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The Quality of Our Water: Emerging Contaminants Effect on Human Health

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ABSTRACT

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In a world that uses plastics in almost every aspect of life, microplastics have become an emerging concern in the context of human health. Known to have cytotoxic effects on life, these particles have been detected in our water systems, including both wastewater treatment plants, and drinking water treatment plants. Additionally, the proliferation of heavy metals is an ongoing issue in modern water infrastructure. Thus, the goal of this paper is to explore the effects of microplastics and heavy metals on our health, how they infiltrate the water supply, how we can mitigate their proliferation, and obstacles in implementing change in our infrastructure. Although the full effects of microplastics on humans are not yet known, it is clear they pose a risk, as they have been linked to genotoxicity, inflammation, cytotoxicity, and more. The effects of heavy metal exposure are well known to cause health problems in humans. The use of membrane bioreactors, magnetic-based separation, and point-of-use devices can help mitigate their infiltration into the human body, and governmental efforts are necessary to implement the changes needed in our infrastructure to deal with this pollution.

Keywords: microplastics, wastewater treatment plants, drinking water treatment plants, microfibers, membrane bioreactors, microfilters.

TABLE OF CONTENTS

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Introduction

In the past several millennia, mankind has slowly progressed to become a master of his environment. More recently, since the advent of the first and second industrial revolutions, mankind's ability to gather resources and tame his environment has grown exponentially. With this has come the ability to extract far more resources from the earth than ever in recorded history. With this great increase in technology, many new materials have been introduced for commercial and construction purposes. Included in this are plastics. Plastic is one of the most well-known environmental pollutants, as we are constantly reminded of "trash islands" in the ocean (Mohrig 2020). As plastics degrade, they introduce a new pollutant into the environment – microplastics. These pollutants find their way into our water supply, and research has suggested that they have infiltrated the natural environment, as well as our drinking water (Danopoulos et. al., 2020). Although many would assume that water quality is not something that we should be concerned about and that municipal water systems take care of this enough to warrant it being disregarded, this is not always the case. New evidence has shown that many municipal water treatment plants are not always effective in treating and removing all contaminants from the water system. In other cases, the contaminants are removed at the treatment plant, but by the time they reach the customer, they are not up to healthy standards. These contaminates range from heavy metals, such as copper and lead, to microplastics - which have been shown to harbor dangerous bacteria that can have a negative impact on physiological health (Dybas 2020). Although these contaminants are known to some, not everyone is aware of their prevalence in our water supply and the risk that they pose to our health. As recently as 2021, Congress has been eyeing these contaminants, specifically microplastics, as emerging pollutants that pose a threat to public health and require legislation to deal with (Toloken 2021). The goal of this paper is to research the effects that these contaminants have on our health, how they get into the water system, the current methods available to us to remove them from our water supply, and obstacles that prevent changes in our infrastructure from occurring.

The Problem

The goal of water treatment systems is to treat the potable water that we use on a daily basis, from the water in showers, to faucets, to toilets, and more. The purpose of these systems is to deliver sanitary water to the general public. Although these systems are very effective at treating water for compounds such as VOCs (volatile organic compounds), heavy metals, bacteria, and other debris, recent evidence has shown that these plants do not always treat all compounds that could potentially be a hazard to human health. In other cases, the systems are relatively effective at treating the water for hazardous compounds, but by the time it reaches the customer, it is not up to standards due to issues in the delivery system (Pan et. al., 2022). There are two main categories of materials that can bypass the treatment system or get into the water supply while in transit – heavy metals and microplastics. Although research is still ongoing about the effects of microplastics on human health, they are known to have detrimental effects on the health of marine life, and as also known to harbor dangerous chemicals and bacteria, such as leftover pharmaceutical drugs and bacteria (Martinho et. al., 2022). Microplastics were first detected in drinking water in 2017, and after this initial detection, many other studies followed (Volgare et. al., 2022). In the context of heavy metals, which are well known to have negative effects on human health (Liping et. al., 2016), often the water is contaminated by out-of-date delivery systems or through the scaling of these delivery systems (Pan et. al., 2022). With all these unknowns in the potable water supply, it is imperative that we find ways to improve our water at the tap – and although a complete overhaul of the many ineffective water treatment plants across the world would be ideal, it would be costly and time-consuming – and thus the goal of this paper is to propose ways the typical building or homeowner can protect themselves from this, as well as review the known health effects and contamination avenues of these particles.

Health Effects

The effects of heavy metals on human health are a well-known and documented phenomenon and have been for many years. Heavy metals hinder our body's cells' ability to function properly, causing health complications in growth and development, cancer, organ damage, circulatory and nervous system damage, and in even death (Liping et. al., 2016). For example, exposure to high amounts of lead, which was used extensively in building materials and everyday products in the 20th century, can have devastating effects on the body. It was dubbed the "Miracle Metal." It was used in paint, plumbing piping, glass, gasoline, and other products. However, after many decades of lead use in commercial products and building materials, the full effects of lead poisoning came into view. Birth defects, kidney issues, fertility rates, and developmental disabilities have all been linked to high exposure to lead (Nkosi et. al., 2022).

