Sources, Transport Pathways, Entry and Impacts of Microplastics in Conventional Drinking Water Treatment Plants: A Critical Review

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Abstract
Microplastics, usually defined as insoluble synthetic polymer particles under 5 mm, occur almost everywhere in the water cycle, from freshwater sources and raw intake water to treated drinking water and even the pipes that carry it to our taps. They enter these systems through a mix of primary and secondary routes: fragmenting plastic debris, shedding textile fibres, tyre and road wear, industrial losses, wastewater effluent, stormwater runoff, and atmospheric fallout. Conventional drinking-water treatment plants (DWTPs) built around coagulation, flocculation, sedimentation, granular-media filtration and disinfection form an important barrier against these particles, but how well they work depends heavily on particle size, shape, density, polymer type, surface weathering, water quality and how the plant is operated. Larger particles and fibres tend to get caught up in flocs and settle out or get filtered, while small microplastics and nanoplastics are much harder to pin down and remove with any consistency. It is also worth stressing that removing MPs from the water phase is not the same as destroying them; they typically end up concentrated in clarifier sludge, filter backwash water, and other residual streams. This creates its own set of downstream issues: interference with coagulation and filtration, buildup in treatment residuals, possible fragmentation during oxidative steps, and the risk that poorly managed backwash or sludge disposal sends retained particles right back into circulation. As for human health, the evidence so far does not point to a clear-cut risk from MP exposure through drinking water, though real uncertainty remains around small particles, the chemicals associated with plastics, and biofilm-related contaminants. This review takes a critical look at where these particles come from, how they travel, how they enter treatment systems, and what happens to them once they are there and it flags the analytical gaps and research priorities that matter most for keeping MPs out of the water we drink.

Keywords: Microplastics; drinking-water treatment plant; coagulation; filtration; source water; transport pathway; sludge.

1. Introduction

Decades of plastic production, use, and disposal have left microplastics scattered across aquatic, terrestrial, and even atmospheric environments. They are generally defined as solid, water-insoluble polymer particles under 5 mm, and particles smaller than roughly 1 µm are usually grouped as Nanoplastics; though there is still no agreed-upon lower size cutoff (Koelmans et al., 2019). In practice, they show up in many forms: fibres, fragments, films, foams, beads, and pellets, made mostly from polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC).

Drinking-water sources receive MPs from a range of sources, including municipal and industrial wastewater discharges stormwater runoff, combined sewer overflows, degraded plastic litter, agricultural runoff, and atmospheric deposition. The World Health Organization points to surface runoff, treated and untreated wastewater effluent, industrial effluent, plastic-waste degradation, and atmospheric deposition as key pathways into these sources (WHO, 2019).

Conventional DWTPs were not designed with microplastics in mind; their primary purpose has been the removal of turbidity, pathogens, natural organic matter, and suspended solids. Even so, the particulate-removal units built for those purposes end up cutting MP concentrations too, whether or not that was the intent. Microplastics have been found throughout freshwater systems such as rivers, lakes, reservoirs, groundwater from those various sources municipalities draw drinking water, which means environmental plastic pollution and drinking-water treatment are directly linked. In that sense, conventional DWTPs function as an important barrier standing between contaminated freshwater and the people who eventually drink it (Novotná et al., 2019).

Some of the earliest full-scale studies confirmed that MPs show up in both raw and treated drinking water. Pivokonsky et al. (2018), for instance, found MPs at drinking-water facilities in both raw and treated samples, showing that conventional treatment cuts particle numbers substantially, but does not eliminate them completely. Since then, other studies have found that overall performance varies quite a bit from one facility to the next, driven by differences in raw-water quality, particle size, polymer type, treatment configuration, and even the analytical methods used.

WHO assessments keep coming back to the same point: there is still considerable uncertainty about what human exposure to micro- and nanoplastics through drinking water actually means for health. The current evidence indicates that research and control of plastic pollution should continue rather than assuming that every particle detected translates into a demonstrated health effect.

With that in mind, this critical review sets out to identify the main primary and secondary sources of MPs entering drinking-water catchments, trace the pathways that carry them toward conventional DWTPs, and examine what impact they have once they reach treatment operations.

2. Sources of Microplastics Entering Drinking-Water Catchments

Microplastic contamination of drinking-water sources rarely traces back to one single activity. Instead, the MPs that end up at water-treatment intakes are the cumulative product of urban, industrial, domestic, agricultural, and atmospheric emissions spread across an entire watershed.

