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Microplastics in Local Communities' Tap Water

Zachary T. Rattell
University of Massachusetts Amherst

Microplastics in Local Communities' Tap Water

A Thesis Presented

By

ZACHARY T. RATTELL

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Approved as to style and content by:

_____

Baoshan Xing, Chair

_____

Masoud Hashemi, Member

_____

Om Parkash Dhankher, Member

_____

Baoshan Xing, Department Head

Stockbridge School of Agriculture

_____

Masoud Hashemi, Graduate Program Director

Stockbridge School of Agriculture

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ABSTRACT
Microplastics in Local Communities' Tap Water

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ZACHARY T. RATTELL

B.S., UNIVERSITY OF MASSACHUSETTS, AMHERST, MA

M.S., UNIVERSITY OF MASSACHUSETTS, AMHERST, MA

Directed by: Professor Baoshan Xing

Microplastics are an emerging environmental contaminant. One of the ways microplastics can get into the environment is by the breakdown of larger plastics. These plastics can come from industrial practices, discarded fabrics, agriculture, and general plastic waste. As these plastics are broken down microplastics leach into the environment. The widespread use of plastics has resulted in the spread of microplastic contaminants all over the world. Microplastics have been reported to be in drinking water, so this paper is looking at the presence of microplastics in local communities of different demographics and socioeconomic statuses. In other studies of different drinking water contamination, minority, and low-income communities had worse quality water. In this paper, methods for sampling, extraction, and analysis with Laser Direct Infrared Spectroscopy were used. Out of Cities A, B, and C, City A, with the largest population, higher percentage of minorities, and worse off socioeconomic status, had the highest particle count. More research is needed in this field to find how socioeconomic status can affect exposure to microplastic contamination.

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CHAPTER I

LITERARY REVIEW

A. Background/Formation of Microplastics

The first synthetic plastic was created in 1907. Due to plastic's beneficial properties like low density, low thermal and electrical conductivity, and ease of manufacturing, plastic has become used in a wide array of applications [1]. When macroplastics are broken down, whether intentionally or naturally, it becomes microplastics (MPs)[2]. These MPs size ranges from 1 μm to 5 mm [3]. Due to their small size, MPs are bioavailable to organisms. MPs large surface areas make them prone to adsorb organic pollutants and can leach plasticizers [2]. MPs are an emerging global contaminant with ever-increasing interest.

The extent of MPs contamination is great. One study estimated the abundance of MPs in the ocean. Using almost 12,000 data points collected from manuscripts and expeditions using marine surface sampling techniques were able to model the extent of contamination. Between 82 and 358 trillion plastic particles, mostly composed of microplastics is estimated to be floating in the ocean. This is estimated to weigh between 1.1 and 4.9 million tonnes[4]. Another study estimated global MPs release is about 3 million tonnes annually while 5.3 million tonnes of larger plastic are released. These larger plastics can degrade into MPs over time[5].

Plasticizers are added to plastics. These plasticizers are used to change the properties of plastics, extending their life. Plasticizers can be added to improve heat, oxidative damage and microbial degradation resistance. Since additives can improve the life of plastics, degradation will be prolonged, and additives can be leached out. The leached-out additives could potentially be hazardous chemicals. PVC, a polymer that makes up piping, can contain phthalates making up

to 50% of its weight. Phthalates can soften plastics but when leached it can be an endocrine-disrupting chemical[2].

MPs bioavailability can be affected by several factors. The main factors identified in one review focused on zooplankton are abundance/co-occurrence, characteristics of plastic, transformation, and selectivity of zooplankton [6]. Abundance/co-occurrence can increase bioavailability when MPs are further degraded into more MPs. As the concentration of MPs increases, there have been observed increases in ingestion[7, 8]. Characteristics that can affect MPs bioavailability are size, shape, color, and composition. Size and color could lead to MPs being mistaken as natural prey[9]. Size can also determine if a phytoplankton can ingest the MPs depending on the species' mouth size[10]. The shape of MPs can determine the bioavailability of MPs. Microbeads have been found to be bioavailable in a wide range of taxa[7, 11]. Irregularly shaped MPs, which were also consumed, were found to negatively affect larvae swimming where total distance and maximum velocity decreased[12]. MPs shape may influence bioavailability and influence biological effects from changes in gut passage time[6]. Composition and density can determine where certain MPs are found. Polyethylene (PE) has a lower density and will likely be present on the surface of water but can be altered by different factors that will be covered in the following paragraph. Dense MPs like polyvinyl chloride (PVC) will sink and can become bioavailable to benthic feeders[6, 9].

MPs are not in a constant state, just like the plastics MPs may have been apart of, and are still susceptible to degradation and other changes. As MPs age, weathering and biofouling alters the physical and chemical characteristics[10]. Over time MPs size will decrease, the shape will become more irregular, and the surface area will increase[3]. Along with these changes, once entering a marine environment, a film or organic and inorganic substances is formed by

adsorption. MPs and microorganisms will have attractive and repulsive forces which results in biofilm forming[13]. This influences bioavailability in phytoplankton since the biofilm may contain similar prey that secrete chemicals aiding in their chemo-detection. This may lead to an increased risk of microplastic ingestion[6, 10].

Another change MPs undergo is bio-mediated density transformation. As biofouling takes place on MPs, the buoyance will change. MPs can sink and become bioavailable to marine organisms throughout the water column, but do not accumulate on the seabed[14]. Organisms, including zooplankton, migrate to different depths which will lead to interactions. Organisms can transport MPs to different depths through fecal pellets which are then consumed by other organisms[6, 15].

MPs have hydrophobic properties. Hydrophobicity can lead to aggregates forming with other particles in a marine environment. The formation of aggregates can increase particle size and change the density which will make it bioavailable to different sized species at different depths. These aggregates can gather on appendages, swimming legs, feeding apparatus, and other parts of their body. This comes to a possible reduction of mobility, ingestion, reproduction and mechano-reception. MPs aggregates can form inside the digestive system[6, 11].

Fish ingest MPs in both freshwater and marine environments. Different species of fish have had recorded MPs in their gastrointestinal tract. The MPs range in color, shape, and polymer type. Fish, just like the phytoplankton, can mistake MPs for prey or ingest MPs through other organisms that already have ingested MPs[16]. MPs are usually retained in the digestive system but can adhere to the skin of fish or move to the gills, liver, and muscle. If the MPs are very fine, it could translocate across living cells where MPs move throughout the whole body via the circulatory or lymphatic system[16, 17].

MPs sizes can be similar to sediments and planktonic organisms, making it more bioavailable to fish. Filter feeding fish, being less selective in feeding, are believed to be more susceptible to consuming MPs. Like how color may influence phytoplankton consumption of MPs, fish can mistake colored MPs for prey[9, 16]. Visual predators have been reported that black and red, white MPs were preferentially consumed by the common goby. It is believed that the white MPs could be mistaken for brine shrimp[18]. Fish consumption, like with phytoplankton, can also be influenced by the depth MPs are found due to the density[16, 19].

In a lab environment, the ingestion of MPs can lead to accumulation in gastrointestinal tracts of fish[16]. The accumulation of MPs can cause blockages in the digestive system, reduced feeding through saturation, and structural and functional deteriorations in the gastrointestinal tract, leading to nutritional and growth problems for fish[9, 16, 20]. Ingesting MPs could lead to inflammatory responses, changes to the metabolic profile, and/or affect the immune system[21, 22]. Since MPs in a natural environment have large surface areas and hydrophobicity, MPs can accumulate hazardous chemicals to higher-than-normal concentrations[23]. The plastics MPs come from typically have additives like polybrominated diphenyl ethers, nonylphenol, bisphenol A, and triclosan[24]. These could be dangerous once leached out and could be toxic when in a biological matrix[2]. Simulations found that the desorption rate of persistent organic pollutants from MPs under gut conditions was increased by 30 times[25]. PE MPs increased bioaccumulation of polycyclic aromatic hydrocarbons, such as polychlorinated and polybrominated biphenyls, and caused damage to fish livers. The damage to the livers included glycogen depletion, fatty vacuolation, and single cell necrosis[26]. Mercury concentrations in gills and liver of seabass, while exposed to MPs and mercury went up 2.0 and 1.6 times

respectively, compared to seabass exposed to only mercury[27]. MPs could serve as a carrier for bacterial fish pathogens, but more research is needed[16].