Chronic copper exposure, a much less known (and rarer) phenomenon, can also cause liver and kidney damage, as well as gastrointestinal issues (Araya et. al., 2004). Although it is not as much of a concern, since mammals tend to have efficient bodily systems to deal with copper toxicity it is still imperative that the water treatment systems properly filter out copper to prevent adverse health effects in the people that consume the water, and that the delivery systems of water do not leach copper into the water supply. Although low levels of copper are not harmful to human health, as mentioned before, higher levels cause issues. Leaching of unsafe levels of copper has been shown to happen, especially in new copper pipes (Araya et. al., 2004). Arsenic is another heavy metal that can be found in water that has adverse health effects, increasing the risk of skin, lung, and bladder cancer (Ćurković et. al., 2016).

Another issue in the water supply that has come up is the prevalence of microplastics in the water supply. Microplastics are plastic pieces less than 5 millimeters in size are microplastics, as defined by the National Oceanic and Atmospheric Administration (Poerio et. al., 2019). Within microplastics, there is another category known as nanoplastics – or plastics smaller than 100nm. There are two types of microplastics: primary microplastics are microplastics that have been intentionally manufactured into small particles, such as what is found in abrasive material in toothpaste, exfoliants, and other cosmetics. Secondary microplastics are microplastics that originate from larger plastics that decompose into smaller particles, due to UV radiation as well as mechanical, physicochemical, and biotic factors (Schymanski et. al., 2021). This includes not only normal plastics but also “biodegradable” plastics, which have been shown to disintegrate rather than degrade in the natural environment (Igalavithana et. al., 2022). The most prevalent and serious of these avenues for disintegration seems to be through UV radiation, which can lead to the biodegradation of plastics. Through this process, the surface area increases while the molecular weight of the plastic decreases, leading to more microbial colonization (Igalavithana et. al., 2022) Additionally, there are several different types of secondary microplastics – microbeads, micro-flakes, foams, microfibers, and granules, which are each associated with different types of plastic degradation (Conesa & Ortuño 2022).

They can infiltrate water supply systems through many different avenues, but the main culprit seems to be that wastewater treatment plants do not filter them out, so they are free to return to the water supply. This, in combination with general pollution, means that microplastics have infiltrated the natural environment – and eventually, they find their way back to us. According to an editorial published in 2017, an analysis of tap water showed that “83% of the worldwide samples and 94% of those in the United States were contaminated with microscopic fragments of plastic” (Dybas 2020). Other studies have shown little to no microplastic contamination in water (Hussein et. al., 2022), but the data seems to show this is largely localized and dependent on the region and specific water treatment plant. Microplastics find their way into the water supply in various ways. Within agriculture, plastic mulch, and the application of sewage waste to fertilize soil, accumulate to “125–850 [tons] of MP per million habitants added to the Europe soils each year by farmlands” (Martinho et. al., 2022). When microplastics are introduced into the soil, the water table becomes contaminated. Here they can also interact with and attach to pesticides (Martinho et. al., 2022). It is no wonder, then, that the water our treatment plants extract from the ground, rivers, or sea, has unusual amounts of microplastics in them.

Some studies have also found that microplastics can harbor dangerous chemicals and contaminates, including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), dioxin-such as chemicals, polybrominated diphenyl ethers (PBDEs), toxic metals, pharmaceuticals, and pesticides (Martinho et. al., 2022). In one experimental study done in 2022, researchers had the goal of uncovering absorption rates of a particular kind of pesticide, α-endosulfan, into 6 different kinds of plastics. Although α-endosulfan was banned by the Stockholm Convention, it is still currently being used in some countries, despite many other developed countries banning its use and importation due to its negative health effects (Martinho et. al., 2022). The researchers put the pesticide in a solution with an organic solvent. After 48 hours of exposure, the researchers found that two plastics, LPDE and UPVC, removed 96% and 32% of the pesticide from the solution, respectively. This former is especially concerning since LPDE (Low-density polyethylene) is a widely used, and largely unrecycled, plastic. It usually goes unrecycled due to its low flexibility, low mechanical performance, and low cost (O'Rourke et. al., 2022). It is used for computer hardware packaging, plastic bags and containers, pipes, automotive parts, milk jugs, and more. This makes the chances of it reaching the water supply through pollution much higher.

Pesticides aren't the only harmful contaminants infiltrating the water supply. Pharmaceuticals, both veterinary and human, are finding their way into our water supply. There are currently over 3000 recognized medicinal chemicals on the market and through a combination of overuse in livestock and humans. Because they are difficult to remove at sewage treatment plants, human pharmaceuticals often end up in the water supply (Pant et. al., 2020). Additionally, the pharmaceuticals used in livestock are excreted at rates from 30%-90%. Within the United States, it was found that 95 pharmaceuticals were in 139 waterways across 30 states (Pant et. al., 2020). Since pharmaceuticals can often attach themselves to microplastics (Martinho et. al., 2022), this is yet another concerning figure.

These aren't the only contaminants that can attach to microplastics and infiltrate the water supply. Another contaminant that can attach itself to microplastics is various types of bacteria and antibiotic-resistant genes (Kruglova et. al., 2022). In their research, they set out to determine whether microplastics provide "harbors" for these pathogens, with the microplastic surface composition allowing for bacterial colonization. They found this to be true; microplastics are a great substrate for "biofilm-forming micro-organisms in municipal wastewater, potentially including pathogens and antibiotic resistance genes" (Kruglova et. al., 2022). This claim is supported by another journal written in *Science*, stating that "biofilms growing on microplastics may be a source of harmful microorganisms" (Vethaak & Legler 2021). Although wastewater treatment systems seem to be efficient at filtering out some microplastics, due to their small size, many of these particles still escape filtration and find their way into the natural environment through the effluent. These are not light pathogens either, as Streptococcus, Pseudomonas, Lactobacillus, and Acinetobacter were all identified in the microplastic biofilm. The presence of Streptococcus (known commonly as "strep") is especially concerning since many streptococcus diseases have become increasingly antibiotic resistant over the past few decades (Kruglova et. al., 2022).

