to the continual abrasion of clothes and upholstery made from synthetic textiles, and the release of washing machine effluent **(Napper & Thompson, 2016)**. Although synthetic fibers, essentially made of polyester, polyamide, and acrylic, are secondary MPs, they are released to the environment together with primary MPs **(Horton *et al.*, 2017)**. It has been found that 1900 fibers per item may come out during washing and are released to terrestrial and aquatic environments through wastewater effluents and sewage sludge applications **(Browne *et al.*, 2011; Akdogan & Guven, 2019)**.

2.2 Microplastics in the marine environment

Recreational and commercial fishing, coastal tourism, marine-industries (such as oil-rigs and aquaculture) and marine vessels are sources of plastic entering the marine environment directly, and causing a risk to living organisms either as macroplastics or as secondary MPs after long-term deterioration **(Derraik, 2002)**. Marine debris found on beaches can also originate from the beaching of substances carried on in-shore- and ocean currents **(Cole *et al.*, 2011)**.

On the other hand, large plastic materials and their degraded products can enter aquatic environments through different ways, including surface runoff from urban areas and agricultural lands, soil erosion and wind dispersal that can transport light macro- and MPs across the land **(Horton *et al.*, 2017)**. Further, there is an evidence that road markings and tires may also lead to MPs pollution, storm water runoff serving as an important transport pathway to carry road wear particles and tire (TRWP) to surface waters **(Horton *et al.*, 2017; Jan Kole *et al.*, 2017; Akdogan & Guven, 2019)**. MPs are considered to be a major constituent of marine debris; however, estimating the abundance, and density of these pollutants in the marine environment is difficult owing to temporal and spatial variability due to seasonal patterns and oceanic currents **(Ryan *et al.*, 2009; Cole *et al.*, 2011; Doyle *et al.*, 2011)**. **Eriksen *et al.* (2014)** developed a model demonstrating that around 5.25 trillion particles weighing 268940 tons float in the world's oceans. Most of MPs components in the Arctic Polar waters are found as fibers (95%) **(Lusher *et al.*, 2015)**. Generally, fibers are followed by fragments as the most common form of MPs in the marine environment **(Lusher *et al.*, 2015; Frias *et al.*, 2016; Martin *et al.*, 2017; Akdogan & Guven, 2019)**.

When MPs enter the ocean, they accumulate toward the circulation zone under the influence of wind and ocean currents, forming a highly polluted area with MPs **(Bakir *et al.*, 2014)**. Moreover, in closed or semi-closed sea areas, like the Mediterranean Sea, MPs form circulation pollution zones easily. **Vermeiren *et al.* (2016)** reported two fates for MPs in the ocean. Firstly, when MPs with a density greater than that of seawater sink under the influence of gravity accumulating in the sediments, and secondly, when MPs with a density less than that of seawater float on the surface of water and transport to the coastline under the influence of waves **(Gong & Xie, 2020)**.

Physical properties of MPs including shape, size, and density (0.9– 1.4g/ cm^3) have an important role in migration of MPs between seawater and marine sediments where smaller particles disperse farther into seas **(Isobe *et al.*, 2014; Xiong *et al.*, 2022)**. The MPs migration is also influenced by tides **(Wessel *et al.*, 2016)**. The size of the plastic particles is important since it affects their potential hazard to individual organisms, communities, and ecosystems. Larger plastic litter items may be eaten by or cause entanglement of marine fish, birds and mammals, while the micro- and nanoplastic particles are more prone to be ingested not only by large but also by smaller invertebrates such as mussels and zooplankton with the potential for accumulation in food chains **(Andrady, 2011; Wesch *et al.*, 2016)**.

The global seas and oceans confronted the issue of high concentrations of MPs found in the water column, surface sediments, and even present within marine species in abundant levels. Oceans and marine ecosystems act as repositories for plastic particles originating from inadequate solid waste management. These particles are transported through rivers and even the atmosphere, ultimately finding their way into coastal and oceanic environments **(Allen *et al.*, 2020)**. The nature and amount of these pollutants are contingent upon several factors, including the origin's location, water dynamics, chemical composition and density of the particles. These factors influence the buoyancy and biofouling of the particles **(Van Sebille *et al.*, 2020; Carvalho Ferreira & Lôbo-Hajdu, 2023)**.

2.2.1 Seawater

It is crucial to take into account that the presence of MPs in surface water tends to rise as the production and utilization of plastic materials increase. This influx can occur due to inadequate disposal practices and ineffective removal during wastewater treatment **(Rodrigues dos Santos *et al.*, 2023)**. MPs concentrations were detected in minimal quantities (0.233 items/ m^3) in certain oceanic waters, while in other oceans, notably higher levels were observed, ranging from 39,217 to 514,817 items/ km^2. The levels of MPs in the oceans worldwide and marine ecosystems depend on diverse sources within various regions, leading to a random distribution **(Biswas & Pal, 2024)**. The migration and transformation of MPs in the ocean are affected by external factors, including physical, chemical, and biological elements. The transport of MPs through seawater movement, both horizontally and vertically, plays an important role, serving as a significant force driving the extensive distribution of MPs throughout the ocean **(Pohl *et al.*, 2020; Fan *et al.*, 2023)**.

