



Controlling Microplastics in Urban Wastewater Treatment Plants: A Policy Brief

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Abstract

Background: Microplastics, defined as plastic particles smaller than 5 mm, are persistent environmental contaminants that enter urban wastewater through domestic, industrial, and urban runoff sources. Conventional wastewater treatment processes do not completely remove microplastics, allowing them to reach receiving waters and potentially affect ecosystems and human health.

Objectives: This article examines the role of urban wastewater treatment in mitigating microplastic pollution, with particular attention to the Iranian context and to densely populated or industrialized areas such as Zahedan, and proposes policy and management approaches to strengthen pollution control.

Methods: A policy-oriented review of the available evidence was conducted to assess the persistence of microplastics across conventional wastewater treatment stages and to evaluate technical, regulatory, institutional, and source-control measures for reducing their environmental release.

Results: Evidence indicates that microplastics can persist through standard wastewater treatment processes and remain in treated effluents and associated residuals, thereby contributing to ongoing environmental dispersion. Consequently, current treatment capacity is insufficient to fully address the scale of microplastic pollution. Effective mitigation requires advanced treatment technologies, source-control measures, enforceable effluent standards, improved monitoring, institutional coordination, and greater public awareness.

Conclusions: Microplastic pollution is a growing, unresolved environmental challenge that cannot be adequately addressed through conventional wastewater treatment alone. An integrated framework combining technical, regulatory, institutional, and societal interventions is required to reduce microplastic discharge, protect ecosystems and public health, and support sustainable wastewater management.

Keywords: Microplastics, Wastewater, Wastewater Treatment Plants

1. Background

Microplastics, defined as plastic particles smaller than 5 mm, have emerged as major pollutants in recent decades, raising concerns for human health and the environment (1). These particles enter the environment through various pathways, among which their introduction into urban wastewater systems and subsequent release via treated effluent are among the most critical (2-4).

Microplastics enter wastewater from two primary sources:

1) Primary sources (microbeads): These include primary particles or microbeads in personal care products such as cosmetics, detergents, and toothpaste, as well as plastic fibers released during clothes washing. For example, washing polyester and acrylic garments releases millions of fibers annually into wastewater systems (5).

2) Secondary sources: These particles result from the weathering, degradation, and fragmentation of larger plastic debris.

This manuscript is a policy-oriented brief based primarily on original, thesis-derived observational data collected from the Zahedan wastewater treatment plant, together with contextual evidence from relevant published studies.

2. Objectives

This article examines the role of urban wastewater treatment in mitigating microplastic pollution, with particular attention to the Iranian context and to densely populated or industrialized areas such as Zahedan, and proposes policy and management approaches to improve pollution control.

3. Methods

3.1. Evidence Base

The local findings presented in this policy brief were derived from a descriptive, applied, observational study conducted at the Zahedan wastewater treatment plant. Wastewater samples (10 L) were collected from the effluent of different treatment units, including screening, grit removal, primary sedimentation, aeration, secondary sedimentation, and disinfection. Samples were passed through stainless-steel sieves with different mesh sizes (25, 250, 500, 1000, 2000, and 4760 μm). Microplastic particles were characterized using light microscopy for counting and for determining color and shape, scanning electron microscopy (SEM) for surface morphology, and micro-Raman spectroscopy for polymer identification. Broader public health and policy interpretation was supported by the relevant literature.

The study setting was the Zahedan urban wastewater treatment plant, which serves a large urban population and includes primary treatment units (screening, grit removal, and sedimentation), secondary treatment processes (aeration, sedimentation, and disinfection), and sludge treatment operations.

4. Results

4.1. Key Study Findings

- Microplastic concentrations were higher in spring than in winter due to seasonal weather changes, including increased temperatures, UV radiation, and rainfall, which wash microplastics from street surfaces into wastewater systems.

- More than 70% of microplastics were removed during treatment; however, smaller particles (25 - 500 micrometers) and lower-density particles readily passed through the treatment stages and remained in the effluent.