Although the effects of microplastics on humans aren't entirely known yet, one study did find that they may lead to adverse health effects, such as "inflammation (linked to cancer, heart disease, and rheumatoid arthritis), genotoxicity (damage to the genetic information in a cell, causing mutations), and oxidative stress (leading to chronic diseases such as cancer, diabetes, stroke)" (Dybas 2020). Researchers published a study in Biomolecules on the cytotoxicity of microplastics in mammalian cells. In their study, they maintained human colorectal epithelial cell line HRT-18 (intestinal lining cells) and murine rectal epithelial cell line CMT-93 in culture plates. Once they entered the log phase, they were exposed to the same concentration of PS-MPs (1 mg/mL) for different periods of time; 6 hours, 24 hours, and 48 hours. After analysis, the researchers found that cytotoxicity was not only present, but it increased with time - 18.4% at 6 hours of exposure, to 24.9% at 24 hours, and 42.8% at 48 hours. (Mattioda et. al., 2023). For reference, the type of plastic the cells were exposed to, polystyrene, is used in packing peanuts, Styrofoam, disposable cutlery, and other areas. Again, this is another plastic that is a common pollutant, so it stands to reason that it would enter the water supply. The researchers contributed the cytotoxicity to the microplastics' effects on membrane damage and oxidative stress (Mattioda et. al., 2023). This research shows the effects that microplastics can have not only on marine life but also on human cells. Not only do they harbor dangerous chemicals (such as pesticides), but they themselves can have harmful effects on cells.

Another study published in the Journal of Biomolecules also researched the effects of exposure to microplastics on human intestinal cells. Using Caco-2 human colon adenocarcinoma cells, they exposed the cells to a variety of microplastic concentrations for 8 weeks. The researchers found that after long-term exposure, these types of cells did not experience any significant damage due to microplastic exposure. This suggests that this specific type of cell is particularly resistant to the cytotoxic effects that microplastics are known to have on other types of cells, such as those that have been reported in blood, brain, epithelial, and placental human cells (Domenech et. al., 2021). However, this does not mean that uptake of the microplastics did not happen in the Caco-2 cells, as this was observed to have happened during their experiment. This can lead to an accumulation in the cells' lysosomes. Lysosomes are responsible for the disposal and recycling of worn-out and damaged cellular macromolecules and organelles, and the disruption of their function has been linked to failing to clear the potentially toxic cellular waste and the dysregulation of cellular signaling, which has been linked to cancer (Hsu et. al., 2022). Therefore, lysosome disruption has been linked to mitochondrial dysfunction (Domenech et. al., 2021). Although the researchers did not find any significant genotoxic or oxidative stress in the cells, they acknowledged that without the use of weathered microplastics – which can have different properties – the results are not completely true to what actually happens in cells when exposed to microplastics in the natural environment.

This is not the only research showing the toxic effects of chronic exposure to microplastics. In a study published in the Journal of Environmental Health Perspectives, researchers aimed to determine the neurotoxicity of chronic microplastic exposure on mice. Due to the little research on the effects of microplastics on mammals, they aimed to see if the mice were affected by the exposure over a prolonged period. The mice were given water with 100 μg/L and 1,000 μg/L polystyrene microplastics with diameters of 0.5, 4, and 10 μg for 180 consecutive days. After the exposure period, they tested the mice's cognitive ability through a series of tests, as well as analyzed some of the mice's vital organs to determine any negative effects. They found that prolonged exposure to microplastics led to the build-up of microplastics in the brain, as well as disruption of the blood–brain barrier, lower level of dendritic spine density, and inflammatory response in the hippocampus (Jin et. al., 2022). The exposed mice also experienced cognitive and memory impairment compared to the control mice, which was dependent on the concentration of microplastic exposure, but not necessarily the size of the particles. This research suggests that microplastics not only have cytotoxic effects on our intestinal cells, but if they enter the nervous system at chronic concentrations, they can have detrimental effects. Of course, more research needs to be conducted to determine the true effects of microplastic exposure on the human nervous system.

Other research on the effects that microplastics have on mice has shown that exposure does not just affect the nervous system and brain. Exposing the mice to 1,000μg/L of microplastic-contaminated water for four weeks, the researchers set out to determine the effects that the microplastic contamination had on the intestinal tract of the mice. They fed the mice two different types of diets, one was a "normal diet" while the other was high in fat. In their research, they found that gene expression of genes associated with inflammation was higher in mice exposed to microplastics, and the mice fed the high-fat diet also "exhibited dysbiosis, thinning of the intestinal mucin layer, indications of inflammation of the intestinal tract, and different gene expression of nutrient transporters in the intestine" (Takuro et. al., 2023). This is the first research to suggest that high-fat diets can affect the absorption rate, and thereby health risks, of microplastics in the body.