Lee *et al.* (2013) observed that plastic particles in South Korean waters consist of intact plastics, fragments, and Styrofoam, with an average concentration of 27,606 particles/ m^2 for large MPs. Meanwhile, **Song *et al.* (2015)** documented the presence of paint resin particles (75%), spherules (14%), fibers (5.8%), PS (4.6%), and sheets (1.6%) with an average concentration of 88± 68 particles/ L. In India, the primary types of MPs were identified as PP and PE **(Veerasingam *et al.*, 2016)**. **Castillo *et al.* (2016)** illustrated that in Qatar's water, the main MPs types were PP, with an average concentration of 0.71 particles/ m^3 and a size ranging from 125μm to 1.82mm, and fibrous particles with sizes from 150μm to 15.98mm. In Scotland's marine waters, PET and microfibers predominated, with an average of 70.8 particles/ m^3 and sizes of 0.4 and 8.3mm for PET and microfibers, respectively **(Courtene-Jones *et al.*, 2017)**. In Antarctica's waters, fibers and fragments, PE, and PP were identified as the major components, with an average concentration ranging from 0.0032 to 1.18 particles/ m^3 **(Cincinelli *et al.*, 2017; Ashrafy *et al.*, 2023)**.

2.2.2 Marine sediments

Marine sediments have shown long-term sinks for MPs **(Cózar *et al.*, 2014)** and have the ability to accumulate MPs **(Nuelle *et al.*, 2014)**. Now, very high levels of MPs are found within marine sediments; these plastics can account for 3.3% of sediment weight on highly impacted beaches **(Van Cauwenberghe *et al.*, 2015; Auta *et al.*, 2017)**. The elevated concentrations of MPs in sediments than water may be due to their hydrophobic nature and density, which make them prefer accumulation in sediments **(Xu *et al.*, 2020)**. Moreover, **Zhang *et al.* (2020)** reported that aquaculture facilities are a main source of MPs sheets in the sediment samples.

The impacts of MPs are increased by the adsorption of different toxic pollutants **(Khalid *et al.*, 2021; Cordova *et al.*, 2022; Liu *et al.*, 2022b)**. These include organic contaminants like polybrominated diphenyl ethers (PBDEs) **(Tanaka *et al.*, 2015)**, polycyclic aromatic hydrocarbons (PAHs) **(Diepens & Koelmans, 2018; Lo *et al.*, 2019)**, polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT) **(Wang *et al.*, 2018a)**, and polyfluoroalkyl substances (PFAS), as well as pharmaceuticals and personal care products **(Ateia *et al.*, 2020; Zhou *et al.*, 2020)**. Furthermore, they include heavy metals **(Wang *et al.*, 2017, 2021)**. Additionally, MPs can also release some additives **(Celino-Brady *et al.*, 2021; Herrera *et al.*, 2022)**. Chemical/ metal-based toxicity is also identified with MPs besides physical toxicity (due to ingestion and the subsequent effect on vital organs) that enhances the harming effect of these micro polymers **(Vaid *et al.*, 2021)**.

2.2.3 Biota

Different aquatic and marine organisms including invertebrates, mammals, birds and fish ingest MPs by mistake for food. This can trigger reduced efficiency of feeding, malnutrition and physical blockages. Moreover, animals can become entangled in larger MPs, leading to impairing the capability to reproduce and move. MPs can also pass in the food chain, beginning from primary producers such as algae and phytoplankton then continuing through higher organisms **(Thacharodi *et al.*, 2024)**.

3. Impacts of microplastics toxicity

MPs can have several negative impacts on marine organisms, including zooplankton, fish and invertebrates causing a range of harmful consequences **(Palmer & Herat, 2021)**. The primary influences include physical consequences, ingestion, biomagnification, chemical toxicity, bioaccumulation, impaired reproduction and developmental issues, disturbances in physiology and behavior in addition to ecological effects.

Unreacted chemical additives, oligomers and monomers released from plastics are accountable for the probable toxicity of MPs **(Padervand *et al.*, 2020; Adegoke *et al.*, 2023)**. **Hahladakis *et al.* (2018)** examined the movement and supply rates of additives in addition to their probable harmful influences on environment and inhabiting organisms. They found that the real release rate relies on the initial concentration of additives and the lipophilicity. The release of volatile components from plastics, including methylene, chloride, toluene, benzene, ethylbenzene and styrene can negatively influence long-term health **(Andrady, 2017; Padervand *et al.*, 2020)**, which is a causal issue of chronic health impacts. In a study by **Bashirova *et al.* (2023)**, accumulation of PET and NPs in larvae of zebrafish (*Danio rerio*) was observed in kidney, intestine and liver, HRMAS NMR analysis showed that PET and NPs resulted in significant change of compounds correlated with pathways related to oxidative stress and detoxification; damage of integrity of mitochondrial membrane through level elevation of polar head sets of phospholipids and changes in several compounds related with paths of energy metabolism.