2.1 Primary and secondary microplastics

MPs are typically classified, based on where they come from, as either primary or secondary microplastics.

Primary MPs are made intentionally at microscopic size, or generated directly as products are used as industrial polymer pellets, plastic powders, and particles worn off polymer-containing materials. Secondary MPs, on the other hand, come from the fragmentation and breakdown of larger plastic items: bags, bottles, containers, packaging, fishing gear, disposable products, synthetic textiles, agricultural plastic film, and municipal plastic waste that was not disposed of properly, among other things.

Weathering in the environment steadily changes these particles physical and chemical characteristics, often roughening their surfaces and shifting how they interact with suspended solids, dissolved substances, and treatment chemicals (Andrady, 2017; Koelmans et al., 2019).

Urban catchments matter more than most, simply because dense populations, heavy traffic, paved surfaces, and extensive drainage networks all speed up how quickly MPs reach receiving waters. This effect is particularly evident during rainfall events, tyre and road-wear particles, synthetic textile fibres, fragmented packaging, paint particles, industrial dust, and atmospheric fallout all get mobilized at once. Wastewater treatment plants cut down MP loads, but given the sheer volume of water passing through them, some particles still get discharged and combined sewer overflows can bypass treatment altogether during high-flow events (WHO, 2019).

How far and how fast MPs travel depends on both particle properties and environmental conditions. Low-density polymers like PE and PP tend to float at first, while denser ones such as PET and PVC are more likely to settle or attach to suspended solids. Biofilm growth, adsorption of natural organic matter, mineral coatings, and aggregation can all shift a particle's effective density, surface charge, and settling behaviour over time. Fibres, thanks to their high aspect ratio, often stay suspended, while small fragments can travel long distances through rivers and reservoirs.

3. Transport Pathways of Microplastics Toward DWTPs

Once released into the environment, MPs move through a complicated mix of terrestrial and aquatic pathways.

Surface runoff: Rainfall washes MPs off roads, agricultural soil, landfill surfaces, and urban land into nearby waterways. How much moves depends heavily on rainfall intensity, how long it has been since the last rain, catchment slope, and land use.

Rivers act as the main conveyors of land-derived plastic. Once in a river, MPs might stay suspended, float, clump together, settle into sediment, get resuspended, build up in vegetation, interact with aquatic life, or simply travel long distances downstream; which of these processes occurs depends heavily on particle size and density.

Low-density polymers such as polyethylene (PE) and polypropylene (PP) tend to stay near the surface at first, while denser ones like polyethylene terephthalate (PET) and polyvinyl chloride (PVC) are more inclined to sink.

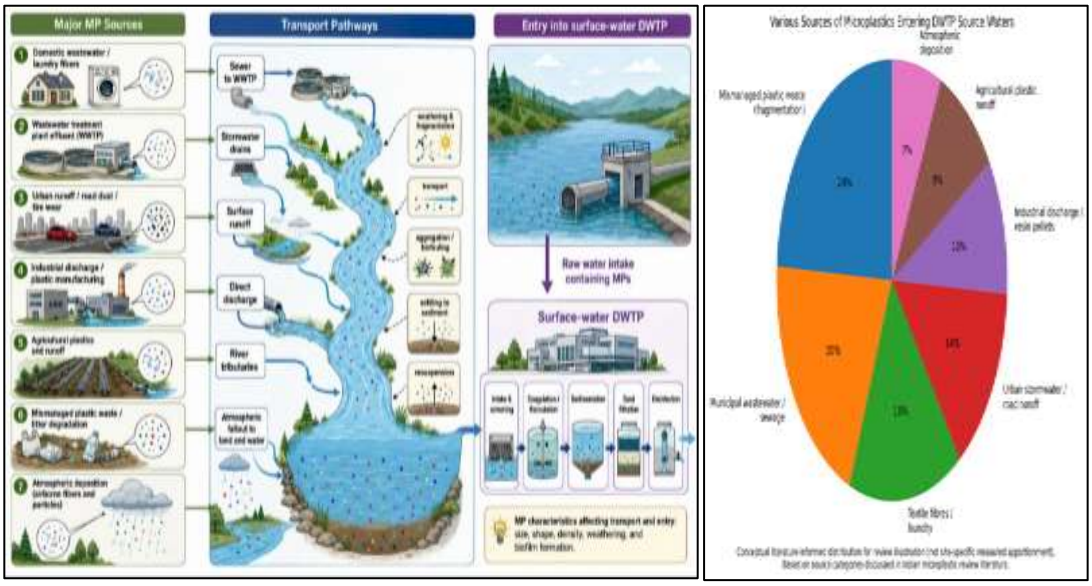

Figure 1: MP sources, transport pathways and entry into surface-water DWTPs.