In another study at Utrecht University in the Netherlands, researchers studied the uptake, transport, and toxicity of microplastics, as well as nanoplastics, in human placenta cells. Due to recent research suggesting the toxicity of exposure to microplastics, the researchers set out to determine how much, and how often, micro and nanoplastics can be absorbed by the placenta, and therefore the fetus, during pregnancy. The placenta plays a vital role in the development of a human fetus, responsible for the "exchange of gases, nutrients, metabolites, and waste products" (Dusza et. al., 2022). The main structure in the placenta that is responsible for this exchange between the mother and fetus are chorionic villi covered by villous trophoblasts. The cells within the villous trophoblasts are responsible for most of the fetomaternal exchange, as well as acting as an endocrine system, they are responsible for the biosynthesis and metabolism of a variety of hormones (Dusza et. al., 2022). Disruption of these cells can lead to pregnancy complications, and thus research on microplastics' effect on them is imperative. In order to mimic the effects of real microplastic exposure, the researchers used weathered microplastic particles (as well as "pristine" particles – or particles that are intentionally manufactured to be microscopic) – specifically polystyrene (PS) and high-density polyethylene (HDPE). The researchers did not find any evidence that the microplastics caused cytotoxicity in the cells, although they acknowledged that other studies have found significant cytotoxicity effects (Dusza et. al., 2022). Therefore, their recommendation was to continue research on the effects of micro and nanoplastics on placenta cells, and by extension maternal and fetal health, especially in the context of long-term exposure.

Other research has aimed at studying not only the effect of microplastics on the placenta but also on children and pregnant women. In a review of available research on microplastics' effect on pregnant women and children, researchers took several studies analyzing these effects and quantified them into a cohesive review. Their main concern is the fact that children tend to consume more per unit of body weight than adults, meaning that exposure to hazardous contaminants can be more dangerous. Their review found evidence that microplastics were transferring through the placenta, as different papers detected microplastics in the human placenta, which can vary at different stages of the gestation period (Sripada et. al., 2022).

There is other research on the effect of microplastic contamination on human cells. In another study, researchers used vein tissue samples from five participants undergoing surgery, with their consent, to see whether their vein tissue cells contained microplastics. In their analysis, they found a total of 20 microplastic particles in 4 out of 5 of the participants. This research suggests that microplastic particles are not only infiltrating our bodies but staying there. Although this is the first study of its kind, other research has suggested that microplastics are also present in the lungs and colon (Rotchell et. al., 2023).

Although the complete effects of microplastics on humans are still not completely known, it is obvious that microplastics have negative effects on organisms that are exposed to them. As seen in the research above, microplastics have cytotoxic effects causing distress to cells exposed to them. They can also harbor dangerous pharmaceuticals and pesticides (Mattioda et. al., 2023), causing more harm, and have been found in human tissue (Rotchell et. al., 2023). They have also been linked to nervous system damage in mice (Jin et. al., 2022), as well as intestinal issues in mice (Takuro et. al., 2023). With the toxicity of microplastics slowly being understood, such as what happened with lead in the 1970s, it is imperative that steps be taken to help prevent more harm to human health and the environment. This includes further research into the full effects that microplastics have on the body, as well as methods to prevent human exposure to them There are many different avenues by which microplastics can infiltrate the human body, many of which will be addressed in the research below.

How Contaminants Infiltrate the Water Supply

Despite the great lengths many local governments take to filter potable water of any contaminates, from sediment to bacteria, to heavy metals, and more, many water treatment systems do not always account for or do not filter out microplastics during the filtration process. This is not to say that all water treatment systems do not filter out microplastics, because many studies have found little to no microplastic contamination in water supplies. However, the fact that only *some* water treatment systems filter these out is concerning. As discussed before, microplastic contamination usually occurs through the degradation of plastics in the natural environment (Igalavithana et. al., 2022). Microplastics have been found in the soil, water (fresh and saltwater), and even in some cases, the air (Dris et. al., 2015). Additionally, as mentioned before, microplastics can also enter the natural environment through wastewater treatment plants, with one study recently finding that one wastewater treatment plant can release up to 100 billion microplastics per year (Saboor et. al., 2022). Once they enter our waterways, they can find their way back to water treatment plants for potable water. Although most studies focus on the prevalence of microplastics in the marine environment, freshwater studies only take up around 4% of reports (Zhang et. al., 2020). However, a recent study found that the prevalence of microplastics in freshwater is comparable to that of marine environments (Peng et. al., 2017).

The prevalence of microplastics in drinking water is a continuous field of research, one that can sometimes lead to conflicting results. In one meta-analysis of twelve studies aiming to study the prevalence of microplastics in drinking water (six studies on tap water and six on bottled water), researchers found overwhelming evidence that microplastics were in the water supply (Danopoulos et. al., 2020). Using a proper systematic review, the researchers set out to determine whether microplastics were truly in drinking water, as some research has suggested. They only included studies that used one of the following types of microplastic detection methods: "Fourier-transform infrared spectroscopy (FTIR), Raman spectroscopy (RM), pyrolysis gas chromatography/ mass spectrometry (Pyr-GC-MS), and scanning electron microscopy plus energy-dispersive X-ray spectroscopy (SEM/EDS)" (Danopoulos et. al., 2020). This decision is supported by another experimental study that attempted to find the best way to analyze microplastic contamination in water, namely FTIR spectroscopy and Raman spectroscopy (Glöckler et. al., 2023), which were cited as being the most accurate. This is due to the fact that these methods are spectroscopic, so they are sensitive to the vibrational modes of the molecule under study (O'Donnell & Lee, 2019). In one experimental study, researchers used Raman spectroscopy on intentionally contaminated tap water to determine its accuracy of detection. Two types of common microplastic contamination, polyethylene, and polystyrene (among three others) were successfully detected in their study (Kniggendorf et. al., 2019).