Toxicity of MPs was further confirmed by **Lu *et al.* (2016)**, who assessed the harmful impact on zebra fish after 7 days of exposure to PS MPs. It was found that exposure to MPs caused the gathering of MPs (5µm) in the stomach, gills and liver of the fish, while MPs (20µm) were detected in the fish gut and gills. Additionally, the most substantial toxicity impacts in this investigation were inflammation and lipid buildup of the liver, along with unfavourable alternations and oxidative stresses in the metabolic outline of the liver. The absorption capability and toxicity of consumed MPs are also affected by the texture and form of the MPs. The spherical form of PE MPs had less toxicity on amphipod *Hyalella Azteca* than in the case of exposure to PP in the form of fibers, as was shown by **Au *et al.* (2015)**. Owing to the investigators, this is as a result of the fibers' prolonged dwelling period in the gut, which has an effect on the abilities of food processing, leading to significant modifications. **Hawke *et al.* (2024)** examined the probable influences of MPs from PE, biopolymer and a petroleum-derived polymer on routine swimming, aerobic metabolism and the escape performance of fish *Forsterygion capito*. They reported negative effect of PE on the fish after exposure through slower speeds, higher sensitivity in escape performance comparing to control fish.

An investigation of the effect of phenanthrene-loaded low-density polyethylene glycol MPs on the reactions of biomarker in the juvenile African catfish showed noteworthy tissue modifications in brain and liver **(Karami *et al.*, 2016)**. Ingestion of MPs could also trigger functional and anatomical alterations in the digestive tracts, initiating development and dietary problems in fish **(Bhuyan, 2022)**, with mortality happening normally before reaching maturity according to MPs intake. Most of the investigations were directed on *Danio rerio*. Decreased mobility, injury of reproductive organs, oxidative stress, and disruption of gene expression are the most mutual impacts on *Danio rerio* **(Zhao *et al.,* 2021; Zhang *et al.,* 2022)**. The second most investigated fish species was *Oryzias melastigma*, which was exposed to physical damage as a result of MPs consumption **(Xia *et al.,* 2022)**. Dysbiosis of gut, weight reduction, damaging reproductive organs, growth inhibition and anti-oxidative disturbance are noticeable impacts in *Oryzias melastigma* **(Feng *et al.,* 2021; Luo *et al.,* 2021; Li *et al.,* 2022; Wang *et al.,* 2022)**.

Hämer *et al.* (2014) reported that MPs are normally ingested by biota, and they caused progress of toxicological impacts in the organisms. Exposure of *Mytilus* spp. (a marine mussels) to polystyrene MPs for seven days caused an increase in the level of fluoranthene compounds in the mussels **(Paul-Pont *et al.,* 2016)**, and mussels exposed to pure fluoranthene had less fluoranthene content and also less histopathological damage than in the case of exposure to fluoranthene-loaded MPs. They stated that the process relies on interaction of MPs and p-glycoprotein in the cell wall of sea mussel.

Seasonal levels of MPs and biomarkers such as oxidative stress, energy, neurotoxicity and condition index, in addition to human risk of MP intake (HRI) were assessed in the mussels *Mytilus galloprovincialis*. Seasonal means of MP in mussels fluctuated between 0.312± 0.092MPs/ g (summer) and 0.111± 0.044 (spring). HRI ranged from 2438 to 2650MPs/ year. Seasonal variation of mussel stress ranged from IBR: 1.4 in spring to 9.7 in summer, and the concentrations of MP were not correlated **(Ferreira *et al.,* 2023)**.

Zhang *et al.* (2017) investigated the negative effects of MPs on the photosynthesis process of the sea microalgae *Skeletonema costatum*. They detected that the highest inhibition of growing ratios occurred after 96h of exposure to MPs (a diameter of 1mm). It was detected that 32% decline in photosynthetic efficiency and 20% of chlorophyll contents in addition to the damaging effect on growth of microalgae were observed after exposure to 50mg/ L of MPs. SEM analysis proposed that aggregate formation and sorption of MPs on microalga surface were the probable ways of toxicity.

In a very recent review, **El-Naggar *et al.* (2024**) discussed threats of microplastic pollution on different fish species and its implications on human health. They found that the negative consequences on fishes start from showing abnormal behaviors to complete intestinal obstruction affecting the basic metabolism of fishes. On the other hand, among the major impacts of such polymers on human health are: oxidative stress, immunosuppression, neurotoxicity, and malignant tumors. The aforementioned diseases can eventually lead to either fish mortality, thus affecting the national income or human death.

The toxicity and biological influences of LDPE-MPs on the marine microalgae *Chaetoceros calcitrans* were examined by **Senousy *et al.* (2023)**. The results showed that LDPE-MPs exhibited a concentration-dependent hostile consequence on the performance and growth of *C. calcitrans*. Monosaccharides and extracellular polysaccharides contents of *C. calcitrans* were enhanced in case of low concentration of LDPE-MPs, which could assist the adsorption of MPs on the cell wall. The process of adsorption triggered structure damage to the algal cell, as detected by scanning electron microscope (SEM). *Chlorella* sp. was negatively affected by MPs concentrations (0.01– 100mg/ L) compared to natural fibers, such as pp fibers, PET, wool and cotton through an effect on the accumulated energy, the exchanged substances and interaction of cells in the environment **(Cheng *et al.,* 2024)**.

Sublethal effects of consumed plastics in free-living seabirds were observed. Birds with consumed plastics had more deterioration and inflammatory response, higher damage of tissues through several organs, and also more concentration of embedded MPs in the kidneys, spleen and proventriculus compared to cases without ingestion of plastic. The ingested plastics caused inflammation of the proventriculus, mainly the inferior part. This appeared as loss of tissue structure and oedema, erythema (redness). This effect was relative to plastic density. It was detected that this inflammation was as a result of injury caused by the presence of obtrusive or sharp plastics that physically injured the epithelial surface of the proventriculus, causing swelling of the surrounding tissues or considerably enlarged water content. Consumed plastic also caused a noteworthy loss of rugae which acts a serious role in the absorption and digestion of nutrients via raising the surface area and permitting the increase of the proventriculus **(Rivers-Auty *et al.*, 2023)**.