MPs or nanoplastics (NPs) ingested by mice can be found in the digestive tract, liver, and kidney. The effects that could be had on mice in the digestive tract are reduction in mucus secretion, gut barrier dysfunction, intestinal inflammation, and microbiota dysbiosis[28–31]. The liver had recorded effects like inflammation, lipid accumulation, and changes in lipid metabolism[31]. Some mice have shown disorders with energy metabolism and bile acid metabolism[28, 32]. During gestation, exposure to polystyrene (PS) resulted in metabolic disorders in the offspring[33]. The presence of MPs aggravated the environmental toxicant, organophosphorus flame retardants fish[34]. MPs toxicity observed in mice has been less severe than in fish. This may be due to fish having more routes of MPs uptake through ingestion and gills, compared to mice only having ingestion[31].

The toxicity of MPs/NPs in human cells has been studied to some extent. Regarding pristine MPs/NPs, in some studies there have not been significant findings of cellular toxicity, but there has been cellular uptake[31]. A study using a model of a cell-based intestinal barrier has noted there has been NP uptake and crossing of that barrier[35]. Other studies have noted toxicity or pathological effects in human cells. 20 nm NPs are taken up easily by human monocytic cells and are cytotoxic. Larger NPs, 100 and 1000 nm, stimulated secretion of cytokines from monocytes and macrophages, and induce a respiratory burst in monocytes[36]. MPs can induce reactive oxygen species production, causing oxidative stress and induction of cytotoxicity at the cell level[37]. Another study was able to increase arsenic toxicity with NPs and small MPs, 0.1 and 5 μm, by inducing mitochondrial depolarization and inhibition of the toxicant efflux pump. Arsenic exhibited a weak adsorption capacity with PS-MPs in a cell

medium and intracellular with particle sizes of 0.1 and 5μm[38]. MPs induced pro-inflammatory cytokines from human peripheral blood mononuclear cells and increased histamine release from mast cell lines[31, 39].

Exposure to PS MPs by inhalation has produced cytotoxic effects, oxidative stress, and inflammatory responses in human lung epithelial cells and are disruptive to that cell layer. PS NPs, 25 and 70 nm, impaired viability, induced cell cycle arrest, and upregulated nuclear factor in the lung[40]. There is not an indicator of severe effects from pristine MPs/NPs, but negative effects are still noted which include reactive oxygen species production and increased inflammatory responses[31].

Undigested MPs are usually excreted through fecal matter, but NPs can enter the body. The intestinal epithelium is the first place where ingested MPs/NPs could enter. High concentrations or contamination carrying MPs/NPs appear to cause acute impairment and inflammation of the gut lining[9, 31]. Human gut impact is not yet known, with constant exposure. Instead, analogues will have to be used. Fish gut exposure to MPs and NPs has been widely researched and mouse experiments have been performed. Mouse experiments have shown gut toxicity. In some mouse models, it has been demonstrated that MPs/NPs can enter circulation through an impaired gut-vascular barrier gaining access to the liver. When MPs/NPs reach the liver and accumulate, chronic inflammation takes place and could lead to diseases and metabolic problems. Accumulation in the lungs can potentially cause chronic pulmonary disorders[31].

A more common finding is that mice experience gut microbiota dysbiosis[28]. This could lead to gustatory dysfunction and affecting homeostasis[41]. When gut microbiota changes different effects can take place. Chronic diseases of kidney, cardiovascular system,

inflammation, cancer, and neurological disorders[33, 42–44]. There could be a connection with the behavioral changes of animals treated with MPs/NPs and the potential of neurological disorders when gut microbiota changes[31].

B. MPs Interactions with Other Contaminants

Since MPs are hydrophobic, MPs can adsorb contaminants. MPs can absorb polybrominated diphenyl ethers, endocrine-disrupting chemicals, and pharmaceuticals and personal care products (PPCPs). Persistent organic pollutants can be absorbed to MPs as well. Contaminants can bind to MPs due to large surface areas and hydrophobicity, but in the environment many different factors can affect MPs ability to adsorb contaminants like MPs characteristics, release medium, and contamination factors[45].

Solution pH and ionic strength can affect the MPs/contaminant interactions. Depending on the contaminant, decreasing the pH of the solution can increase the sorption of contaminants onto MPs. The sorption mechanisms may be dependent on physiochemical properties of MPs and solution chemistry[45, 46]. The properties of sorbent and sorbate influence sorption kinetics[47]. Salinity can influence adsorption of contaminants to MPs. PFAS preferred to adsorb on MPs in solutions with higher salinity due to hydrophobic forces and the salting-out phenomenon[48]. Sorption and salinity changes depended on the type of MPs[45].

MPs/contaminant interactions can be affected by the surface roughness and porosity of MPs. One study found that the surface roughness was found to influence PFAS adsorption. This adsorption can be influenced by the type of MPs involved. A study showed that PFAS adsorption

was higher on PS compared to PE and PVC[49]. For DDT, PVC and PE had a significant sorption capacity[45].

MPs that have microbial colonies, forming biofilms can affect MP/contaminant interactions. Wastewater treatment plants effluent have a stronger affinity towards MPs in that environment since there is a high concentration of inorganic nutrition[50]. Bacteria have shown to have an affinity towards MPs and the MPs influence the biofilm structure[51]. Microbial communities growing on MPs are influenced by MPs' rough surfaces. When accounting for MPs buoyancy, hydrophobic surface can promote different unique and specific microbial colonies to grown on MPs. Some of these microbes that show preference of MPs have been shown to aid the degradation of some polymers like high- and low-density PE, polypropylene (PP), and polyvinyl alcohol[45, 52–55].

A review analyzed studies looking at PPCP compounds' adsorption to MPs. MPs assist in the transportation of PPCP compounds in water. PPCPs can include antibiotics, non-steroidal drugs, hormones, antimicrobial agents, and personal care products. Aged microplastics can efficiently retain hydrophilic compounds, due to the induced polarity on the MPs surface[56]. MPs have been shown to have the potential to facilitate the transport of contaminants, but further research is needed[57].

C. MPs in Water Sources

1. Water Sources Background

City A is supplied by a system of reservoirs located in that city. Those reservoirs primarily supply only A. This supplies a city of 37,720 people according to 2022 population

estimates[58]. City B's drinking water source in this study comes from the Quabbin Reservoir in Massachusetts. The area of Quabbin Reservoir has been considered since 1895 and was done so by blocking Swift River and Beaver Brook where these rivers exited the valley. The project was finished in 1939 and the reservoir was filled entirely by 1946. Quabbin adds 412 billion gallons of drinking water to the water supply. In 1950, the Chicopee Valley Aqueduct was completed bringing water to one of the cities of interest in this study. Water flows from that aqueduct into a water treatment plant, then to a chlorination site, before it is stored in storage tanks close to the city[59].

2. MPs in Freshwater

The global cycling of MPs is not well known. There are some significant transport pathways that are identified and can have quantities reported, but relative flux of plastics from one section to another is unknown or has uncertainty. Many different aspects of MPs and their movement and deposition are generally unexamined. Freshwater transportation of plastics is one form of movement for MPs[57]. Rivers are estimated to transport 70-80% of plastics that eventually end up in the ocean. Sources of these plastics can be manufacturing, agriculture, and wastewater treatment plants[60]. The concentration of MPs is dependent on location but can compete with marine concentrations. The spatial factors can include proximity to urban areas, industrial sites, and wastewater treatment plants[61, 62]. A difference between marine and river MPs contamination is that river MPs contamination is typically closer to the source and MPs can get stuck on the shoreline, accumulate, and degrade[63]. Rivers will have more debris and blockages as well like branches, logs and dams which can serve as a hotspot for plastics[57, 64, 65].

The concentrations of MPs are significantly different when comparing upstream of a point source and downstream. While sources of contamination may be closer to the contamination, the identification of origin of specific particles is hard. To make identification even more difficult, rivers have changes in flow from bends and deep or shallow sections can lead to particle buildup and influence transport. When contaminants are released, it may not be at a constant rate, these pulsed releases are the primary source of peak loading events[57]. When flow rate increases, the MPs in sediment can be resuspended and deposited onto shorelines[60].