Danopoulos and their colleagues' review included only using descriptive and analytic observational study designs (as opposed to experimental studies) in their data. For tap water (our main concern in this paper) the cumulative number of samples between all the studies was 155. Within these samples, the different studies found microplastic contamination between 24-100% after the filtration process. Three of the studies were in Europe, two were in Asia, and one was in North America. The two most prevalent microplastics found in the samples were polypropylene and polyethylene, with the highest exposures being in Europe and the lowest in North America (Danopoulos et. al., 2020).

Another avenue of possible microplastic contamination in our water supply is through gray water, or water that has been used for typical household purposes such as washing clothes, doing the dishes, or showering. One major avenue for this contamination is laundry. Due to the increased use of synthetic fiber clothing, laundry wastewater seems to be an emerging source of microplastic contamination. Polyester-based clothing (mainly polyethylene terephthalate) seems to be the main culprit in this, with a recent study showing that a 100% polyester shirt being washed could release nearly 5 million microfibers per kilogram of washed fabric (Volgare et. al., 2022). This is not the only example of clothing washing causing microplastic contamination – clothing manufacturing is another culprit. Primary microfibers from the washing stage of clothing manufacturing get into the water and are thus released into the environment (Munhoz et. al., 2023). Once they reach the wastewater treatment plant, they continue their path, as it has been shown that up to 70% of microplastics released in the final effluent of wastewater treatment plants are made up of microfibers from synthetic clothing (Conesa & Ortuño 2022).

Other research has suggested that one reason microplastics may be infiltrating the water supply is the ineffectiveness of wastewater treatment plants filtering out microplastics (Danopoulos et. al., 2020). It has been shown that the effluent from wastewater treatment plants can release “5900 MPs/m−3 on wet-weather days” and “3000 MPs/m−3 on dry ones” (Conesa & Ortuño 2022). Most water treatment plants have four stages of filtration to make the water safe to enter the water supply. First comes the preliminary treatment, where larger particles are filtered out. Second comes the primary treatment, where coagulants are added to the water to help with sedimentation. After this comes the secondary treatment, where “organic matter in suspension is” negated “in the activated sludge reactor” (Conesa & Ortuño 2022). This ensures a high-quality final effluent. Lastly comes the disinfection process, which eliminates pathogens using chlorine, ozone, or ultraviolet light.

Although it has been shown that wastewater treatment plants can remove up to 90% of microplastics, they are still being seen as the major contributor to the introduction of microplastics into the environment (Conesa & Ortuño 2022) Despite this high percentage, since many of the microplastic waste is separated in the sludge (which is often used for soil enrichment), these microplastics find their way back into the environment. The concentration of microplastics escaping wastewater treatment systems depends on the type of filtration techniques that the plants use. Using the primary clarification technique during primary treatment, it was found that 84-88% of microplastics ranging from 100–1000 μm were filtered out (Saboor et. al., 2022). Using the sedimentation technique, a conventional wastewater treatment technique, it was found that microplastics could be filtered out at a rate of 57-64% after the primary and secondary treatment (Saboor et. al., 2022). Although these numbers are promising, they still show that many microplastics are escaping the filtration process and escaping back into our water supply, especially particles smaller than 100 μm.

This is not the only avenue through which microplastics contaminate the water supply through waste-water treatment plants. Even though it has been shown that some waste-water treatment plants can filter out microplastics at somewhat acceptable rates, the pollution does not end here. As discussed earlier, the application of waste sludge as commercial fertilizer is another culprit in microplastic contamination in our water supply. Typically, microplastics that are filtered out of the water are captured in the waste-water treatment plants' waste sludge. This sludge, in turn, is often used as a recycled fertilizer in agricultural lands. Thus, microplastics that are filtered out at the wastewater treatment plant often end up right back in the environment to contaminate the water supply further, providing opportunities for it to harbor the dangerous chemicals and pharmaceuticals previously mentioned in this paper (Igalavithana et. al., 2022). This contamination not only extends to the water supply but also to the plants being grown in the soil that extract nutrients from it.

Sludge waste is not the only way that microplastics are introduced into the soil – industrial plants and the pollution they create also play a role in the introduction of microplastics into the water and soil. In one study outside of Minsk, Belarus, researchers set out to determine the amount of microplastic contamination in the soil near a plant that manufactured expanded polystyrene insulation boards and other expanded polystyrene items (Kukharchyk & Chernyk 2022). Using soil samples from both near the riverbed and farther up into the floodplain of the river the plant sat next to, they determined the amount of microplastic contamination in the soil. It was found that the soil samples showed anywhere from 621–5594 particles/kg of soil (within the industrial site) (Kukharchyk & Chernyk 2022). Their study showed that microplastic contamination can also come from poor industrial practice and the fact that the type of microplastic contaminating this area is polystyrene, which has been shown to have high rates of pollutant absorption (Kukharchyk & Chernyk 2022). Additionally, the accumulation of microplastics that were found in the floodplain was also concerning – as this shows that the plastics are infiltrating the river, which deposits them in the floodplain and could potentially carry them farther downstream.

Lastly, there are a few avenues through which heavy metals can infiltrate the water supply. The first of these is through the transportation system of the water – it has been shown that pipe scales can build up in the transportation system, thereby accumulating inorganic compounds (Pan et. al., 2022). These scales can consist of iron, copper, aluminum, and lead. After a long hydraulic retention time in storage and transport, different reactions can lead to scaling in transport pipes. When the environment of the pipes changes, such as the water source, the scaling within the pipes can release these compounds into the water. Oftentimes, water supply systems that use low pH, soft water, tend to experience more pipe corrosion, increasing the problem (Rupp 2001).