Fackelmann *et al.* (2023) investigated the effect of MPs ingestion by 2 species of seabird. They observed changes in cloacal and proventricular microbiomes. The concentration of MPs in the gut was interrelated with a decrease of commensal microbiota and an increase in pathogens, plastic-degrading and antibiotic-resistant microbes. These observations demonstrate that microplastic concentrations in the environment are associated with variations in gut microbiomes of wild seabirds.

4. Transfer of microplastics along the trophic chain

The consumption of plastics by marine biota has been shown in the environment and the laboratory experiments. The dwelling period of MPs in the gut was related to the shape, size, roughness and species **(Botterell *et al.*, 2020)**. A report by **Walkinshaw *et al.* (2020)** underlined that there is no risk to health. Though, few reports revealed that NPs were transmitted from prey to predators such as from mussels to crabs. As NPs were detected in the gills, hepatopancreas, stomach and ovary of mussels **(Farrell & Nelson, 2013)**. Another investigation revealed that NPs could be transmitted from algae to fish and herbivores, causing change in their behavior, such as disorder in lipid metabolism, less hunting and slower movement. Despite the fact of trophic transfer, no biomagnification of SMPs has been detected **(Walkinshaw *et al.*, 2020)**. However, even if trophic transfer occurred, it is still not known if the transferred particles are emitted at higher trophic levels, or whether bioconcentration and bioaccumulation occurred **(Provencher *et al.*, 2019)**.

MPs pollution in marine environment and its negative impacts via trophic transfer among marine organisms are still a developing concern. Trophic transfer and impacts of MPs was investigated using a primary organism including *Artemia salina*, secondary organism such as *Litopenaeus vanamei*, and tertiary organism viz. *Oreochromis niloticus*. Transfer of MPs among the three model organisms was investigated (24- 48h) after exposure of *A. salina* to 1µm polystyrene. The presence of MPs in the faecal matter and gut epithelium was observed. This study suggested the potential hazard of microplastics ultimately reaching human through the food chain **(Saikumar *et al.*, 2024)**.

Transferring MPs to human frequently happens through the consumption of seafood (e.g., crustaceans and fish) **(Smith *et al.*, 2018; Albazoni *et al.*, 2024)**. The process of MPs absorption from food to body of human is relatively clear. Particles with nano-size are capable of passing through cellular membranes. Additionally, these particles can make circulation through the stream of blood reaching the placenta and brain barrier **(Barboza *et al.*, 2018)**.

Penetration of tiny particles (smaller than 2.5µm) occurs simply in the intestinal tract via endocytosis by Peyer's lymph node. Transport of MPs mucosa-associated to lymphoid tissues is aided by microfold cells. This can occur also between cells. After infiltration of MPs into human body, a toxicity effect can be noted leading to an inflammation **(Wright & Kelly, 2017)** and causing severe health problems.

5. Characterization of microplastics

The characterization of MPs, involving isolation, identification, and/or quantification, poses an analytical challenge due to the absence of standardized methods, hindering comparisons across different studies **(Elert *et al.,* 2017; Rochman *et al.,* 2017; Picó & Barceló, 2019)**.

5.1 Extraction

The extraction of (MPs) from various samples, primarily environmental samples such as water, sediments, and biota, serves as a preliminary step before their characterization. This extraction process involves separation techniques based on density differences, sieving, digestion (depending on the organic matter content in the sample), and filtration, as documented in the literature **(Nguyen *et al.,* 2019; Prata *et al.,* 2019; Peñalver *et al.,* 2020)**. Conversely, there are three recent methods for extracting micro and nanoplastics highlighted in the literature **(Dierkes *et al.,* 2019; Grbic *et al.,* 2019; Zhou *et al.,* 2019)**, which hold significant promise for future investigations. One of these methodologies involves extracting MPs (such as PE, PET, PS, polyurethane (PU, PVC, and PP) from seawater **(Grbic *et al.,* 2019)**. This method utilizes modified iron nanoparticles that bind to plastics, allowing for their recovery through magnetic attraction. Plastics are then directly analyzed on the magnet using fluorescence microscopy without the need for additional steps. A second study centered on the separation of MPs through a cloud-point extraction procedure (CPE) **(Zhou *et al.,* 2019)**. In this approach, two types of nanoplastics (PS and poly(methyl) methacrylate (PMMA)) were extracted from environmental waters using Triton X-45 as a non-ionic surfactant. This led to the formation of micelles containing the nanoparticles when the temperature exceeded its cloud-point temperature. A third technique, as outlined by **Dierkes *et al.* (2019)** involves the extraction of MPs using automated pressurized liquid extraction. This solvent extraction method facilitates both matrix removal and MP enrichment in a single, fully automated step. The approach has demonstrated successful application to various environmental samples, enabling the comprehensive analysis of PE, PP, and PS by pyrolysis-gas chromatography-mass spectrometry (Py-GC-MS) within a 7-hour timeframe.