Table 1: Major MP sources, transport routes and entry points to DWTPs

Source category	Typical polymers forms	Main transport pathway	Entry point to conventional DWTP	Key implication
Fragmentation of plastic litter	PE, PP, PS fragments, films and foams	River runoff, direct littering, reservoir accumulation	Surface-water intake	Increases after rainfall, flooding and seasonal runoff
Domestic laundry	PET, polyester, polyamide fibres	Sewerage, wastewater effluent, combined sewer overflows	River or lake source water	Fibres may evade settling because of low settling velocity
Tyre and road wear	Rubber-polymer composites, styrene-butadiene particles, fragments	Road runoff and storm drains	Urban river or reservoir intake	Often associated with metals, soot and road-derived contaminants
Industrial plastic handling	Resin pellets, powders, fragments	Effluent discharge, accidental loss and runoff	Surface-water intake or groundwater recharge zone	Can create localized high-concentration hotspots
Agricultural plastics	PE mulch fragments, irrigation tubing and packaging debris	Soil erosion, drainage and runoff	Reservoir, river and groundwater source	Seasonal transport may occur during monsoon or irrigation periods
Wastewater-treatment discharge	Fibres, fragments, beads	Treated effluent discharge	Downstream surface-water intake	High flow can make residual MP discharge significant
Atmospheric deposition	Fibres, fragments and urban dust	Wet and dry deposition onto catchments and reservoirs	Open reservoir and raw-water storage	Important even in remote source-water areas
DWTP and distribution materials	Pipe fragments, coating particles, membrane wear and gasket debris	Internal shedding or abrasion	Treated water, storage and distribution system	Can confound apparent treatment removal performance

4. Entry and Fate in Conventional DWTPs

Most conventional DWTPs draw raw water from rivers, reservoirs, lakes, or groundwater, and surface-water facilities tend to be more directly exposed to whatever plastic is moving through the watershed. Pivokonsky et al. found MPs in both raw and treated drinking water, and later studies confirmed that how much gets through — and how much gets removed — varies a lot between facilities. Groundwater is generally less exposed than surface water, but that does not mean it is automatically free of MPs; transport through soil, infiltration from contaminated surface environments, and infrastructure-related inputs are all still possible. That said, groundwater-based systems have reported comparatively low MP levels under some conditions.

Table 2. Fate of MPs during conventional drinking-water treatment

Unit operation	Dominant MP-removal or transformation mechanism	Expected performance	Potential limitation or impact	Representative references
Intake screening and pre-sedimentation	Removal of large debris and settleable particle-associated MPs	Limited for small MPs and fibres	Fine particles pass to downstream units	Novotná et al. (2019); Xue et al. (2022)
Coagulation and flocculation	Sweep flocculation, adsorption, charge	Effective when MPs are	Small, hydrophobic and low-density particles may remain poorly captured	Lapointe et al. (2020); Ma et al. (2019)

Unit operation	Dominant MP-removal or transformation mechanism	Expected performance	Potential limitation or impact	Representative references
	neutralization and heteroaggregation	incorporated into flocs		
Sedimentation or clarification	Gravitational settling of MP-containing flocs	Removes floc-associated fragments and fibres	Transfers MPs to sludge; floating MPs may escape	Pivokonský et al. (2022); Wang et al. (2020)
Rapid sand or dual-media filtration	Straining, interception, attachment and depth filtration	Important polishing barrier for remaining particles	Filter breakthrough and backwash-water release require evaluation	Xue et al. (2022); Shen et al. (2020)
Granular activated carbon filtration	Physical retention and attachment within GAC bed	Can reduce small MPs after clarification	GAC is not a destruction process; retained MPs need residuals management	Wang et al. (2020)
Chlorination, UV or ozonation	No primary removal mechanism; possible surface modification or fragmentation	Limited direct removal	Possible alteration to smaller particles; evidence remains inadequate at full scale	Cheng et al. (2021); Xue et al. (2022)
Sludge and filter backwash handling	Partitioning of retained MPs into residual streams	Major sink within the plant	Potential re-release if sludge or backwash is poorly managed	Enfrin et al. (2019); Cheng et al. (2021)

At the intake itself, MP levels are shaped by source-water hydrology, land use, rainfall, flow velocity, reservoir mixing, and how close the intake sits to wastewater discharges. Storm events tend to push raw-water MP concentrations up, since runoff stirs up road dust, tyre-wear particles, litter fragments, and atmospheric fibres that had settled out. That is part of why seasonal monitoring matters so much, especially in catchments affected by monsoons.