Wastewater treatment plants are a significant point source of MPs contamination in freshwater. In the Chicago River, downstream from a wastewater treatment plant, there was a 10-fold increase in plastic fibers. This 10-fold increase is happening after 95-99% of plastics partition into wastewater biosolids[66–68]. That increase may not be the same everywhere because plants with tertiary treatment can release as little as 0.1% of MPs that passed through[69]. Although there may be different treatments and partitioning of wastewater biosolids, estimates have Europe treatment sites releasing 52000 tons per year of plastic waste[57, 60].

Besides rivers, MPs are present in other freshwater systems. Lakes can be temporary or long-term sinks of MPs. The Great Lakes have been found to be as polluted as ocean gyres in some areas[70]. It is estimated that the Great Lakes get 10000 tons per year of plastic every year[57, 71]. More information about the spatial distribution of MPs in lakes will be covered in the following section.

3. MPs in Lake/Reservoir Systems

MPs have been found in the water column and with differing concentrations depending on depth. The difference in distribution can be affected by MP shape and wind, but variation occurs on a small spatio-temporal scale. It was recorded that there have been significant differences between sampling sessions. The number of MPs found in a reservoir system found differing concentrations between September and the following March. Sampling between March 2019 and March 2020 had significant differences as well. There were no noticeable patterns noticed. Notable differences between MPs' concentration were noticed between depths. This difference was linked to particle shape. Fibers were equally distributed throughout the water columns during sampling periods. Irregular particles were more abundant in surface sampling than sub-surface. Local wind patterns may have influenced the intensity of vertical gradients, affecting the abundance of irregular particles. Particle size did not appear to differ depending on depth. Irregularly shaped MPs found were 59% PE, 20% PP, 12% PET, 4% polyamide (PA), 1% PS, 1% epoxy resin, and 1% POM. Fiber MPs found were 71% PET, 18% PP, 7% PA, 3% PAN, and 1% PE[72].

As previously mentioned about MPs in marine environments, vertical distribution can also be affected by biofilms forming on the MPs, MP size, and polymer type. A study researching a dammed reservoir in China investigated horizontal and vertical distributions of MPs. For horizontal distribution, MPs with the particle size range of 200 to 500 μm was the majority at 52.47% of observed MPs. MPs less than 200 μm accounted for 24.22% of observed MPs. The particles less than 200 μm were found to be disproportionally in the front section of the reservoir compared to the middle and end sections. The abundance of MPs has been found to be linearly correlated with distance from the dam. More of those MPs were found in the

shoreline waters than central waters. At the surface of the water, these MPs were identified: PS, PP, PE, PA, PVC, and PET. PS, PP, and PE were the most abundant[73].

The vertical distribution of MPs had significant variation. The abundance of MPs was higher in the shoreline waters than central water. Going by depth for shoreline waters, abundance in MPs was significantly higher for the surface layer. MPs were then higher in deep water layer compared to intermediate, but this difference is significant. For central waters, MPs concentrations were significantly higher at the surface compared to intermediate and deep. For depth, different shapes affected the distribution. Foams and films decreased as depth increased, while fragments increased with depth. MPs smaller than 200μm concentration increased with increasing depth, while MPs between 200 and 500 μm concentration decreased with increasing depth. The percentage of PP, PE, PS decreased with increasing depth while PVC, PE, and PS increased with increasing depth. A positive correlation was observed between weight of plant residues and MPs abundance in the surface layer of central waters. There was a positive correlation between the dry plant residues in surface water and surface, intermediate, and deep layers on the shoreline. Shoreline waters were found to have higher MP concentrations than central water where free-floating plant residue accumulates and sinks MPs[73].

4. MPs in Groundwater

Groundwater is used by two different locations in this study, one near the Quabbin Reservoir and the other near the Connecticut River. MPs can get into groundwater through groundwater-river interactions, groundwater-lake interactions, and infiltration through the soil.

MPs have been found in groundwater monitoring bores at 38±8 MPs/L including the polymers PE, PP, PS, and PVC. This study used different bores around Australia. The sites were in areas categorized as agricultural, industrial, urban, and rural. The site with the greatest number of MPs detected was from a bore hole near a meat processer plant. This location averaged 97± 110 MPs per liter, with the average size of 68 ± 26 μm. The most common particles were PVC, PE, PS, and PET. When comparing MPs detected in that water to a commonly used packaging in meat processing there are some overlaps. Packaging most commonly uses PE, PP, PVC, and PET. This study hypothesis that if an on-site disposal area is uses, disposed of packaging could slowly leach into the soil and enter the groundwater system[74].

MPs can enter via the streambed of rivers where surface water and groundwater interact through the hydraulic gradient. Water moving between a river and groundwater will transport MPs and potential toxic substances. Long contact with pore water and large surface area of contact can cause the migration of contaminants into the groundwater[75]. Compared to a lake where water can settle and accumulate contaminants in the sediment. Lake and groundwater flow depend on the season and water level. Water seeps from the lake, carrying MPs contaminants into groundwater. MPs will accumulate in the pores, allowing longer exposure times for the particles and water to react. This leads to the leaching of plasticizers and additives into the aquifer[75].

Contaminated groundwater can cause issues. Using groundwater contaminated with MPs to irrigate crops can lead to the uptake of MPs through plant roots. Another potential effect of MPs contaminated water being used for irrigation is the changing of soil properties which leads

to affecting plant growth. MPs in groundwater could leach additives like plasticizers or UV stabilizers. PE, PP, PA, PET, PMMA, and PS have been recorded to release brominated and chlorinated disinfection by-products with no light in water. When PVC is in water it has been observed to leach phthalates and bisphenol A which can be endocrine disrupters[74].

D. MPs in Animals

1. Aquatic Species

A review of microplastics within the marine system looked for bioaccumulation of microplastics across five main trophic levels: producers, primary consumers, secondary consumers, tertiary consumers, and quaternary[76]. The review found that MP bioaccumulation did not seem to increase with trophic levels. Microplastic accumulation was highest for herbivores and lowest for tertiary consumers. The highest found microplastic was in secondary consumers, which are filter feeders. Microplastic accumulation is more influenced by feeding strategy, leading to filter-feeding having the highest microplastic accumulation compared to other feeding strategies covered in the review, whether it was in the field or in a laboratory. The authors concluded that bioaccumulation of microplastics can occur in numerous individual marine species but could not support biomagnification of microplastics in the marine food web[76].

A study looking at three benthic species in the Arctic found microplastics in these animals. The three species are the sea anemone, deposit-feeding starfish, and snow crab. The most common polymer types were polyester, nylon, and PET[77]. Other isolated marine environments with microplastics are deep ocean trenches. Another study looked at amphipods across six Pacific hadal trenches: Japan, Izu-Bonin, Mariana, New Hebrides, Kermadec, and

Peru-Chili. The study found that deep trench (hadal) amphipods had ingested microplastics in all locations. These findings of microplastics make it unlikely that there are marine ecosystems left not contaminated by plastic[78].

In aquatic environments, it is expected that species experience chronic exposure to MPs and likely NPs. Invertebrates like crustaceans, barnacles, polychaetes, mussels, and amphipods have ingested MPs. Other studies have shown that fish, shellfish, and fur seals have ingested and accumulated MPs in their gut and stomach. Further research is needed for the accumulation of NPs in aquatic species[57].

2. Terrestrial Species

Pollinators interact with plants, air, soil, and water, which are all exposure points for microplastic contamination. A study of the honeybee, *Apis mellifera*, explored the effects of ingested PE on mortality and behavior. Three treatments were added to purified water with sucrose: high concentration (50 mg/L), medium concentration (5 mg/L), and low concentration 0.5 mg/L). Bee mortality was affected at only high concentrations, but the authors expect medium and low concentrations to be a more accurate representation of PE concentration in nature. A change in behavior was noticed where bees would take in more food when exposed to low concentrations rather than medium or high concentrations. The authors hypothesize that PE ingestion may trigger energy-demanding detoxification activities. It is speculated that medium concentrations have an increased energy requirement to detoxify and a loss of appetite. The high concentration increased the loss of appetite, exceeding the energy required for detoxification, causing increased mortality[79].