5.2 Identification

5.2.1 Visual inspection methods

Visual inspection is commonly the initial method employed by researchers in the characterization of MPs. The examination of MPs involves direct observations using the unaided eye, optical microscopes, and/or electron microscopes. These methods are employed to choose and categorize MPs, as well as to assess their color and size **(Hidalgo-Ruz *et al.,* 2012; Filella, 2015)**. On the other hand, it offers the advantage of easily identifying samples with a substantial presence of large MPs, providing a quick and cost-effective overview of their abundance. However, this method has limitations, as it cannot establish the nature of the samples, and identification techniques need to be combined. Additionally, the identification of MPs smaller than 100µm is challenging, even with a microscope **(Dümichen *et al.*, 2017)**. Hence, the development of advanced technologies for more precise and effective identification of MPs is crucial.

5.2.2 Thermal analysis

Thermal analysis presents an effective protocol for investigating MPs in environmental samples. The methodology relies on identifying the polymer based on its degradation products. Indeed, the pyrolysis-gas chromatography/mass spectrometry (Pyr-GC-MS), thermogravimetry (TGA), hyphenated TGA such as TGA-mass spectrometry (TGA-MS), TGA-thermal desorptiongas chromatography-mass spectrometry (TGA-TD-GC-MS), thermal extraction and desorption (TED)-GC/ MS , and differential scanning calorimetry (DSC) approaches are widely utilized for the identification of MPs iin the environment, primarily because of their outstanding detection accuracy **(Peñalver *et al.*, 2020)**.

5.2.3 Spectral analytical methods

Currently, spectroscopic techniques can both detect and confirm the composition of MPs. This is possible since the spectral signal reflects distinctive characteristic peaks produced by each type of MP. Polymer types of MP particles, with minimum particle sizes of 10 and 1µm, have been identified using FTIR and Raman spectroscopy **(Rashed *et al.*, 2023)**.

5.2.4 Other analytical techniques

Scanning electron microscopy (SEM) is commonly used for surface morphology investigation, coupled with energy dispersive X-ray spectroscopy (EDX) for the elemental microanalysis. The association of morphological and elemental composition analyses has been confirmed as a beneficial tool to characterize plastic materials **(Naji *et al.*, 2018; Ding *et al.*, 2019; Gniadek & Dąbrowska, 2019)**. Currently, there is limited independent research on the direct detection of MPs using SEM-EDS, likely since this technique does not provide chemical composition **(Lin *et al.*, 2021)**.

6. Plastics pollution in Egypt

The plastic consumption in Egypt has reached an unsustainable level. According to data from the Our World In Data Organization (OWID) by **Ritchie *et al.* (2022)**, Egypt generates around 5.4 million tons of plastic annually, with this figure steadily increasing each year. Alarmingly, 67% of this plastic waste is mismanaged, leading to incineration and improper disposal in open and illegal landfills. This mismanagement poses a significant risk of plastic finding its way into water bodies through various means such as winds and streams, as reported by the World Wide Fund for Nature (WWF) in 2019. Despite the data being from 2010, projections for 2025 suggest a continued high rate of growth in plastic production within the country **(Ritchie *et al.*, 2022)**. **Abdellatif *et al.* (2021)** reported that Egypt released 0.25M tons of plastic to the Mediterranean Sea. The most required and produced polymers in Egypt are PP, HDPE, LDPE, LLPE and PET **(Shabaka *et al.*, 2019)**. This highlights the urgent need for effective measures to address plastic waste management in Egypt.

The European Commission, in collaboration with the Ministry of Environment of Egypt and the United Nations Environment Programme (UNEP), has spearheaded a nationwide initiative to address the issue of plastic pollution. This initiative focuses on restricting the use of commercial high-density polyethylene (HDPE) plastic bags, developing policies to reduce single-use plastics, and promoting eco-friendly alternatives. The Egyptian Environment Agency Authority (EEAA) has played a role in organizing consultation workshops to raise awareness about the detrimental effects of plastic litter, as outlined by **Sharma *et al.* (2021)**.

Despite the active involvement of EEAA in leading awareness campaigns and initiatives, the problem of marine litter persists in Egypt. This is attributed to the lack of enforcement of existing legal instruments, insufficient operational infrastructure at both national and local levels, inadequate penalties for offenders, insufficient education on sustainability, and a lack of coordinated efforts across various economic sectors. Additionally, the absence of transparent research with scientifically sound data hampers the ability of stakeholders and decision-makers to formulate effective management plans, leading to challenges in addressing the plastic pollution issue effectively **(Abdel Ghani *et al.*, 2022)**.

7. Microplastics in Egyptian coasts

Fig. (1) shows the Egyptian coasts on which studies were recently conducted to determine the occurrence, identification, and distribution of MPs.

7.1. Mediterranean Sea

Limited studies have been conducted along the Egyptian coast of the Mediterranean Sea, with a focus on monitoring the distribution of MPs in various marine environments. Given that Alexandria has been recognized as a city making the most significant contribution to marine litter inputs into the Mediterranean Sea, it was imperative to conduct a local study on the primary sources of plastic pollution and polymer composition. Alexandria, situated on the southeastern coastline of the Mediterranean Sea, stretches around 40km along the northwest edge of the Nile delta in Egypt. Recognized for its historical significance, this city stands as a vital economic center and boasts a population exceeding 5.3 million, ranking it as the second-largest city in Egypt. Its appeal is further enhanced by picturesque beaches that attract millions of visitors each summer, placing significant demands on the city's crucial facilities and infrastructure. The fusion of historical charm and contemporary attractions solidifies Alexandria's status as a prominent hub in Egypt **(Frihy *et al.*, 2004)**.