This research shows that there are many different avenues through which microplastics and heavy metals can infiltrate the human body, and how they enter the water supply in the first place. Because this summary has to do with microplastics in the water supply, this does not include every source of microplastic exposure, such as through food (Igalavithana et. al., 2022). However, it is still important to understand the prevalence of microplastics and heavy metals in the water supply and to take steps to ensure that it is filtered out (which can be done at various stages of the delivery of the water supply, from wastewater to the faucet tap). Additionally, steps should be taken to mitigate the application of sludge waste on farmland (or ensure that it is properly decontaminated), as well as place industrial controls to ensure that industrial plants do not pollute waterways and soil further.

Filtration Techniques for Microplastics and Heavy Metals

Due to the increase in microplastics in the water supply, new methods for filtration are being researched and integrated into treatment systems to lessen the prevalence of these contaminants. Since microplastics are small particles, they can be filtered out through a few different ways, ranging from incredibly small mesh filters, to coagulation, reverse osmosis, or distillation, which will each be outlined below. For example, one study aimed to understand the effect that coagulants have on filtering out microplastics. These coagulants work by destabilizing “colloidal suspended particles that are stable through their mostly negative surface charges” and allowing the plastics to settle (Adib 2022). In their study, they used PACl and ferric chloride to coagulate microplastics and test their effectiveness. However, their study found that these coagulants are ineffective at filtering out microplastics from the water, finding only a removal rate of 18.75%. Although PAC1 and ferric chloride are popular coagulants, according to this study, further research needs to be done on alternative coagulants for microplastic filtration.

There are other ways that microplastics can be filtered out of the water, and in much more effective ways. This can include membrane bioreactor (removal rate 99.9%), sand filtration (removal rate 97%), dissolved air flotation (removal rate 95%), or disc filtration (removal rate 40–98.5%) (Conesa & Ortuño 2022). Membrane bioreactors are an especially promising technology. Throughout several studies conducted in the Netherlands, The United States, China, and the United Kingdom, researchers found that membrane bioreactors can remove microplastics at a rate between 64.4% to 99.0%. This filtration technique works by a combination of a biologically activated sludge process and membrane separation. In one study, after being applied after the biological reactor, the effluent had a removal rate of 100%. Another study using similar methods found a removal rate of 79% (Saboor et. al., 2022).

These are not the only studies confirming the viability of membrane bioreactors. In another study published in the Journal of Membranes, researchers analyzed the concentration of microplastics in three different wastewater treatment plants' waste sludge, two of which used the conventional activated sludge process, and one of which used the membrane bioreactor process. They collected samples from the treatment plants once a month over the course of three months. Using a combination of visual identification to determine the composition and amount of microplastics, along with FTIR analysis, they determined that the plant that utilized the membrane bioreactor was far more effective at extracting microplastics from the waste sludge, finding nearly double the concentration of microplastics in the membrane bioreactor's waste sludge than in the two other plants' waste sludge. They also found that the membrane bioreactor extracted a larger range of microplastic particles, both in size and in type, such as polyethylene and polystyrene (Di Bella et. al., 2022). An especially important part of this finding was the fact that the membrane bioreactor was far better at filtering out microplastic fibers, which are smooth and have a high ratio of length to width, making them more difficult to extract. In terms of the distribution of different types of microplastics found in the waste sludge, the composition of microplastic fibers compared to other types in the membrane bioreactor was 47%, while the other two plants' waste sludge was only composed of 21% and 24% microplastic fibers for particles smaller than 1 millimeter. The bioreactor also had a more uniform composition percentage of microplastics above and below 1 millimeter, with the other two plants having very different levels of extraction of specific particle types, dependent on the size of the particle (Di Bella et. al., 2022).

A second promising filtration technique being researched is magnetic-based separation. Using magnetic-seed filtration, microplastics smaller than 150 μm can be successfully removed from the effluent. This method employs two steps; the first is to agglomerate the microplastics with magnetic nano seeds, and then separate the microplastics from the water using magnetism. In one study, researchers found that this method could remove microplastics smaller than 20 μm at a rate of 92%, including the popular contaminates polyethylene and polystyrene (Saboor et. al., 2022).

Despite this promising research, studies consistently find different rates of removal of microplastics in water, possibly due to different analytical techniques used to test the effectiveness of microplastic removal. Issues continue to arise due to the lack of standard protocol, which reflects the fact that there are currently no government regulations regarding the prevalence of microplastics in water (Conesa & Ortuño 2022). This is exemplified in another study done in Norway, where researchers were trying to determine the number of microplastics found at different stages in the wastewater treatment process.

Studying the Viikinmäki Wastewater Treatment Plant, researchers attempted to determine the prevalence of microplastics at the pre-treated phase, after the primary stage, after the secondary stage, and after the tertiary (final biological) phases. Despite positive results showing good filtration of microplastics by the end of the process, with most of the microplastics being filtered out at the sedimentation phase, the researchers acknowledged that their study can't be compared to others due to a difference in methods to analyze and test the microplastic composition in the water. This includes things like the mesh size of the filter, sample volume, and filtering pressure (Talvitie et. al., 2015). Even the World Health Organization is becoming aware of this; in a recent report by the W.H.O., they recognized that standard procedures for measuring microplastics need to be established (Schymanski et. al., 2021). In addition to no coherent procedures for measuring microplastics in wastewater treatment plants, there are no government regulations regarding the prevalence of microplastics in wastewater effluent, because these systems are not specifically designed to extract all of them. A lack of quality enhancement technologies is another culprit in the prevalence of this particle in wastewater. It is difficult and expensive to upgrade water treatment systems, and with such varying research, it is unlikely to happen in the near future.