Coagulation–flocculation is a major treatment barrier in the treatment train. Aluminium- and iron-based coagulants destabilize colloids and pull suspended matter into flocs that can settle out. MPs get caught up in this process through sweep flocculation, charge neutralization, heteroaggregation with natural particles, and simple physical enmeshment within the flocs themselves. Larger, rougher, more weathered, and denser particles tend to be removed more easily than small, smooth, buoyant ones and performance depends strongly on coagulant type and dose, pH, mixing intensity, natural organic matter, and turbidity (Lapointe et al., 2020; Xue et al., 2022).

Sedimentation then moves those floc-bound MPs out of the water and into sludge. But buoyant polymers and small particles or fibres with low settling velocities can slip through clarification. One full-scale study of a conventional plant found 52% overall removal of anthropogenic particles, with coagulation, flocculation, and sedimentation together contributing the largest share of that removal among all the individual treatment steps (Pivokonský et al., 2022).

Rapid sand, dual-media, and granular activated carbon filters add another layer of MP removal straining particles out, intercepting them, letting them attach to filter media, or trapping them within deposited solids. These filters are especially useful for particles that make it past clarification but are still too big to slip through the effective pore spaces in the filter bed. The However, captured MPs may accumulate in the filter and eventually get carried off in backwash water and if that backwash is not treated properly, or gets recycled without any control, those retained particles can find their way right back into the treatment process.

Disinfection is not primarily designed for MP removal and generally provides limited direct MP removal. Chlorination, ozonation, and UV irradiation can alter surface chemistry or accelerate weathering under certain conditions, but exactly how much this contributes to MP fragmentation at full scale is still not well understood. So oxidation should not be treated as a validated MP-removal step. And a high percentage removal figure does not automatically mean low concentrations in finished water either — influent concentration, particle-size distribution, and the detection limits of the analytical method all shape what final exposure actually looks like.

5. Removal Efficiency of Conventional DWTPs

Coagulation and flocculation can promote MP removal by destabilizing suspended particles and entrapping MPs within aluminium- or iron-based flocs. Removal depends on coagulant type and dose, pH and alkalinity, natural organic matter concentration, turbidity and suspended solids, MP size, shape, density and surface charge, polymer hydrophobicity and weathering state, flocculation intensity and detention time, and the presence of biofilms or co-adsorbed contaminants. Larger fragments and particles associated with suspended matter may be more readily incorporated into flocs. Fine fibres may remain difficult to remove because of their high aspect ratio, buoyancy, low settling velocity and tendency to remain suspended.

Sedimentation and pulse clarification transfer particle-associated MPs to settled solids. Performance is influenced by particle density and aggregation. Dense polymers such as polyvinyl chloride and some weathered or biofouled particles may settle more readily than buoyant polyethylene and polypropylene particles (Sarkar et al., 2021).

Rapid sand filtration is expected to be a major physical barrier to MPs through straining, interception, sedimentation in pore spaces and attachment to filter media. Removal is generally better for larger particles but may decline for fine particles, fibres and nanoplastics (Dhruba et al., 2021).

An important Indian full-scale study was conducted at the Indira Gandhi Water Treatment Plant, Palta, Kolkata, treating Ganga River water. Raw water contained 17.88 MPs/L. Pulse clarification achieved approximately 63% cumulative removal and sand filtration increased cumulative removal to approximately 85%. Fibres and films/fragments were dominant, with PET and PE identified as major polymer types. This study is highly important but should be treated as a site-specific benchmark, not a national removal value (Dhruba et al., 2021).

Reported removal efficiencies vary substantially among studies, Cheng et al. (2021), reviewing multiple drinking-water purification facilities, found overall MP removal ranging from roughly 69.9% to 100% across the studies they evaluated. Full-scale work associated with Pivokonsky has reported removal in the high-80% range at some facilities, while other systems show quite different numbers depending on which size fraction is being measured.