- The dominant microplastic forms in the effluent were fragments and fibers, primarily from domestic sources such as laundry and cosmetics.

- Removal efficiency varied across treatment units, with grit removal being the most effective and sedimentation the least effective, because lighter particles settle less readily and enter the effluent.

- Foam and film microplastics used in packaging and construction constituted a significant proportion of the microplastics in the effluent.

Local findings from the Zahedan wastewater treatment plant indicated that microplastic abundance was higher in spring than in winter. Black particles were the most frequently observed color, fragments were the dominant shape, and the identified polymers included polyethylene terephthalate (PET), polystyrene (PS), polyamide (PA), polypropylene (PP), and Teflon.

During the study period at the Zahedan municipal wastewater treatment plant, a total of 440 microplastic particles were isolated and identified. Seasonal analysis revealed a higher microplastic abundance in spring ($n = 263$) than in winter ($n = 177$). The treatment process achieved an overall reduction in microplastic counts from the influent to the final effluent. Among the evaluated treatment units, the grit removal and primary sedimentation stages demonstrated the highest particle removal efficiencies, suggesting that they act as primary barriers in the conventional treatment train. Despite this reduction, a substantial concentration of particles remained in the final effluent. Morphological analysis indicated that fragments were the dominant shape and that black particles were the most frequently observed, consistent with the polymer types identified by micro-Raman spectroscopy, including PET, PS, PA, PP, and Teflon.

5. Discussion

5.1. Health and Environmental Impacts of Microplastics

Microplastics are widely recognized as emerging environmental contaminants in aquatic and wastewater systems, with potential implications for ecosystem quality and human exposure (6). Their persistence in treated wastewater is concerning because wastewater treatment plants may act both as partial barriers and as pathways for environmental release (7). Current evidence indicates that the potential health effects of microplastics should be interpreted cautiously and in accordance with the strength

of the available evidence (8). Environmental occurrence and the potential for human exposure are well established. In contrast, many reported biological effects, including oxidative stress, inflammatory responses, endocrine-related effects, and immune modulation, are supported primarily by experimental and toxicological studies rather than by definitive human epidemiological evidence (9). Some studies have reported the presence or translocation of micro- and nanoscale plastic particles in biological tissues, including placental tissue, raising questions about their ability to interact with biological barriers. However, the extent, mechanisms, dose relevance, and clinical significance of these findings under real-world environmental exposure conditions remain uncertain. Similarly, although experimental studies have suggested pathways that may be relevant to chronic inflammation and possibly other long-term adverse effects, direct causal evidence linking environmental microplastic exposure to specific human diseases, including cancer, remains limited. Therefore, health-risk statements should be regarded as emerging and precautionary rather than definitive. From a policy perspective, the persistence of microplastics in wastewater effluent justifies preventive monitoring and control measures even in the presence of scientific uncertainty, particularly because long-term exposure pathways and cumulative effects have not yet been fully characterized (4, 10-12).

A limitation of the present policy interpretation is that the health relevance of environmental microplastic contamination cannot yet be fully quantified on the basis of currently available evidence. Much of the literature on biological effects is based on in vitro, animal, or experimental exposure studies, and direct extrapolation to human disease risk under typical environmental exposure conditions remains uncertain.

5.2. Role of Wastewater Treatment Plants in Microplastics Control

Urban wastewater treatment plants are not fully equipped to remove microplastics, although some particles are captured during preliminary treatment, sedimentation, and aeration. However, treated effluent still contains microplastics. On average, treatment processes remove 70% to 99% of microplastics, but small and low-density particles often pass through because of their size and buoyancy and accumulate in the environment because of their non-biodegradable nature (13, 14).

In Zahedan, the capital of Sistan and Baluchestan Province, with a population of approximately 800,000, the active wastewater treatment plant serves about 300,000 people. The facility includes primary treatment (screening, grit removal, and sedimentation), secondary treatment

(aeration, sedimentation, and disinfection), and sludge treatment (anaerobic digestion). The effluent from this plant contains significant amounts of microplastics, which are discharged into seasonal rivers and urban green spaces.

