

Microplastic Pollution Threatens the Working Capacity of the Reverse Osmosis Plant Located Near the Sea Beach

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Abstract

Microplastic pollution has emerged as a significant environmental threat, particularly in marine and coastal ecosystems. This scientific report reviews the impact of microplastic particles on the operational integrity of reverse osmosis (RO) desalination plants located near seashores. Microplastics, originating from both primary and secondary sources, can infiltrate RO systems through seawater intake, leading to pretreatment filter clogging, membrane fouling, and performance deterioration. Their ability to act as carriers for organic pollutants and biofilms further exacerbates fouling mechanisms, resulting in increased operational costs, higher energy consumption, and maintenance frequency. Case studies from coastal RO facilities reveal a correlation between microplastic presence and reduced system efficiency. The report highlights advanced pretreatment methods, modified intake designs, and policy-based approaches as potential mitigation strategies. Overall, addressing microplastic contamination is critical for the sustainable and efficient operation of coastal RO plants and necessitates integrated efforts in monitoring, engineering design, and coastal waste management.

Keywords: microplastic, RO plant, sea beaches, reduced efficiency

1. INTRODUCTION

Minor plastic debris, referred to as microplastics, with a size range of <5 mm, and their smaller counterparts known as nanoplastics (NPs, <100 nm), are particularly concerning due to their problematic elimination and potential to translocate into the bodies of organisms. The common MP includes Polyethylene (PE), Polypropylene Plastic (PP), polyethylene terephthalate (PET), polytetrafluoroethylene (PTFE), and polyester. The massive production and consumption of plastics result in a vast amount of plastic pollution being emitted into the environment [1]. Approximately 10 to 25 million tons of plastic waste are directly or indirectly discharged into the oceans globally every year [2]. These minute plastic fragments present in the environment, originating from the degradation of solid plastic consumer products and industrial waste, which are often found as litter in oceans and other waterways (Fig.1). They are defined as synthetic solid particles or polymeric matrices, either regular or irregular in shape, ranging in size from 1 μm to 5 mm. The assessment of the risk to humans and the environment associated with MPs is related to the inconsistency in the physical and chemical properties, composition, and concentration of the particles. Also, it is challenging to identify microplastics in the environment due to the unavailability of standardized methods for the identification of MPs [3].

These particles, whether of primary or secondary manufacturing origin, are insoluble in water, which means that the amount of these materials in our oceans can accumulate over time. Microplastics pose a serious threat to ecosystems due to their potential adverse effects. The rapid expansion of seawater desalination technologies as a response to escalating global freshwater shortages has prompted extensive research into the factors that influence RO performance. Among these, membrane fouling remains a critical challenge, as it directly affects operational efficiency, energy consumption, and membrane lifespan [4]. In recent years, the role of microplastics (MPs) as emerging contaminants in the front end of the RO system (pretreatment) has gained increasing attention. Within the framework of United Nations Development Programme (UNDP) programs, ensuring access to potable water through reclamation processes presents substantial challenges. It is critically essential to alleviate the risks posed to human health by the presence of microplastics (MPs) and nanoplastics (NPs) in drinking water. The present article summarizes the sources, behavior, and consequences of microplastics on RO plant performance and long-term operation [5].

1.1. Sources

Microplastics in coastal areas can originate from various sources, including wastewater treatment plant effluents, river runoff, and the degradation of larger plastic debris in the ocean. When released into the environment, undergo surface weathering due to mechanical scraping and ultraviolet (UV) exposure, which leads to the formation of microplastics (Fig. 1). These microplastics, when present as a mixture with other co-existing organic and metallic contaminants, may interact with each other through adsorption mechanisms, thus demonstrating an increased level of toxicity [5-7]. Such interactions may be altered due to UV aging and biological (biofouling) surface weathering of these microplastics, raising a question about how contaminant-microplastics interactions will evolve as biotic and abiotic factors in the environment alter microplastics (Fig. 2). With increasing anthropogenic activity, the discharge of MPs into the ocean and their accumulation on sea beaches have become a critical environmental concern. Reverse osmosis (RO) plants, especially those situated near coastal areas, are particularly susceptible to microplastic contamination due to their reliance on seawater as the feed source [8-10]. Primary microplastics are manufactured in micro-size for use in personal care products,

industrial abrasives, and paints, while secondary microplastics are formed from the breakdown of larger plastic debris due to photodegradation, mechanical abrasion, and biological processes. The size of MPs is the only standard parameter for microplastics since chemical composition and shape can differ extensively. The type of material the plastic is made from and the method used to make the different types of plastic polymers result in a variability of additives, colorants, and other poisons in a single piece of plastic. Due to their adaptable applications, plastic particles can occur in a wide variety of forms, including fibers, films, foams, beads or spheres, pellets, and irregular fragments while the shape of MPs is linked with the environmental conditions as well as resources where they are generated.