Lumbricus terrestris experienced a 0% mortality rate when exposed to PE as a microplastic treatment. Treatments of 7%, 28%, 45%, and 60% of PE are added to plant litter

that is then mixed into a sandy soil substrate. Growth rates were significantly lower at 7% and 60% PE compared to the other concentrations. The ingestion rate was higher in 45% treatment compared to 7%. PE concentration was significantly higher in 7% compared to 45% and 60% treatment. There was no effect on reproduction observed at any concentration[80]. Earthworms are directly in the soil where microplastic contamination is common, but larger animals that exist above the soil are at risk too.

A study using LDIR with dualslide changers and a polarized light microscope analyzed the lung tissue of a one-year-old domestic pig and a fetal pig[81]. The domestic pig's top three polymer types were PA, PP, and PE. The fetal pig's top three polymer types were PC, PP, and PVC. The abundance and size of microplastics were greater in the domestic pig than in the fetal pig. The main polymer found in the domestic pig was PA and the fetal pig was PC[81].

A study in Japan added disposable polystyrene plates that were cleaned with distilled water and manually broken up, into the food of twenty-four male albino rats. This study added 10g (1%), 50g (5%), and 100g (10%) of polystyrene particles to 1 kg of feed. Group 1 was the control group given normal feed. group 2 was given 1% PS, group 3 5% PS, and group 4 10% PS. At the end of the study, all treated groups had a decrease in body weight with groups 3 and 4 having a significant decrease in body weight. Sperm motility decreased for all treated groups, with significant decreases for groups 3 and 4. Sperm cell count significantly decreased for all treated groups. Testosterone significantly decreased for groups 3 and 4[82].

E. MPs in Humans

A study extrapolated data from different studies to calculate a projection of daily and annual consumption and inhalation of MPs. They found that great variation in MPs exposure. First looking at males, children were estimated to consume 113 and inhale 110 MPs daily. Adults were estimated to consume 142 and inhale 170 MPs daily. Female children were estimated to consume 106 and inhale 97 MPs, while adults were estimated to consume 126 and inhale 132 MPs. The study selected the average MPs concentration for various food, beverages, and air. The foods used were seafood at 1.48 MPs per gram, sugar at 0.44 MPs per gram, honey at 0.10 MPs per gram, salt at 0.11 MPs per gram. The beverages used were alcohol at 32.27 MPs per liter, bottled water at 94.37 MPs per liter, and tap water at 4.23 MPs per liter. The air's average MPs concentration was 9.80 MPs per cubic meter[83].

MPs ingestion varied by item. The consumption of air, bottled water, and seafood were the majority of MPs intake. Air will have a large variation due to studies ranging from concentrations of 2.09 to 17.75 MP per cubic meter. For American adults and children, consuming the recommended amounts of the previously mentioned items would expose them to between 81000 and 123000 MPs[83].

1. Inhalation

Points of exposure to various terrestrial and marine animals are mentioned, but humans have specific points of exposure being studied. As a study previously mentioned pig lungs have microplastics inside, so it could be expected that human lungs might have microplastics as well. Tissue samples were taken from patients ranging from 32 to 77 years old. 11 of 13 lung tissue samples had microplastics, totaling 39 particles. PP (23%) and PET (18%) were the most abundant. This study used μFTIR spectroscopy analysis and was limited to finding microplastics

down to 3 μm, so the smallest microplastic detected was 4 μm. This study supports human inhalation as a potential route for exposure to microplastics[84].

2. Eating

A more commonly thought-of route of exposure is eating. As reported by the study about the marine trophic level's exposure to MPs, animals like shellfish that are filter feeders are more likely to accumulate MPs. This can be a potential point of microplastic exposure to humans through consumption. Shellfish microplastic contamination can affect humans because shellfish are commonly consumed with intact GI tracts where the MPs are accumulated and retained[85].

A study in Ecuador looked at MP contamination in honey. A study mentioned previously that MPs affect bees directly when consumed but they can also get into honey and be ingested by humans. This study looked at 700 mL of honey from craft and industrial sources, both using glass containers. On average, industrial honey had 54 microplastics per liter while craft honey had 67 microplastics per liter[86].

As previously mentioned, animals tend to accumulate MPs in their digestive tract or lungs. MP exposure should not be a concern when eating lean mass, but it can be due to preparation methods. Meat can be prepared and cut on plastic cutting boards. It was found that around 2.47 and 0.29 mg of microplastics per gram of fish and chicken respectively ended up on the meat[62]. Disposable takeout food containers which can be used for storage are also a potential source of microplastic contamination. Fast food packaging was taken from restaurants across seven Chinese cities and checked for microplastics. More than ten polymer types were identified with the most common types being PP, PE, and polyester. The range of microplastic abundance was 3 to 43 particles[87].

3. Drinking

Exposure to MP from drinking is of great interest. One study analyzed MPs using four types of beverages: cold tea, energy drinks, soft drinks, and beers. MP concentration ranked from least to greatest was cold tea (11 MPs), energy drinks (14 MPs), soft drinks(40 MPs), beers (152 MPs). The authors of this study believe MPs may come from the water used to clean bottles before use and produce the beverages. The water used in drink production is typically sourced from municipal water supplies[88].

Bottled water is one of the most common topics when it comes to MP exposure to humans. 17 different polymer types were found in a study of bottled water and tap water. The most common types were cellulose accounting for 68.25%, and PVC for 16.78%. Both PET and glass water bottles had over 80% cellulose and PVC. 4935 particles were confirmed to be MPs, which was about 16% of all particles detected in bottled and tap water. PVC, rubber, silicone, polyacrylamide, and PET were the main MPs detected in the tap water, with only a small amount of cellulose identified. PVC, one of the most common plastics in the world, is commonly used in the distribution system for water supply, making up the pipes in drinking water plants and residential lines. MPs found in bottles is expected to originate from not only water sources and pipes that distribute it, but the bottle as well. Water bottles caps made of PP and PE wear down from opening and closing leading to the generation of PP and PE along with PET MPs in the water[89].

One study from China analyzed the water from 38 locations around the country. This study used drinking water from treatment plants and tap water from households taking two bottles of 1 L each. The water was processed and prepared at the lab for micro-Raman spectroscopy. Out of the 38 sites, only 2 of the sampling sites had no MPs detected. Particle count ranged from 0 to 1247 per liter, with a mean concentration of 440 particles per liter. This study noted that results may vary compared to other similar studies. The variation can be determined by sample volume, methodologies for determining MPs, type of source water and its environment, applied treatment technologies, pipe materials and weather conditions[90].

The study recorded the size of MPs found. The study had the capability of identifying particles ranging from 1 to 5000μm. From samples, particles between 3 to 4453 μm were identified, with a mean size of 66 μm. Particles ranging from 1 to 50 μm were the most prevalent size from the samples, making up 31.25 to 100% of the samples. The most abundant polymers detected were PE and PP. PE and PP are in pipes used in drinking water systems or households and could be a potential source in tap water. Other polymers detected were polyphenylene sulfite, PS, PET, and others[90].

In a review using 9 studies featuring bottled water and 12 studies investigating MPs in tap water, most tap water sources were from groundwater with three studies from surface water and one from desalinated water[91]. Only one study could identify MPs under 10 μm with an average of 266± 56 particles/L, including PA, PVC, PP, PET, PE, and others. This study compared freshwater sources, treated water, and tap water to see how MPs quantities change. Treated water was much lower than the freshwater source. There was no significant difference between tap water and treated water[92]. The concentration of particles found in tap water increased as size decreased. Six studies identified PP and PE, five studies identified PET and PS,

and PVC was identified in three studies[91]. A study using 42 total samples from Japan, the US, and the EU found 29± 45, 46 ± 32, 66± 37 particles/L respectively. 29 different types of MPs were detected with PS, styrene-ethylene-butylene, PP, and PES being the most abundant. PS, PP, PES were found in every site[93]. A study comparing tap water and its freshwater source, it was found there was no significant difference in the abundance of MPs, where 27.7% of MPs were removed at one site, while the other site had 12.7% of MPs removed[94].