Even the proven microplastic removal technologies, such as "agglomeration into biological flocs, the combination of oxidation and fluorescent staining, polycarbonate filters, as well as filtration with 0.45 µm filter paper" has their issues (Nkosi et. al., 2022). The problem with these methods is that they tend to create byproduct waste, thereby "patching" the problem. However, membrane technology is a promising alternative to separate microplastics from water – it is easily scalable, consumes a low amount of energy, is operationally flexible, and can handle larger volumes of water (Nkosi et. al., 2022). When applied at the tertiary stage of the filtration process, these membranes can remove up to 99% of microplastics. One type of membrane that seems especially promising is polyvinylidene fluoride (PVDF), which has a high impact resistance as well as great flexibility. In their study, Nkosi and their colleagues tested this membrane by modifying it with carbon nano-onions to enhance its performance. They used this filter on wastewater treatment (effluent and influent) water, local lake water, and tap water. They found that PVDF was excellent at filtering out microplastics, some of which they found to have heavy metals such as arsenic, copper, and zinc (Nkosi et. al., 2022). This technology is a promising alternative that can be integrated into water treatment systems to help curb the prevalence of microplastics.

Another excellent filtration technique for microplastics is reverse osmosis. Common in industrial and municipal water treatment systems, this filtration technique operates by using nonporous or nanofiltration membranes and applying high pressure to the membrane, leaving substances in a concentrated water solution. However, just like any other technique, it comes with its drawbacks. For example, membrane fouling is the main challenge when it comes to maintaining reverse osmosis filters to perform as expected (Poerio et. al., 2019). Without proper fouling, the water pressure and effectiveness of the membrane are mitigated. (El Batouti et. al., 2022). To mitigate this, plants use a variety of pretreatment processes such as the use of coagulants, antiscalants, oxidizing agents, and disinfectants. This helps extend the lives of the membranes and decrease the risk of contamination in the final effluent (Poerio et. al., 2019).

This is not the only instance of using a mesh filter to filter out microplastics. As mentioned earlier, another possible avenue of microplastic contamination in the water supply is through laundry wastewater. In an experiment to try and reduce the amount of microplastic contamination in laundry wastewater (as well as an attempt to develop a domestic filtering device that can be used in other applications), researchers used a filtering prototype to prevent microplastic contamination in the final effluent. Studying in the Slovenian area, they tested the prototype in three homes and one office area. It was designed with a porosity of 50 µm, allowing for an ideal balance between water pressure and microplastic filtration (Volgare et. al., 2022). Although effective, with a porosity of 50 µm, many other microplastics could still pass through this filter and enter the water supply or your body, depending on the application of the filter.

There are other filtration methods that can be used to protect the average consumer from microplastic contamination in the drinking water, called point-of-use devices, which have previously been used to filter out heavy metals and other contaminants in the water (Cherian et. al., 2023). These filters include "granular activated carbon (GAC), solid block activated carbon (SBAC), ion exchange (IX) and reverse osmosis (RO)." When combined, these filters can be excellent at filtering out microplastics from the water. This can include GAC filters combined with IX filters.

Granular-activated carbon filters work by using small particles of activated carbon that create a high surface area that is effective at extracting particulate matter. Ion exchange filters, on the other hand, "consist of anion exchange (AX) or cation exchange (CX) resin and the latter is commonly incorporated to preferentially exchange charged inorganic species" (Cherian t. al., 2023). Solid block activated carbon filters operate by using fused activated carbon particles resulting in a block that has a porosity between 0.5 –1.0 µm (Cherian et. al., 2023). In their experimental study, researchers used different combinations of these filters to determine their effectiveness at filtering out microplastics. The first used a combination of GAC and IX filters, the second a combination of GAC, IX, and MEM (non-woven membrane) filters, and the third a combination of MF (membrane microfilter), GAC, and IX filters.

In their study, they found all the filters were relatively effective as retaining the microplastics that were present in the water – filter type 1 (GAC + IX) had a mean retainage of 94.3 ± 2.9%, filter type 2 (GAC + IX +MEM) a mean retainage of 90 ± 5.9%, and filter type 3 (MF + GAC + IX) a mean retainage of 93.6 ± 2.2%. However, it was also found that filters that used a membrane component performed better, especially when it came to filtering out microfibers. Microfibers are likely the most common type of microplastic contamination in drinking water, meaning that their effective extraction during filtration is more important compared to particles or spheres of microplastics (Cherian et. al., 2023). The researchers concluded that type 2 and 3 filters were the most effective and viable for use in a residential or commercial setting, due to their use of membrane filters to remove smaller particles.

There are many different types of filtration techniques that can be used to mitigate microplastic contamination (as well as heavy metal contamination, since filters that rely on porosity measures will filter out heavy metals and microplastics), from wastewater treatment plants to water treatment plants, to point-of-use devices. These techniques include bioreactor membranes, magnetic-based separation, and a variety of membrane technologies. In the context of point-of-use devices, this can include granular activated carbon, solid block activated carbon, ion exchange, and reverse osmosis filters, which can be more effective when they are combined. Although more research is needed to determine the best method of action for the integration of effective filtration processes in water infrastructure, the average consumer can protect themselves by using a variety of commercially available filters.