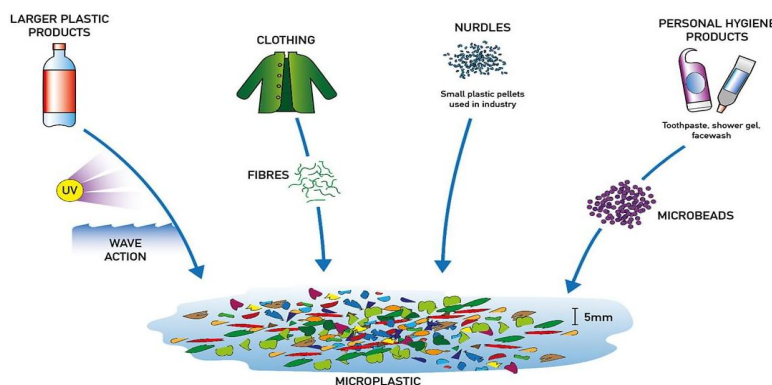


Figure 1: Sources of Microplastics through degradation of consumer products [5]

Microplastics in coastal areas can originate from multiple sources, including wastewater treatment plant effluents, river runoff, fishing equipment left or dropped into the aquatic environment, which breaks down into minor pieces due to scratches, wear, and slit as a consequence of exposure to numerous effects over time and the degradation of larger plastic debris in the ocean. The size, shape, and chemical composition of microplastics can vary widely, influencing their impact on RO pretreatment (Fig. 2-5). Additionally, small microplastic fragments, fibers, and particles can be particularly problematic as they can easily pass through pretreatment filters and directly interact with the RO membrane. Additionally, microplastics less than 5mm in size (Fig. 4) are introduced via various pathways, including land-based sources such as runoff from urban areas and industrial activities, as well as direct discharge from ships and fishing activities. Once in the ocean, microplastics can be transported long distances by currents and winds, eventually accumulating in various marine environments, including the surface, water column, and seafloor sediments (Fig. 2).

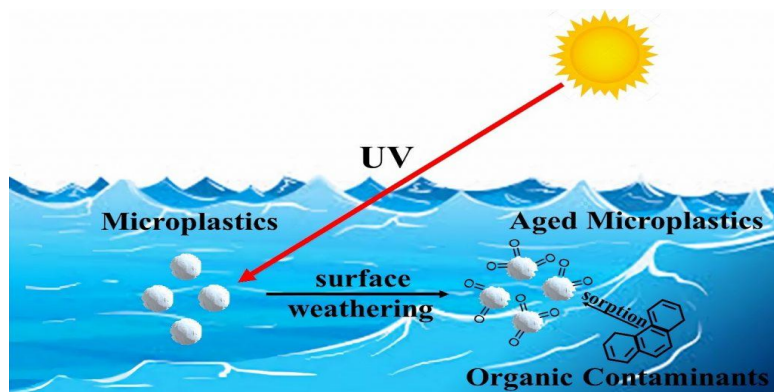


Figure 2: Microplastic pollution in the Sea [6]

1.2. Behaviour

Microplastics pose a significant threat to the performance and lifespan of RO (Reverse Osmosis) plants, particularly those located near the Sea, due to the presence of microplastics in marine environments. These tiny plastic particles can cause membrane fouling, reducing the plant's efficiency and increasing operational costs[13]. Moreover, microplastics can damage the membrane structure, leading to premature failure and necessitating costly replacements. Microplastics, primarily those smaller than the membrane pores, can clog the pores or accumulate on the membrane surface, creating a barrier that hinders water flow and reduces the plant's ability to absorb water. This fouling increases the pressure drop across the membrane, requiring more energy to maintain the desired flow rate, and can also lead to irreversible damage to the membrane[15-21]. The presence of microplastics can also exacerbate biofouling, where microorganisms attach to the membrane surface, further contributing to the fouling problem. Microplastics, particularly those with sharp edges or irregular shapes, can physically abrade or damage the membrane surface, leading to cracks, tears, or other structural defects. Some studies suggest that microplastics can also interact with the membrane material through chemical or electrostatic interactions, potentially degrading the membrane's structure and performance over time[16]. The

combination of physical and chemical interactions can accelerate the aging and deterioration of the RO membrane, resulting in premature failure [21]. Due to reduced efficiency and membrane damage, plants may need to operate at higher pressures, resulting in increased energy consumption (Fig.3).