F. Other Contaminants in Tapwater

One study examining the disparities in exposure to nitrate as a drinking water contaminant found that higher portions of Hispanic residents served by community water systems are exposed to higher concentrations. Although nitrate contamination is typically associated with agricultural sources, some other sources are from urban areas. Some association between Hispanic residents and nitrate levels may be related to sources in urban areas[95]. Locations of PFAS sources and concentrations found in drinking water were positively and significantly associated with the proportion of non-Hispanic Black and Hispanic/Latino residents. There was a positive association with PFAS sources and detection and with residents under the federal poverty line in rural areas[96].

A study researched the spatial and temporal patterns in health-related violations of the Safe Drinking Water Act using data of 17,900 community water systems from 1982 to 2015, while identifying vulnerability factors of communities and water systems to prevent regression. It was found that in 2015, 9% of community water systems violated health-based water quality standards. This affects nearly 21 million people. Each year of the 34 under review discovered that 9 to 45 million people are affected by poor water quality. Spikes in violations appear to

occur after new federal regulations. Urban and rural areas have differences over time for total number of violations. Low-income rural areas have a larger compliance gap than higher-income rural areas with the most disinfection byproduct violations. Minority, low-income populations were more likely to have drinking water quality violations, like total coliform[97].

In a study focusing on the Flint, Michigan lead contamination, there was a preexisting disparity in lead poisoning. Areas with preexisting disparities were from urban areas with high levels of socioeconomic disadvantages and minority populations. Geospatial analysis showed that after the water supply was switched, resulting in more lead contamination, disadvantaged neighborhoods had the greatest elevated blood lead level increase[98].

CHAPTER II

METHODS

A. Sampling Sites

Three cities were sampled in this study, Cities A, B, and C. City A is the most populous city with its own water supply from several reservoirs. B and C are two districts within one city with different water supplies and distribution systems. City B uses the largest reservoir in the state, while C uses a groundwater source near a major river.

Each city had 4 sampling sites that were selected. Cities A, B, and C have a common public tap water source from each city's public library that was selected. A and B both had access to a church and a place of business. A and C were sampled from residential areas. Finally, B and C were sampled from their post-chlorination treatment sites before distribution to the

residents. The goal was to keep sampling sites as similar as possible to allow comparisons, but permission to sample locations limited access.

Identifying a common location that was easily accessible for anyone in most cities was a priority. Libraries were the site first selected. Libraries are an important site because libraries can serve some of the most underserved members of a local community. Libraries offer a public space, allowing for communal use. These locations offer activities, books, computers, and other services like social workers in some locations[99, 100]. Libraries can serve as a shelter from harsh weather for those that have nowhere to go[99, 101, 102].

B. Sampling

To limit plastic contamination, water samples were collected in 4L glass bottles that originally held HPLC-grade solvent. Collecting water samples in the field with glass bottles and then processing them in the lab has been shown before to limit contamination (Prata et al., 2019). 4L glass bottles were determined to be the best volume for tap water samples because of a preliminary study conducted. 1L, 2L, and 4L samples were compared to determine the best volume for MPs recovery and it was concluded that 2L would be optimal, especially for replicates and on-site sampling. For each site, 8L total was collected, which will lead to 4 replicates. Each bottle was rinsed with MilliQ (MQ) water 3 times. Immediately after rinsing, the mouth is covered with aluminum foil, then sealed with the bottle's cap. This is to prevent contamination from the cap and potential air contamination.

At the sites, most had a deep enough basin to fit a 4L bottle, but if it did not fit a 1L glass, prepared and cleaned in the same way, will be used to transfer water. Before collection, the tap water is run at full, cold for 30 seconds before collection. It is recommended to run the tap before

sampling to avoid incidental air contamination[103]. After 30 seconds a 2L bottle that will be referred to as a blank sample, along with the first collection bottle. The bottle is filled and covered with aluminum, then capped. The next bottle is done the same way, then the blank is covered. This blank can serve as a control comparing potential air contamination that the other samples were exposed to during sampling.

C. Extraction and Processing

Extraction of MPs requires the use of a vacuum on a glass funnel. To collect the MPs, a stainless-steel filter was used. The sample is shaken to homogenize the sample right before processing[104]. A laminar flow cabinet was used while wearing cotton lab coats[103]. 2L of the sampled tap water is vacuum pulled through the filter. This filter is then added to a previously covered beaker where 50mL of MQ is added, re-covered, and sonicated for 30 seconds to separate the MPs from the filter. The beaker is returned to the hood. With a pair of metal tweezers, the filter is removed and rinsed using a glass pipet to remove any potential MPs remaining. The MQ-MPs solution is pulled through a smaller glass funnel and steel filter setup. This filter is added to a small, covered beaker and 10mL of pre-filtered HPLC-grade methanol is added. This beaker is sonicated for 30 seconds, and the filter is rinsed. The beaker is covered with aluminum foil with small holes to allow for evaporation. This beaker is left in the oven until dry, about a day.

After the methanol has evaporated, the beakers are removed. 1 mL of MQ is added to a beaker and sonicated for 30 seconds. The MQ-MPs solution is pipetted out and used to rinse the sides of the beaker. The 1mL solution is added to Kevley slides. The slides are then placed in the

oven until dry, about 3 hours, then removed immediately and covered in a petri dish to reduce air contamination.

D. LDIR and Data Analysis

To analyze the slides, Laser direct infrared imaging (LDIR) is used. The LDIR was selected because it has an extensive library for microplastics. LDIR is also a faster and more automated process compared to traditional Fourier transform infrared microscopes (FTIR). The LDIR uses a tunable quantum cascade laser as the IR source. LDIR makes stronger signals and is faster than FTIR[105]. The LDIR can detect the smallest particles compared to any other IR system[106].

After the slide is added to the LDIR, Microplastics Starter library was selected and used for sizes ranging from 20 to 500 μm. After the program was run, information was manually copied into Microsoft Excel. This data was then processed in R studio and used for visualization of the data.

A group of three particles, cellulose derivatives, were removed because they were not relevant to the data presented. These derivates were specifically cellulosic, chemically modified cellulose, and cellulose acetate. These materials are made of cellulose, which is a class of natural carbohydrate polymers found in raw materials[107]. Cellulose derivatives are biodegradable and one of the most abundantly used polymers[108].

Some polymers were grouped to simplify the data. A “polyesters” group was made which contains alkyd varnish, polycarbonate, polyester, polyethylene terephthalate, and polylactic acid. The other grouping is “others” which is comprised of acrylates, acrylonitrile butadiene, calcium stearate, ethylene vinyl acetate, polyacetal, polybutadiene, polycaprolactone, polyether,

polyimide, polyisoprene chlorinated, polymethylmethacrylate, polypropylene, and polyvinylchloride. The others have low concentrations of <1% of the total particle count.

CHAPTER III

RESULTS

The distribution of the mean total particle count of the cities is ordered from least to greatest: C (494 ± 48), B (651 ± 85), A (1,532 ± 349). The blank mean total particle count was 459 ± 45. The top five observed polymers in A were natural polyamide, polyamide, undefined, chitin, and polyethylene chlorinated. The top five observed polymers in City B were natural polyamide, chitin, undefined, polyamide, and silicone. C's top five polymers were natural polyamide, chitin, silicone, polyamide, and undefined. Particle size was recorded as well with A at the highest. B is the second most, and C with the lowest count. Treatment sites for B and C have data from post-chlorine treatment before distribution. The distribution of the mean total particle count of the cities is C with 548± 86, and B with 553 ± 92. The distribution of the mean total particle count of the city libraries is ordered from least to greatest: C (385 ± 67), B (858 ± 227), and A (1865 ± 848).