Difficulties with Infrastructure Integration

Given all of these facts, it would be reasonable to assume that implementing the changes necessary to make lasting changes in our water treatment systems is feasible – however, there are many obstacles that must be overcome in order for these changes to be implemented. These obstacles include governmental regulation, the difficulties of updating infrastructure, and the cost of updating infrastructure. Traditionally, plastic pollution has a long history of regulation – from the 1970s through the 1990s, there were many international laws set in place to deal with plastic pollution (Munhoz et. al., 2023). However, it wasn't until 2008 that microplastics became a known pollutant in the context of legislation.

As mentioned before, the U.S. Congress has recently begun to eye microplastics as emerging contaminants in the water supply. In Congress, microplastics are put under an umbrella term for other emerging contaminates called “CECs,” or contaminants of emerging concern, which also include pharmaceuticals, pesticides, industrial chemicals, and algal toxins (Toloken 2021). Because microplastics are smaller than 5mm, they do not fall under the Clean Water Act of 1972, meaning they are largely unregulated. Many legislators are calling for their regulation at the federal level; setting standards for treatment systems across the country to use. These legislators are looking to the EPA to solve this issue, seeing it as an environmental issue that affects public health. The only government that has shown any initiative in this, and “possibly the first government in the world” to begin the steps to introduce microplastic mitigation regulations, is the U.S. State of California (Toloken 2021).

These changes, however, should not just be limited to the state or federal government. Local governments play a huge role in water infrastructure changes, especially when it comes to wastewater treatment plants and drinking water treatment plants. This is best done with different local government organizations working together to solve an issue. In one study, researchers analyzed how the City of Philadelphia and its many departments worked together in order to implement new “green” stormwater infrastructure. Their research showed that it takes city governments to take the first steps in implementing change in our infrastructure, using piloting programs and testing new technologies in the real world. They also found that implementing this change requires all the departments in a government to work collaboratively (Fitzgerald & Laufer 2017). In the context of wastewater and drinking water infrastructure, the key may be to allow local governments to take the reins and implement changes, rather than depend on the state or federal government to do so. This does not mean that there aren’t other issues that arise in local water systems – oftentimes, only larger systems are capable of making the necessary changes to their infrastructure to mitigate contamination. Smaller water systems often face a shortage of managerial, fiscal, and technical resources (Rupp 2001). This can be mitigated by using solutions specially catered to smaller water systems. In one study published in the Journal of Environmental Health in 2001, the author summarizes the effectiveness of small water treatment system pilot programs for new filtering technologies.

Although this paper does not deal with microplastics, it still offers valuable information as to how changes in water treatment systems can be done effectively. It studied a variety of attempts to implement new treatment systems in water plants and found a few issues that came with attempts of implementation, testing the effectiveness of the techniques, quantifying operating costs, and identifying operational requirements that may inhibit their use in small systems. One of the methods tested was the implementation of microfiltration in water systems. In the pilot program, the operating characteristics of ceramic membranes were tested using surface water at a midwestern water treatment plant. Although there were many obstacles, such as the failure of some of the membranes, the researchers collected a lot of practical data on the ceramic filter. There were many other issues shown in other pilot programs for water system upgrades, but overall, the research demonstrated how local governments can go about implementing changes in their water systems (Rupp 2001).

Conclusion

Through this research, it has been shown that microplastics can have cytotoxic effects on both human and mammalian cells (Mattioda et. al., 2023), as well as can harbor dangerous pesticides and pharmaceuticals due to their chemical nature (Martinho et. al., 2022). Although the full effects of microplastics on humans are not yet known, it is obvious that they pose a potential threat to human health, as research has suggested that microplastics have negative effects on human intestinal cells (Mattioda et. al., 2023), and have been shown to have negative effects on the nervous systems of mice (Jin et. al., 2022). Considering the fact that the U.S. Congress is eyeing microplastics as a potential contaminant (Toloken 2021), it is obvious that steps should be taken to mitigate their proliferation in the environment.

Additionally, several avenues through which microplastics and heavy metals are infiltrating the water supply were also explored. In the context of heavy metals, this has been shown to happen during the transport of the water – often due to it reaming stagnant for too long, thereby causing scaling in the transport pipes (Pan et. al., 2022). The most concerning avenue of microplastic contamination is through wastewater treatment plants, which seem to be ineffective at filtering out microplastics, as they have been detected in the final effluent (Saboor et. al., 2022). Additionally, several filtration techniques were explored, including using a membrane bioreactor, magnetic separation, the use of coagulants, sand filtration, and point-of-use devices. Because the main polluter of the water supply seems to be wastewater treatment plants, these systems need to be upgraded to meet the need for better filtration of emerging contaminates. This would best be done through local regulations, testing, and upgrading of faulty plants that do not effectively filter out these contaminants. Although federal regulation plays a part in this process, such as through certain directives or laws from the EPA, ultimately the responsibility of dealing with these contaminants falls on local treatment plants.

The area of microplastic contamination in our water systems is a very new field of research, with much of the research being conducted sometime in the last 5 years. Although research on their effect on human health is still not yet conclusive, it is becoming increasingly clear that microplastics pose some level of risk to human health, although that extent is unknown. However, through many of the studies explored here, it is clear that microplastics can have negative effects on intestinal cell lining (Mattioda et. al., 2023) and the nervous system (Jin et. al., 2022) in mammalian cells. Additionally, further avenues for the implementation of emerging filtration technologies should be explored, and local, state, and federal governments should be more proactive in determining the risk of microplastics and their effect on our health.

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