Figure 3: Impact of nanoplastics on membrane scaling and fouling in the reverse osmosis desalination process [22]

1.3. Consequences of microplastics on RO Membrane

The shape of secondary microplastics is influenced by the material it is made from, the type of weathering, and the time spent in the natural environment, with various shapes (fibers, fragments, spheres) and densities affecting their transport in seawater. The size, shape, and chemical composition of microplastics can vary widely, influencing their impact on RO membranes. Small microplastic fragments, fibers, and particles can be particularly problematic as they can easily pass through pretreatment filters and directly interact with the RO membrane (Fig. 4), potentially being included in the clear or drinking water after pretreatment.

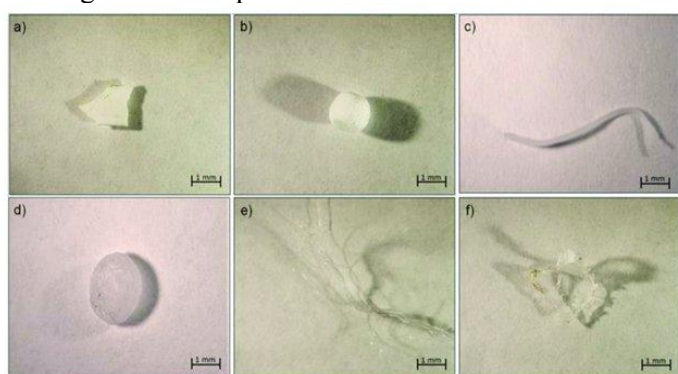


Figure 4: Examples of microplastics with different sizes and shapes: (a) fragment, (b) foam, (c) line, (d) pellet, (e) fiber, (f) film [23]

Microplastic	Chemical structure	SEM image with low magnification	SEM image with high magnification
Polypropylene (PP)	$\left[\begin{array}{c} \text{CH}_3 \\ \\ \text{CH}-\text{CH}_2 \end{array} \right]_n$		
Polyethylene (PE)	$\left[\begin{array}{cc} \text{H} & \text{H} \\ & \\ -\text{C} & -\text{C}- \\ & \\ \text{H} & \text{H} \end{array} \right]_n$		
Polyvinyl chloride (PVC)	$\left[\begin{array}{c} \text{H} & \text{Cl} \\ & \\ -\text{C} & -\text{C}- \\ & \\ \text{H} & \text{H} \end{array} \right]_n$		
Polyethylene terephthalate (PET)			

Figure 5: Chemical structure and SEM images of MPs [24]

RO plants near beaches draw seawater through intake systems, and microplastics can enter through open intakes or accumulate in the sediments of beach wells. They may enter more frequently during storm surges or high tides, increasing the MP load in intake water (Fig. 5). Due to their tiny size, they cause clogging, abrasion of filters, and enhanced biofilm growth. The size, shape, and chemical composition of microplastics can vary widely, influencing their impact on RO membranes (Fig.5) [22-24]. RO plants near beaches draw seawater through intake systems, and microplastics can enter through open intakes or accumulate in the sediments of beach wells. They may enter more frequently during storm surges or high tides, increasing the MP load in intake water (Fig. 4). Although membranes block microplastics, aggregates, and biofouling can still cause mechanical damage and reduce permeability. MPs interact with other foulants, such as humic substances, thereby enhancing complex fouling mechanisms, and microplastics induce reduced efficiency of the RO membrane. For RO operation, higher energy use as well as more frequent cleaning and membrane replacement are required. Additionally, there is an environmental risk from the reintroduction of MPs during brine discharge and sediment disturbance. The overall lifespan of the RO plant may be shortened, requiring more frequent capital investments in new equipment. MPs interact with other foulants, such as humic substances, thereby enhancing complex fouling mechanisms. Microplastics induced a reduced efficiency of the RO membrane. For RO operation, higher energy use as well as more frequent cleaning and membrane replacement are required. Additionally, there is an environmental risk from the reintroduction of MPs during brine discharge and sediment disturbance. Active moderate policies, including optimizing filtration, exploring advanced treatment technologies, and implementing preventative measures at the source to ensure the continuous operation of the RO plant. The impact of microplastics and mitigation strategies is presented in Figure (6).