Shabaka *et al.* (2019) provided for the first time, a precise, simple, and cost-effective method to identify MPs in the Eastern Harbor by using differential scanning calorimetry (DSC). From a 1kg sediment sample, a total of 242 fragments were collected, while, 363 plastic fragments were extracted from 15L bulk water sample. The study identified through this screening, the presence of ten polymers in both seawater and shoreline sediments. The polymers were polyethylene vinyl acetate (PEVA), PP, acrylonitrile butadiene styrene (ABS), PS, polytetrafluoroethylene (PTFE), PET, low-density polyethylene (LDPE), low low-density polyethylene (LLDPE), high-density polyethylene (HDPE) and nylon. The study revealed that the majority of MPs retrieved from the Eastern Harbor were identified as secondary MPs, indicating that they are remnants of larger plastic fragments. The diverse polymer types, colors, and physical forms suggest a range of sources. In addition to land-based sources, marine-based sources, such as fishing and recreational boats in the Eastern Harbor, significantly contribute to plastic litter pollution in the study area.

Abdel Ghani *et al.* (2022) studied the accumulation of plastic particles along the beaches of Alexandria during 2021. However, microscopic examination was used to study the types and sizes of MPs and the numerical estimation of their quantities. Thermal analysis techniques, DSC TGA, were applied for the chemical characterization and quantification of plastic polymers. The investigation delved into the density and polymeric composition of plastic particles at 22 locations, encompassing eight beaches along the shoreline from Abu Qir Bay to the Eastern Harbor. The study reported that, a total of 856MP particles were gathered from the shore sediments, with an average value of 389.1± 285.9 items per kilogram of dry weight (dw). The MPs displayed various colors, including blue, green, red, yellow, translucent, white, and black, with blue being the predominant color. Different types of MPs were identified, such as films, fragments, glossy fragments, and filaments. Among these, glossy fragments were the most prevalent type in the sediment samples. Hard fragments and filaments made similar contributions across most beaches, while films exhibited the lowest occurrences. The size of the plastic particles ranged from 24 to 7829µm, with an average of 1267.9± 1649.54µm and a predominant size class of 50– 200µm. More than 60% of the measured MPs fell within the size range of 50 to 1000µm, while mesoplastics larger than 5000µm accounted for 4%. The DSC analysis of the extracted MPs showed a total of ten plastic polymers in sediments, including LDPE, LLDPE, HDPE, PA, isotactic polypropylene (iPP), sydiotactic polypropylene (sPP), PET, polyethylene-vinyl acetate (PEVA), PTFE, and syndioactic polystyrene (sPS), with the predominant of LDPE. The study recorded a total of 966MP particles extracted from the surface water, with an average of 457.4± 281.8 items m^{-3}. The plastic particles exhibited a size range from 50 to 5273µm, with an average size of 838.5± 962.1µm, and a predominant size class of 500– 1000µm. Over 75% of the measured MPs fell within the size range of 50 to 1000µm, while mesoplastics constituted 2.5%. Thermal analysis revealed the presence of the same polymers in the sediment with the dominance of PEVA. The study concluded that land-based sources including single-use plastic bags and domestic waste, antifouling paints and fishing nets represented the main sources of plastic pollution in Alexandria. The research aimed to assess the extent of MPs accumulation in marine organisms and its implications for human health, as well as evaluating the extent of plastic pollution in the Eastern Harbor of Alexandria Governorate. Recent study focused on determining microplastic concentrations in various fish species **(Shabaka *et al.*, 2020)**. MPs were estimated in the digestive tracts of 8 species of fish from the Eastern Harbor, namely *Siganus rivulatus, Diplodus sargus, Sardinella aurita, Sphyraena viridensis, Boops boops, Lithognathus mormyrus, Terapon puta,* and *Atherina boyer*. Thermal analysis (DSC and TGA) was used for quantitative estimation. The study reported that MPs were detected in all fish samples with the following percentage: 56% of all fish samples had < 500MPs per fish and about 30% had < 100MPs per fish. Large densities of > 5000MPs per fish were represented by 19% of the samples. Stereomicroscopic investigation showed the presence of filaments and foam fragments in all fish. Thermal analysis showed the presence of different types of MPs polymers in the digestive tracts of fish, namely PP, PEVA, HDPE, LLDPE, LDPE, PET, and nylon. The study indicates that the elevated levels of MPs contaminants found in fish signal a significant pollution issue in one of Egypt's crucial fishing zones, potentially impacting both fish populations and human health.