5.3. Policy Recommendations for Health and Environmental Authorities

The following policy recommendations are derived from local findings obtained at the Zahedan wastewater treatment plant, particularly the persistence of microplastics in treated effluent, the observed seasonal variation, and incomplete removal across treatment stages. Although these findings reflect local observations from the Zahedan wastewater treatment plant, the broader discussion of environmental risk, public health implications, and regulatory needs is informed by the international literature.

Based on the local findings from the Zahedan wastewater treatment plant, several policy and management actions can be prioritized. First, because a considerable amount of microplastics remained in the final effluent and seasonal variation was observed, routine and seasonal monitoring programs should be established in Zahedan to assess temporal changes in microplastic abundance and composition. Second, because the treatment process reduced but did not fully eliminate microplastic particles, plant-level assessment of removal efficiency across individual treatment units should be undertaken. This may help identify operational gaps and support evidence-based optimization of existing treatment processes. Third, the persistence of microplastics in treated effluent suggests that conventional treatment processes may be insufficient for complete removal. Therefore, medium-term planning should evaluate the feasibility of advanced or polishing treatment technologies to improve microplastic control where technically and economically feasible. Fourth, the higher microplastic abundance observed in spring may indicate contributions from seasonal runoff and surface wash-off. This supports consideration of source-control interventions and urban runoff-management measures to reduce the entry of plastic particles into wastewater systems. Fifth, although the present study focused primarily on wastewater and treatment-stage observations, incomplete microplastic removal highlights the need for further evaluation of sludge as a potential sink and secondary pathway. Accordingly, sludge monitoring and management should be considered in future wastewater policies. Finally, although the current findings are local in scope, they support the development of broader monitoring frameworks and regulatory guidance at the national level, particularly when interpreted alongside the growing

international literature on microplastic contamination in wastewater systems.

In terms of implementation priority, short-term actions should focus on routine seasonal monitoring and treatment-unit performance assessment in Zahedan. Medium-term priorities include operational optimization, evaluation of advanced treatment options, and source-control measures. Long-term priorities include the development of national monitoring standards, regulatory guidance, and integrated wastewater and sludge management policies for microplastic control.

5.4. Study Limitations and Policy Translation

Although this policy brief provides evidence-based recommendations, several limitations must be acknowledged to contextualize their application. First, the empirical data are geographically restricted to the Zahedan municipal wastewater treatment plant. Generalization of these findings to other regions of Iran should be undertaken with caution because differences in local climate, domestic water consumption patterns, industrial discharges, and specific wastewater treatment configurations across provinces can substantially alter microplastic characteristics and removal efficiencies. Second, temporal and analytical limitations exist; sampling was conducted during specific seasons (winter and spring), which may not capture the full annual variation, such as summer droughts or autumn rains. In addition, physical collection was limited by sieve mesh sizes (minimum 25 μm), potentially underestimating smaller microplastics or nanoplastics. Third, as noted above, the health relevance of environmental microplastic contamination cannot yet be fully quantified on the basis of currently available evidence because much of the biological literature relies on in vitro and animal models. Consequently, the proposed policy actions, such as upgrading treatment units or establishing monitoring standards, should be interpreted as a flexible pilot framework. Rather than implementing rigid national mandates immediately, policy actions should prioritize adaptive, localized strategies and support further multicenter, long-term monitoring across diverse wastewater treatment facilities in Iran.

5.5. Conclusions

As emerging pollutants, microplastics pose a growing environmental concern, particularly where treated wastewater is discharged into aquatic environments or reused for urban green spaces. Urban wastewater treatment plants can play a critical role in reducing their entry into aquatic and terrestrial environments but cannot

eliminate them entirely. Comprehensive management strategies, adoption of advanced technologies, supportive regulations, national standards, and increased public awareness are essential to control and reduce microplastics in Iran, particularly in densely populated and industrial areas such as Zahedan.

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Footnotes

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