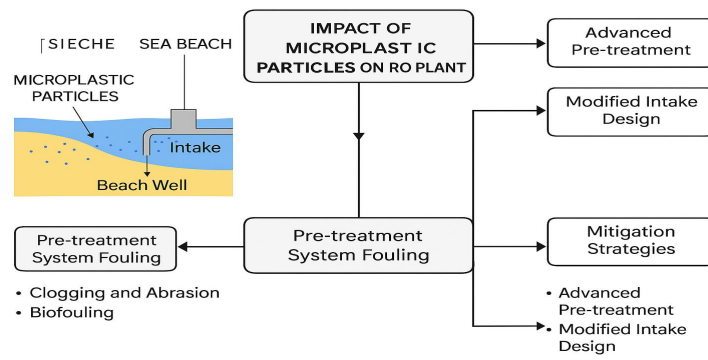


Figure 6: Impact of Microplastics on RO Plant and Mitigation Strategies

1.4. Performance and long-term operation of RO plant

Addressing the root cause of microplastic pollution by promoting responsible plastic consumption and waste management is essential for long-term sustainability. Optimizing pretreatment processes to remove microplastics before they reach the RO membranes is crucial. They can be removed by effective coagulant dosing, such as polyaluminum chloride. Exploring advanced filtration technologies, such as microfiltration or ultrafiltration, to remove microplastics before the RO stage is another potential solution. Developing and utilizing anti-fouling membranes that are more resistant to microplastic interactions and biofouling is an area of active research. Advanced pretreatment methods, such as DAF, membrane bioreactors, and GAC filters, are required, followed by subsurface intakes and improved screen designs. Continuously monitoring and adhering to MP-specific feedwater standards, coupled with effective coastal plastic waste management, are essential. Microplastics, primarily those smaller than the membrane pores, can clog the pores or accumulate on the membrane surface, creating a barrier that hinders water flow and reduces the plant's ability to absorb water.

1.5. Recommendation

In reverse osmosis (RO) plants, especially those located near coastal areas, such as beaches in Pakistan, which are heavily polluted by various types of waste, a modified novel intake design is critical for minimizing the intake of microplastics (MPs) and other suspended contaminants. Some modified intake design strategies are proposed to mitigate the impact of microplastics, which may be most effective in reducing MPs and increasing the efficiency of RO plants (Fig. 7).

- Wells dug inland near the shoreline draw water that has naturally percolated through sand or sediment. This may be effective in removing large-sized MP due to natural filtration, followed by the removal of turbidity, algae, and pathogens.
- The larger particles and heavier MPs can be removed through a pre-sedimentation tank, where MPs may settle down by gravity before reaching the RO unit.
- Use of a Fine Mesh Screen to capture MPs ($>100\ \mu\text{m}$).
- Low-velocity intakes (typically $< 0.15\ \text{m/s}$) reduce entrainment of floating particles.
- Directional intake heads placed facing away from surface current can limit MP capture.
- Using engineered wetlands or biofilters between the intake point and the pretreatment system.
- To remove floating MPs before they reach the intake point, surface skimmers may be used.

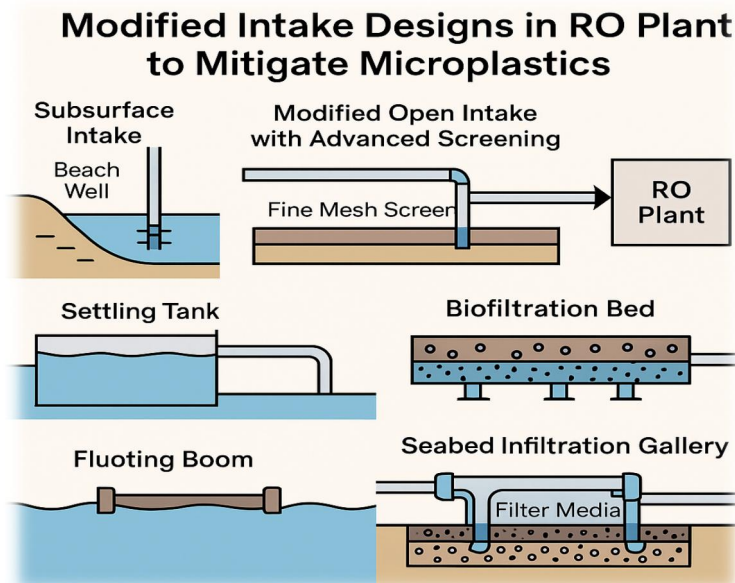


Figure 7: Modified Design of RO Plants for controlling MPs

CONCLUSION

The significance of the article lies in raising awareness about plastic pollution and other pollutants dumped into the Sea. It was recommended that the state take action to prevent the dumping of all types of waste and wastewater in coastal areas, followed by a crucial need to develop standard water treatment techniques for removing microplastics and nanoplastics. It was concluded that MPs pose a serious threat to the operational capabilities of RO plants, which play a crucial role in addressing water shortages in areas such as Karachi, Pakistan, where residents suffer from water scarcity. Primarily, special attention from the state is required to prevent the dumping of plastic waste in water resources or soil, which is harmful to aquatic life. This is followed by breakage or blockage during treatment, resulting in increased working costs for RO plants.

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