In continuation of the study, **El-Sayed *et al.* (2022)** investigated MPs contamination in digestive tracts of nine economic fish species caught from the

Eastern Harbor and Abu-Qir Bay, Alexandria Governrate. A standardized procedure for extracting and quantifying MPs, incorporating imaging techniques such as microscopy and thermal methods, was utilized. Based on the results of thermal analysis, six semi crystalline polymers, including LDPE, LLDPE, HDPE, polyamide/nylon (PA), PEVA and PTFE were detected with the dominance of PEVA and LDPE. The study concluded that the presence of MPs in the analyzed fish was impacted by both the species and the location, with an observed interaction between these two variables and attributed the differences in MPs types between both to the difference in pollution sources. While Abu-Qir bay gets domestics and industrial wastes from different factories, the Eastern Harbor is influenced by human activities such as, fishing activities, yacht sports, boat building workshops, and recreation activities **(Abdel Ghani *et al.*, 2013, 2022; Shabaka *et al.*, 2020)**. The occurrence and average densities of MPs were found to be 91.8± 8.4% and 11.7± 9.5 items per fish, respectively, which are comparable to highly polluted areas in the southeastern Mediterranean Sea. Specifically, *Sparusaurata* exhibited a significantly higher average MPs concentration of 38.3± 28.4 items per fish compared to all other species. On the other hand, **Said *et al.* (2022)** examined the levels of MPs in the shellfish *Arca noae*. Samples were collected from five locations along the southeastern Mediterranean coast of Alexandria, Egypt, including El Max, Mamoura, Abu Qir, Lake Edku and Rosetta. Stereomicroscope was used to investigate the presence of items resembling MPs, while attenuated total reflection Fourier transform infrared spectrometer (ATR-FTIR) was used to identify different polymers. The results of this study revealed that, *Arca noae* soft tissues exhibited a 48% occurrence of ingested MPs, with an abundance of 1.65± 0.28MPs per individual and 0.58± 0.04 items per gram of wet tissue weight. The most prevalent polymer in *A. noae* was PE, followed by PP and PS.

7.2. The Red Sea

Abdel Ghani *et al.* (2023) introduced the first comprehensive survey of Mps in the Egyptian shores along the Red Sea encompassing the Gulfs of Suez and Aqaba. Sediment samples were collected from stations representing three regions, where human activities and/or coastal habitats differ. The plastic particles were counted and classified based on their shapes and sizes by using microscopic investigation. FTIR was used to identify the plastics polymers. Surface morphology of MPs was examined through a scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM/EDS). The study revealed that, the average concentrations of MPs ranged from 23.3± 15.28 to 930.0± 181.9 particles/ kg dry weight. The pollution load index varied from low to medium levels in most locations. Four plastic polymers (HDPE, PE, PP and PS) with the dominance of PE and PP were detected. However, a study from the Suez Gulf reported a low prevalence of MPs in beach sediments, with an average of 204.3± 146.6MPs/ kg dry weight **(Taher *et al.*, 2023)**. Polymers were identified by using thermal analysis. Four types of thermoplastic polymers were detected: PEVA, nylon, PP, and PTFE, with PEVA dominating across all study areas. This reflected the dominance of marine-based sources and associated industrial activities over land-based activities.

Moreover, **Abd-Elkader *et al.* (2023)** investigated MPs quantity and polymeric composition among invertebrate species (namely *Bivalvia*, *Gastropoda*, *Echinoidea*, and *Holothuroidrea*) for the first examination of MPs in marine invertebrates in the Red Sea Coast of Egypt. Thermal analysis techniques were applied for MPs identification. The study revealed that MPs concentrations differed among species, with quantities ranging from 8.2 to 136.5 items per organism or 0.2 to 18.1 items per gram of wet tissue weight, and a complete occurrence across all specimens. Different polymers were detected: PA, PEVA, isotactic/ sydiotactic PP, PTFE, LDPE, and HDPE. This suggests multiple sources of pollution, coming mainly from tourism and maritime activities.

There are some studies concerned with studying plastic pollution in both the Mediterranean and Red Sea environments. **Hamed *et al.* (2023)** investigated MPs pollution in marine fishes collected from fish markets in Hurghada, Suez, Port Said, and Alexandria. MPs were found in the gastrointestinal system but not in muscle or liver tissues. The most common MPs sizes were >5000 (26%), 500– 1000 (25.8%), and 1000– 5000µm (22.7%). The highest concentration was observed in fish from Hurghada (4.16 items/ individual). Based on FTIR results, seven polymers were detected, including PE, PP PS, polyamide (PM), PET, PVC, and polyacrylonitrile. In the Red Sea, PE was the predominant polymer, whereas PP was dominant in the Mediterranean Sea.

Another study has investigated the abundance of MPs in surface water, sediments, and gastrointestinal tract of different fish species **(Sayed *et al.*, 2021)**. The study indicated that the Mediterranean Sea is more polluted than the Red Sea. The highest abundance of MPs particles in surface waters were 50.66± 0.57 particles/ 100ml for the Red Sea and 46.66 ± 2.27 particles/ 100ml for the Mediterranean Sea. In sediment samples of the Red Sea, the highest MPs abundance was 50.6± 4 particle/ 100g, while, in the Mediterranean Sea, the MPs abundance was 76.6± 4 particles/ 100 g. The highest abundance of MPs, with 5.66± 1.5 particles/ fish, was recorded for fish species caught from the Red Sea, while those caught from the Mediterranean Sea had an abundance of 8.6± 1.2 particles/ fish."

7.3. The River Nile

The River Nile holds a global significance and is vital to Egypt as the longest river in the world, spanning 6693km. Its course runs from south to north, traversing ten African countries before reaching Egypt. Originating in Aswan Governorate in the far south, it flows through eight governorates of Upper Egypt before reaching Lower Egypt in Cairo, ultimately draining into the Mediterranean Sea through the Nile Delta. The River Nile has been recognized as a significant source of plastic litter flux in the eastern Mediterranean basin. It has earned the nickname “Plastic Nile”. Certainly, various pollutants in the River Nile stem from a range of sources, spanning from natural to anthropogenic influences. Common contributors to pollution comprise industrial activities, urban development, tourism, fishing, shipping, resorts, and harbor operations **(Hassan *et al.*, 2023)**.