Cherniak et al. (2022), for instance, reported roughly 52% overall removal of anthropogenic particles >10 µm at a full-scale conventional facility with coagulation, flocculation, and sedimentation alone responsible for around 70% removal at that stage of treatment. Airborne deposition further down the line dragged the apparent final removal figure down. Therefore, a single universal percentage for DWTP MP removal is not scientifically justified.

A 2024 review of drinking-water studies similarly concluded that reported concentrations vary widely and that standardized sampling and analytical procedures are urgently needed; fibres and fragments are frequently dominant, while the smallest particles remain poorly characterized Yang et al. (2024).

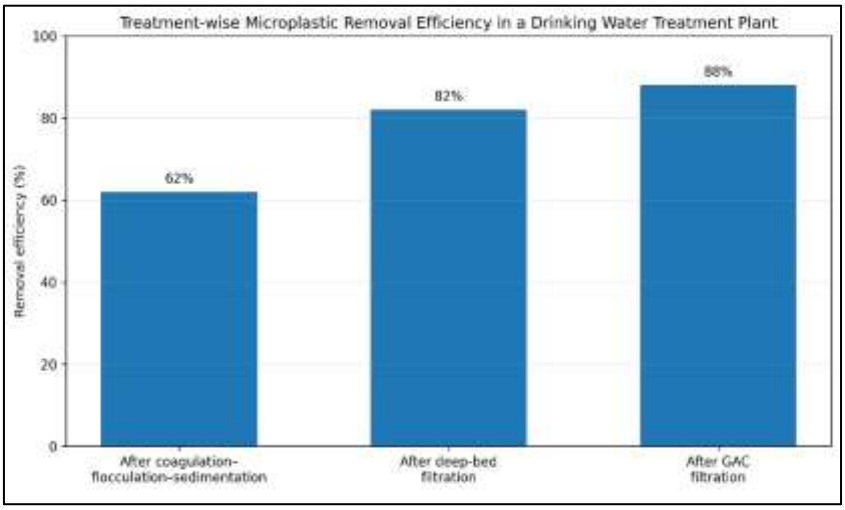

Figure 2: Cumulative removal of MP across DWTP (Data adopted from Pivokonský, et al. (2020)

6. Impacts of Microplastics on Conventional DWTPs

The best-established consequence of conventional treatment is phase transfer: MPs do not disappear, they just move out of the water and concentrate in clarifier sludge, spent filter solids, and backwash water. So conventional treatment protects the quality of finished water, but in doing so it creates a residual-management problem of its own. Once such sludge is disposed of on land, disposal sites, or wastewater systems there is potential for the MPs to be redistributed back into the environment.

A second impact has to do with treatment efficiency itself. Lab and pilot studies show that how well coagulation removes MPs depends on particle size, shape, polymer chemistry, surface charge, and how much natural organic matter is present. In water with high natural organic matter or surfactants, MPs tend to stay stabilized and attach less readily to flocs. Conversely, when MPs associate with mineral particles and natural suspended solids, settling can actually improve. What this suggests is that MP control can often be improved just by fine-tuning existing coagulation conditions, rather than necessarily requiring an additional treatment process at every DWTP.

Third, MPs can affect the filtration systems themselves. Retained particles add to the solids load on the filter bed and can interact with biofilms and natural organic matter already there. How much this actually matters for fouling in conventional sand filters is still poorly quantified, mostly because MPs show up alongside much larger loads of natural suspended solids. In membrane-equipped plants, though, micro- and nanoplastics can genuinely contribute to membrane fouling and can even originate from the membrane material itself degrading or wearing down (Ding et al., 2021; Li et al., 2021).