CHAPTER IV

DISCUSSION

As seen in Figure 2, City A has the highest mean particle count at 1532, while B and C recorded significantly fewer mean particles. C has fewer recorded particles than the blanks as well. A has the largest population with an estimated 38,000 people. B and C are split districts using separate water sources for an estimated 18,0000 people total[58]. When comparing these cities, there is a stark difference in socioeconomic standings. The percentage of people in poverty for A is 26.5% and B/C is 7.4% compared to the state average of 10.4%. Using per capita income in the past 12 months over 2017-2021 shows a similar difference with A at $25,744 and B/C at $45,190 compared to the state's per capita income at $48,617[58]. When comparing the socioeconomic differences and the differences in the demographics of these A, B and C, it appears to be consistent with other studies involving other drinking water contaminants. A study reported that minority, low-income populations were more likely to have drinking water quality violations[97].

A, with the highest observed MPs, has the highest Hispanic or Latino population percentage. They make up about 53% of the city's population, compared to about 6% for B/C and the state's 13%. B/C's population is about 85% white compared to the state average of 70%. One study found that locations of PFAS sources and concentrations found in drinking water were positively and significantly associated with the proportion of non-Hispanic Black and Hispanic/Latino resident[96].

Another aspect of this study completed by a collaborator focused on high- and low-cost buildings affected MPs' concentration. This was researched to determine whether an individual's cost of living could be a socioeconomic factor that could relate to MPs exposure. There was no correlation found between low- and high-income homes[109]. Although there was no correlation between MPs count and housing costs on the individual level, MPs count and city wide

socioeconomic and demographics could have a similar association that those factors have with other drinking water contaminants.

B and C had the same five polymers in the top percentage with natural polyamide, chitin, silicone, undefined, and polyamide, while A had the same besides silicone which was replaced by polyethylene chlorinated reflected in Figure 3. These particles are in contrast to those reported in a study where PVC accounted for almost 50% of MPs recorded from tap water samples, the only similarity is having a notable amount of silicone like City B and C[89]. A's water comes from a series of surface reservoirs located in the city, while B comes from a single major surface reservoir and C comes from groundwater.

B and C allowed access to their tap water post-chlorination before it is distributed to residents. These sites were compared with each other and can be seen in Figure 7 and 8. The mean count is similar for B and C (Figure 8). The occurrence of particles is noticeably different outside of chitin and natural polyamide. B and C have around the same particle count even though it is from different sources (Figure 7). The common site between all the cities is public libraries. Between all three sites, the top five particle count shares four common particles. Those particles are natural polyamide, chitin, others, and undefined. A also contained PA, while B contained silicone and C contained polyethers (Figure 9). Similar to the comparison between all the city sites: A had the highest particle count, B has the second-highest count, and C was the lowest among all sites (Figure 10).

The U.S. National Academies of Sciences, Engineering, and Medicine recommends that the daily intake of water is approximately 3.7 L for men and 2.7 L for women[110]. Using this recommendation, the calculation of the maximum and minimum particles consumed per day can be calculated. The counts used for this calculation are from Figures 4, 5, and 6. It will be

assumed that MPs concentrations will be consistent, and all water is ingested from the same site. The site with the most average MPs recorded is Church A as seen in Figure 4. For males consuming 3.7 L of water from that site in a day it could be possible to consume 4508± 1892 MPs. Females consuming 2.7 L could consume 3290±1381 MPs. The site with the least average MPs recorded is Library C as seen in Figure 6. For males consuming 3.7 L of water from that site in a day it could be possible to consume 712±124 MPs. Females consuming 2.7 L could consume 520± 90MPs.

City A has the highest count of every particle size range observed. Most particles observed for each size were between 0-30 μm (Figure 11). Observed particles in this study ultimately do not cover every plastic containment. Since the LDIR cannot detect MPs smaller than 20 μm, Smaller MPs and NPs are still unaccounted for. The documentation of these particles should be a focus for future research. NPs have been shown to cross cell barriers and be taken up by some cells. Both have been shown to induce stress and inflammatory responses as well[31]. Getting a comprehensive understanding of smaller particles can be beneficial to show potential further exposure communities could experience.

Sources of tap water MPs variation can also come from other aspects than just socioeconomic. One study previously mentioned that was studying tap water around different sites in China mention different factors leading to potential variation. Other factors can include sample volumes, methodologies used to identify MPs, type of source water, ambient environment, applied treatment, pipe composition, and weather conditions[90]. While these factors can cause variations, it could also reflect the socioeconomic status of the city and its ability to invest in the drinking water infrastructure. Differences in water sources can play a role where Quabbin reservoir could be cleaner than City A's reservoirs. This could be due to the level

of access and security. Quabbin is well secured and monitored and has more limited access compared to A. A's reservoirs serve as a recreation area with walking paths. There are prohibited activities like fishing and bringing dogs, but this is not closely monitored.

Regardless of socioeconomic status and demographics of a city, the cities focused on in this study have evidence of MPs in tap water. Further research is needed to understand if certain organic or inorganic contaminants could accumulate on the MPs present within tapwater. If alternative locations could be selected in the future, there could be a focus on potential exposure to MPs specifically on impoverished individuals or those dealing with extenuating circumstances. Potential locations where those individuals could be exposed to drinking water contaminated with MPs could include soup kitchens and various forms of shelters.

CHAPTER V

CONCLUSION

MPs are contaminants that are becoming widely recognized. MPs can be found around the world, from hadal trenches in the Pacific Ocean to benthic species in the Arctic. MPs exposure to humans commonly comes from ingestion. Low-income and minority populations have been found to have more contaminants in drinking water. MPs can be like other contaminants and have higher concentrations in cities with a higher percentage of low-income, minority people. City A had more MPs, as a city with a higher percentage of low-income and minority inhabitants compared to B and C. The findings from this research could support future research into MPs concentration in communities of differing socioeconomic backgrounds.

Further research is needed to understand how MPs could interact with other contaminants in tapwater if present.

APPENDIX

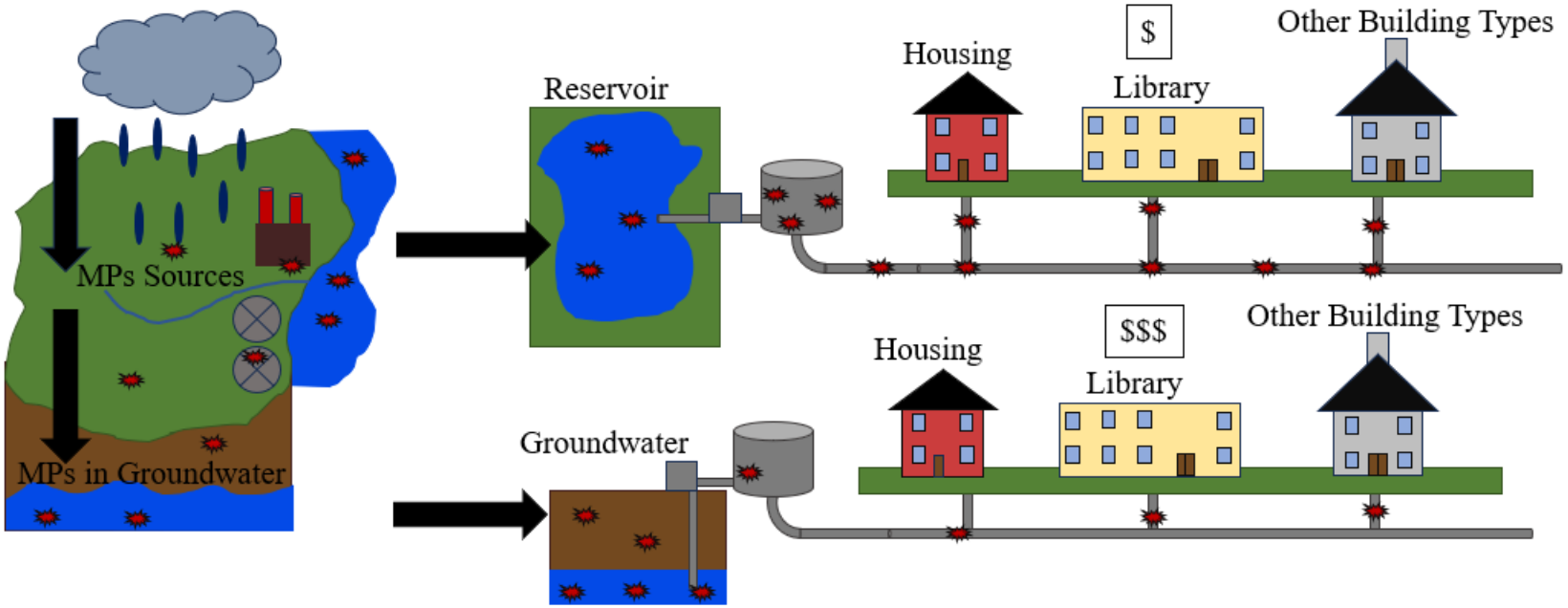

Figure 1. Simplified graphic of microplastics movement and accumulation through the drinking water system depending on socioeconomic status.