Shabaka *et al.* (2022) provided a comprehensive evaluation of the concentrations, composition, and risk of MPs in connection with various human activities in the two main downstream of the River Nile and the vicinity of their estuaries on the Deltaic coast of the Mediterranean. Thermal analysis techniques were applied to identify plastic polymers in sediments and water samples. The study reported that, the concentration of MPs in surface water varied from 761± 319 to 1718± 1008MPs/ m^3 and it ranged from 167± 137 to 1630± 1303MPs/ kg in dry sediments. Seven plastic polymers were identified through thermal analysis, including PE, PP, PET, PEVA, LDPE, HDPE, and PTFE. The results showed that, in both branches (Rosetta, and Damietta) the surface water exhibited the highest levels in both ecological and polymer risk assessments. In general, the study concluded that the Nile estuaries are moderately polluted with MPs.

Khallaf *et al.* (2023) addressed the plastic pollution in two commercially important fish species (*O. niloticus* and *C. gariepinus*) caught from the Nile Canal (Bahr Shebeen), Delta of Egypt. Bahr Shebeen is a semi-independent water ecosystem that traverses three Egyptian governorates: Menoufia, Gharbia, and Dakahlia, located in the Delta region. Originating from the Nile, it reconnects with the river near the Barrage via Alrayah Almenoufi **(Khallaf & Authman, 1992)**. The canal spans approximately 80km in length, with a depth of 2- 3m and a width of 30m **(Khallaf & Alne-na-ei, 1987)**. The presence of MPs was investigated in stomachs and dorsal muscles of fish. The optical microscope equipped with a digital camera was used to identify and counting of MPs, while FTIR technique was used to MPs polymer characterization. The study reported that the number of particles per fish did not exceed 10. Fragments and fibers were predominant. Identified polymers included PA, alkyd resins, PE, PET, and rayon. Polyamides and rayon were found to be highly prevalent in both species.

As the problem of plastics pollution worsens, a study has contributed to provide data on the occurrence and distribution of meso- and macroplastics in the water, sediment, fish, and crayfish from Upper Egypt's River Nile **(Hassan *et al.*, 2023)**. The study was achieved on the basis of visual examination of meso and macroplastics using microscopic analysis. The selection of sites in the study was based on diverse urbanization and a range of anthropogenic activities: Edfu site in Aswan Governorate is a tourist site, Nagaa Hammadi site in Qena Governorate is an urban site, and El-wasta site in Assiut Governorate is a rural site. The study reported that, except for the Nile tilapia, meso- and macroplastics have been detected in all waters, sediments, and vertebrate and invertebrate samples. The results revealed that the highest levels of meso- and macroplastics were detected in Nagaa Hammadi, with an average of meso- and macroplastics of 20.3± 3.5, 4.3± 2.5, and 2.0± 1.7 mesoplastic/ 100mL and 14.3± 1.2, 6.0± 2.3, and 0.0 macroplastic/ 100 mL in water; and 9.0± 3.8, 5.6± 5.9, and 1.3± 1.3 mesoplastic/ 100g, as well as 10.6± 2.8, 10.6± 6.9, and 3.3± 0.5 macroplastic/ 100g in sediment samples, respectively.

Mesoplastics (0.5- 2.5cm) levels ranged between (0.5 and 1.3) and varied from 0.1 to 0.2 particle/ individual in the alimentary canal of the African catfish and crayfish, respectively. Whereas, in gills, measoplastics particles were not present in crayfish species and ranged from 0.0 to 0.6 particle/ individual in the African fish. Notably, no macroplastics were detected in the crayfish's gills or alimentary canal. The differences in macroplastics accumulation were related to feeding habits.

CONCLUSION

The Egyptian coasts hold an economic importance and are subjected to diverse human activities. Plastic pollution poses a significant environmental threat, especially in the Mediterranean Sea, with Egypt being a major contributor. However, research on the impact of plastic pollution along the Egyptian coasts is limited. The existing studies mainly focus on monitoring and assessing pollutant types, leaving numerous areas unexplored, especially concerning MPs. There is an immediate need for increased efforts to investigate both macro- and microplastic pollution along the Egyptian Mediterranean and Red Sea coastlines. Urgent focus is required for critical areas like the Nile Delta and Suez Canal. Additional research is crucial to understand and address this issue comprehensively. Continued monitoring of plastic pollutants in the Egyptian aquatic ecosystem is advised to protect Egypt's food sources. A crucial step in managing plastic debris along the Egyptian coasts and mitigating its negative effects on freshwater and marine ecosystems is the reduction of plastic consumption, effective waste management and regulating the unrestricted disposal of plastic waste. Further, recognizing plastic waste on the Egyptian coasts enables policymakers to explore strategies for minimizing pollution originating from plastic in the region. In addition, there is a pressing need for studies concerning the removal and bioremediation of plastic pollutants, as well as the development of recycling processes and environmentally-friendly plastic alternatives that can be degraded with less harm to the ecosystem and human health.

Conflict of interest

Authors declare that there is no conflict of interest.

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