Table 3. Potential impacts of MPs on conventional DWTP performance and management

Impact area	**Mechanism**	**Evidence status**	**Recommended response**
Transfer to sludge	Floc-bound MPs settle with clarification sludge	Well supported	Quantify MPs in sludge and assess disposal or reuse pathways
Filter accumulation and backwash release	Captured MPs accumulate in media and are discharged during backwashing	Plausible and requires more full-scale evidence	Monitor backwash water; treat or recycle only after risk assessment
Particle fragmentation	Oxidation, abrasion and ageing may generate smaller particles	Evidence remains uncertain at full-scale conditions	Monitor size distribution before and after disinfection
Membrane fouling or membrane-derived particles	MPs interact with cake layers; polymeric membranes may wear	More relevant to membrane-assisted plants	Conduct integrity testing and material-release assessment
Biofilm and microbial interactions	MPs provide surfaces for attachment of microbial communities	Potential concern; pathogen significance in DWTPs remains unresolved	Maintain conventional microbial barriers and investigate site-specific biofilms
Distribution-system contribution	Wear of plastic pipes, fittings, coatings and storage components	Supported as a possible confounding source	Include treatment-to-tap sampling and material audits

Finally, the treatment and distribution infrastructure can be a source of particles in its own right. Plastic pipes, storage tanks, protective coatings, gaskets, and treatment components all shed particles through abrasion, ageing, and mechanical stress. If monitoring only looks at raw and finished water, it can easily miss these internal sources. A proper source-to-tap design sampling raw water, post-clarification water, filter effluent, finished water, and the distribution system itself is what is needed to tell removal apart from internal generation.

Because they provide broad surface area, MPs are well suited to interacting with other substances such as hydrophobic organic pollutants, metals, plasticizers, pigments, and microbial biofilms among them.

7. Analytical Challenges, Risk Implications and Research Needs

Comparing MP data across different DWTP studies is genuinely difficult. Koelmans et al. (2019) found that only 4 of 50 freshwater and drinking-water studies they reviewed met every quality criterion they assessed. Recurring problems included sample volumes that were too small, not enough field and lab blanks, weak recovery testing, particles identified visually without polymer confirmation, and detection limits for particle size that were never reported.

A solid DWTP monitoring framework needs representative sampling across multiple treatment stages, sampling that accounts for seasonal variation, large enough water volumes when concentrations are expected to be low, clean-air procedures, non-plastic equipment wherever feasible, procedural blanks, recovery experiments, and chemical confirmation of polymer type. For polymer confirmation, micro-FTIR, Raman microscopy, and pyrolysis-GC/MS are the preferred methods, though each comes with its own trade-offs in size range, throughput, and quantification.

From a health standpoint, the potential concerns include physical effects from the particles themselves, leaching of additives and monomers, contaminants adsorbing to or desorbing from particle surfaces, and interactions with microbial biofilms. Even so, the available evidence is currently insufficient to support quantitative drinking-water guideline value for MPs. WHO's conclusion is that current evidence points to low concern for human health from MPs in drinking water — while still flagging major uncertainty, particularly around small particles and nanoplastics (WHO, 2019).

8. Conclusion

Microplastics reach conventional drinking-water treatment plants through a web of interconnected pathways: degradation of plastic litter, household wastewater, textile fibres, industrial activity, WWTP effluent, urban stormwater, agricultural runoff, and atmospheric deposition all play a part. Rivers and reservoirs act as the main transport and storage systems carrying these particles toward drinking-water intakes.

How MPs move is governed by particle size, shape, polymer density, surface aging, biofilm development, natural organic matter, aggregation, and the hydrodynamics of the water itself. Conventional drinking-water treatment does offer a meaningful barrier, mainly through coagulation-flocculation, sedimentation, and granular filtration — but removal efficiency varies widely, and small MPs and fibres remain particularly stubborn. Full-scale evidence also shows that atmospheric deposition and post-treatment infrastructure can add secondary contamination of their own. Removing MPs from water usually just shifts them into sludge and filter-backwash streams rather than destroying them, which is exactly why treatment-plant mass balances and responsible residual management matter so much. As for health, the concerns center on particle exposure and interactions with additives, sorbed contaminants, and microorganisms but how significant that risk actually is for drinking-water exposure specifically remains uncertain. Going forward, research should prioritize standardized analytical protocols, particles under 10 μm, nanoplastics, seasonal monitoring, full-scale DWTP studies, source-to-tap mass balances, and simultaneous assessment of both water and sludge streams. On the management side, the best path forward combines preventing plastic from entering drinking-water catchments in the first place with optimizing the coagulation and filtration systems already in place, alongside developing low-impact sorbents and bio-based treatment approaches.

Overall, conventional DWTPs are neither complete barriers nor ineffective systems; they are best understood as critical interception points within the environmental microplastic cycle, and getting the most out of them will always need to go hand in hand with preventing plastic pollution upstream if we want any meaningful, long-term reduction in human and environmental exposure.

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