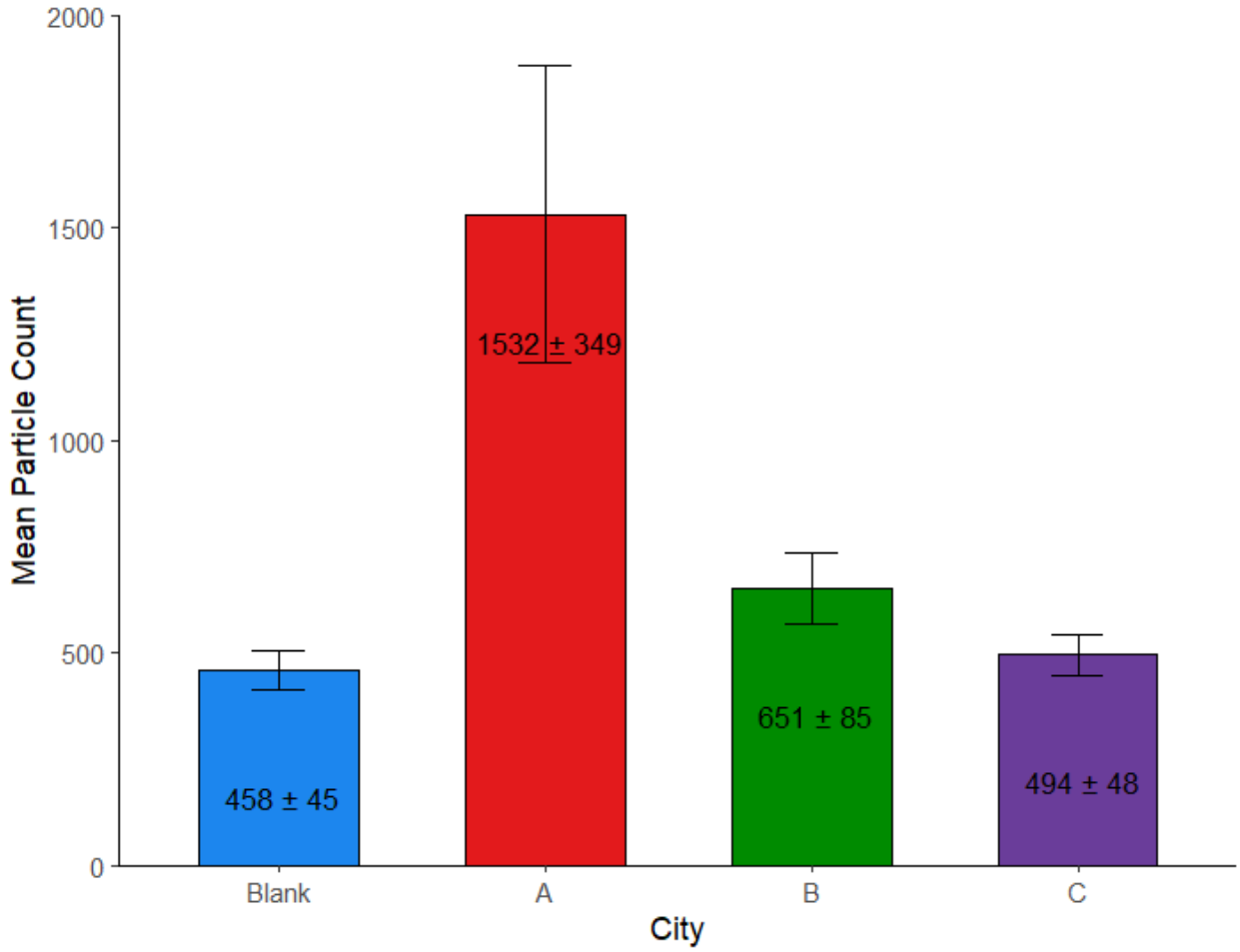

Figure 2. The mean (±s.e.)particle count in different cities.

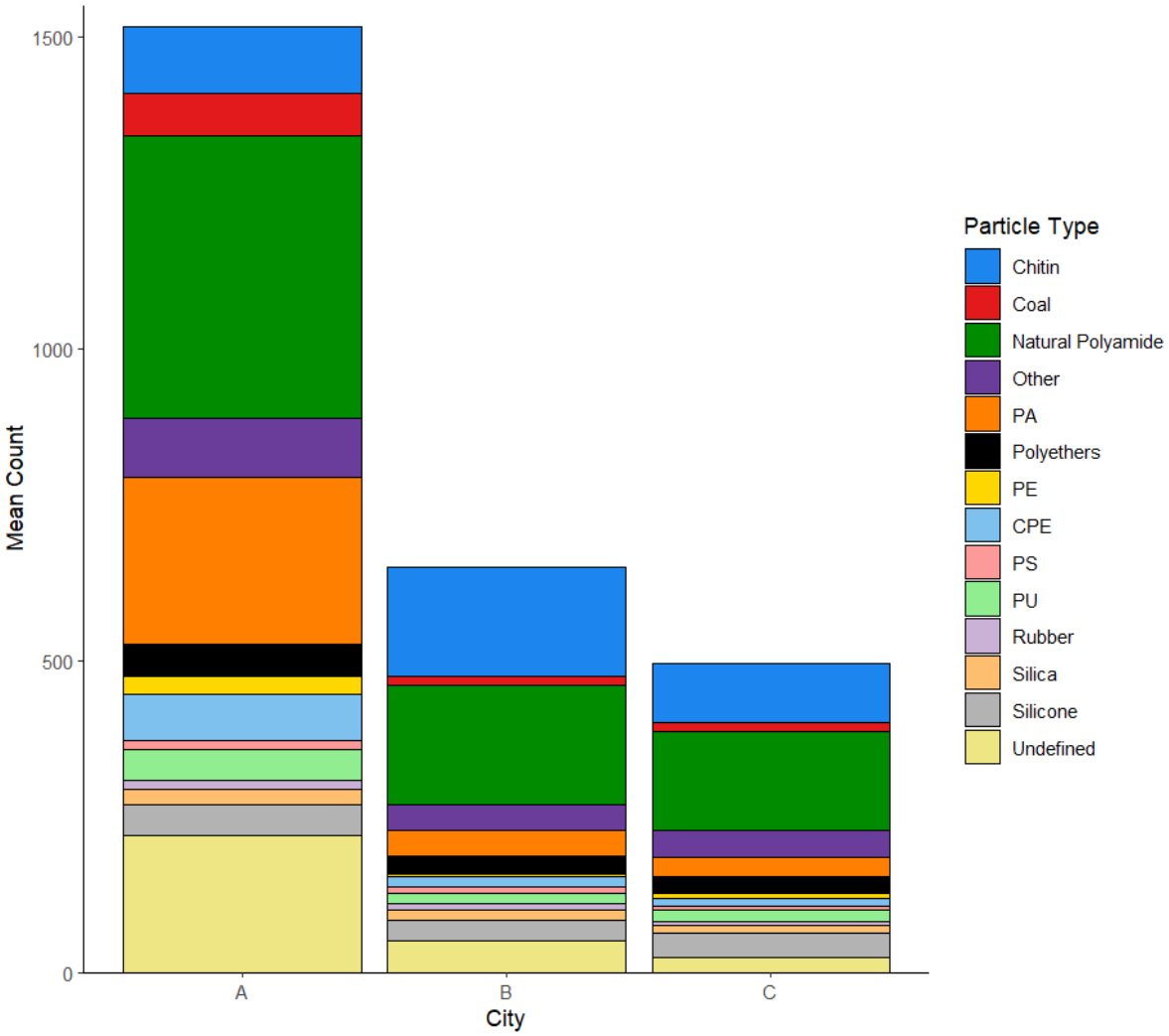

Figure 3. The mean particle type by city.

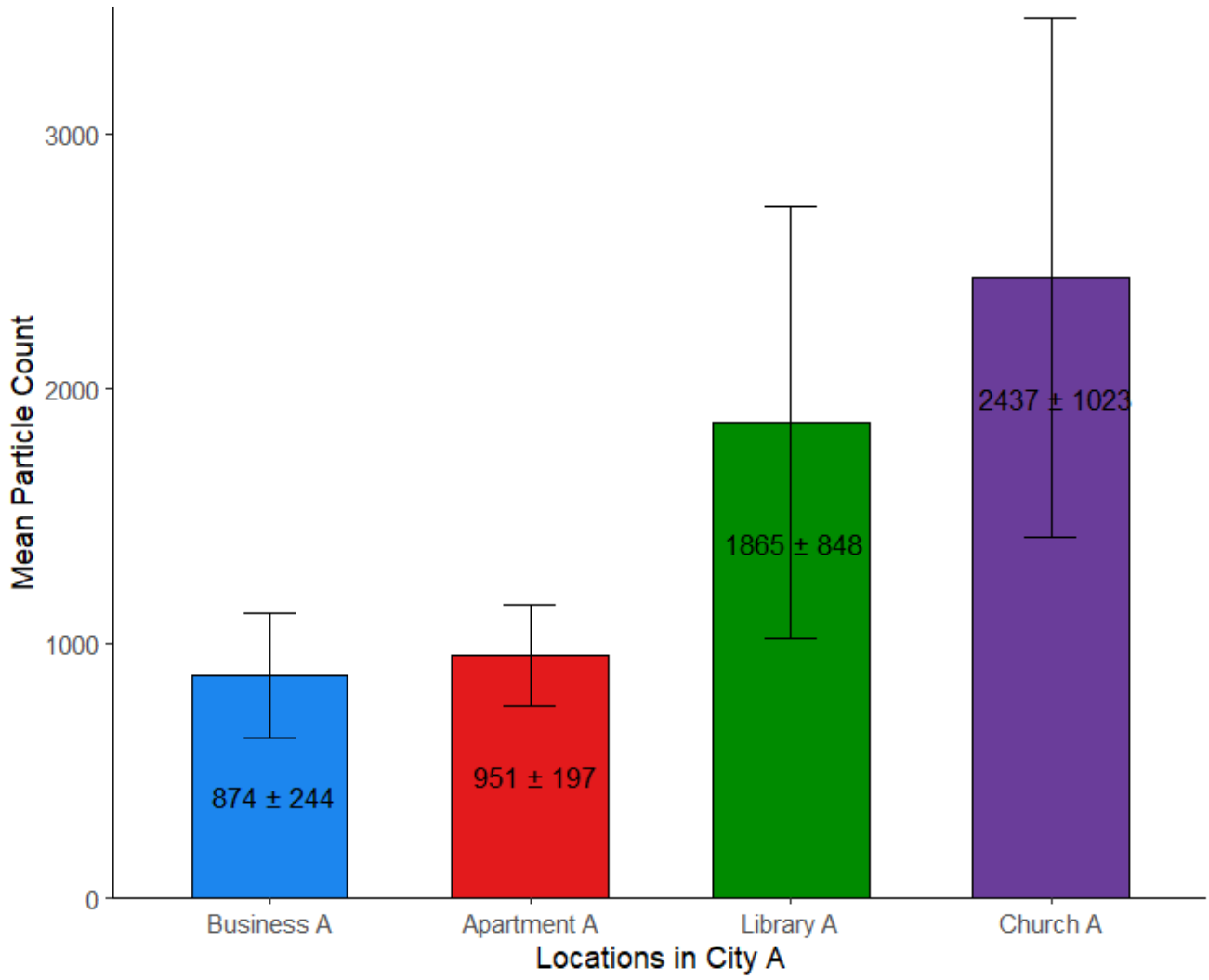

Figure 4. The mean (±s.e.) particle count from the locations sampled in City A.

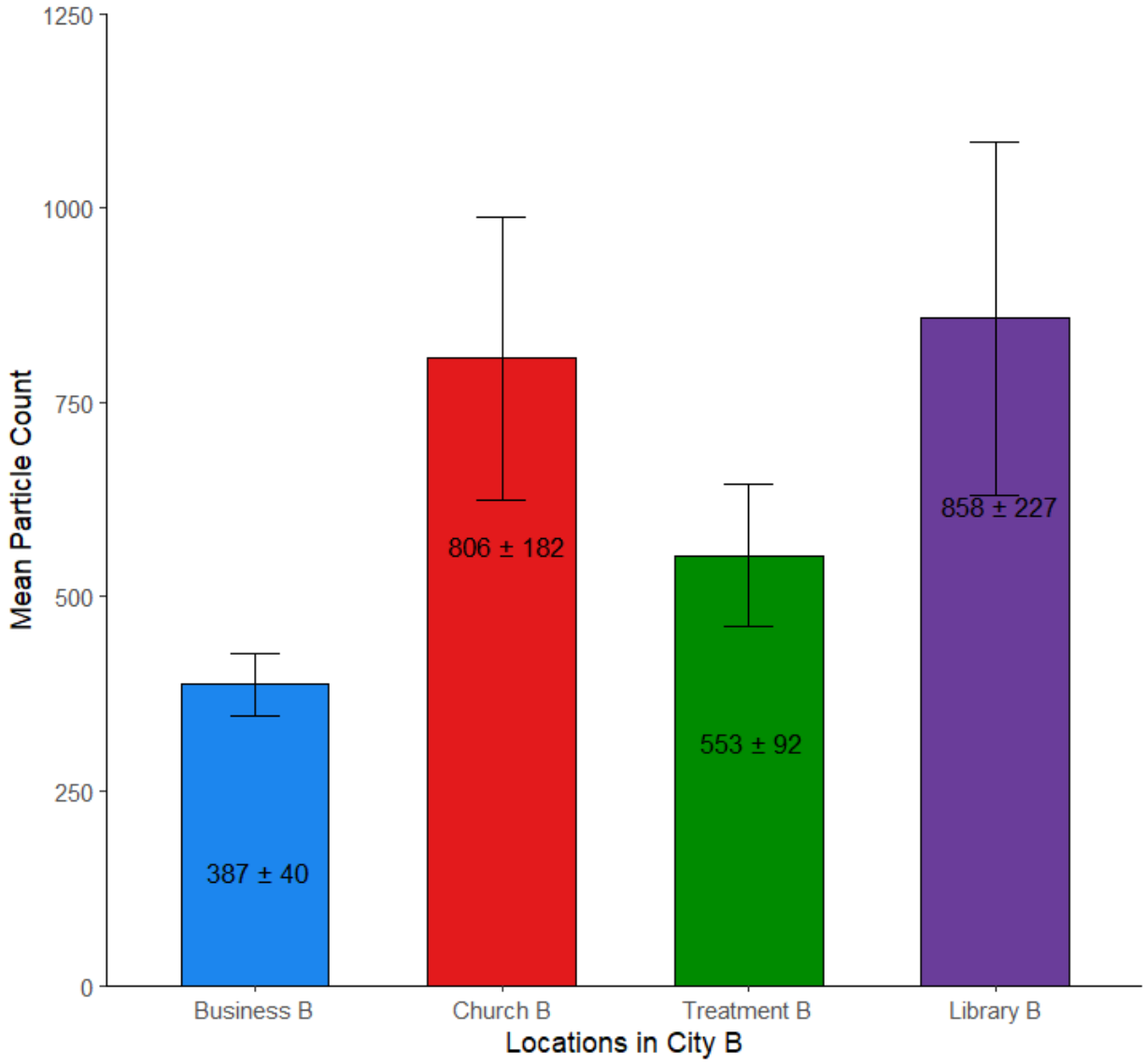

Figure 5. The mean (±s.e.) particle count from the locations sampled in City B.

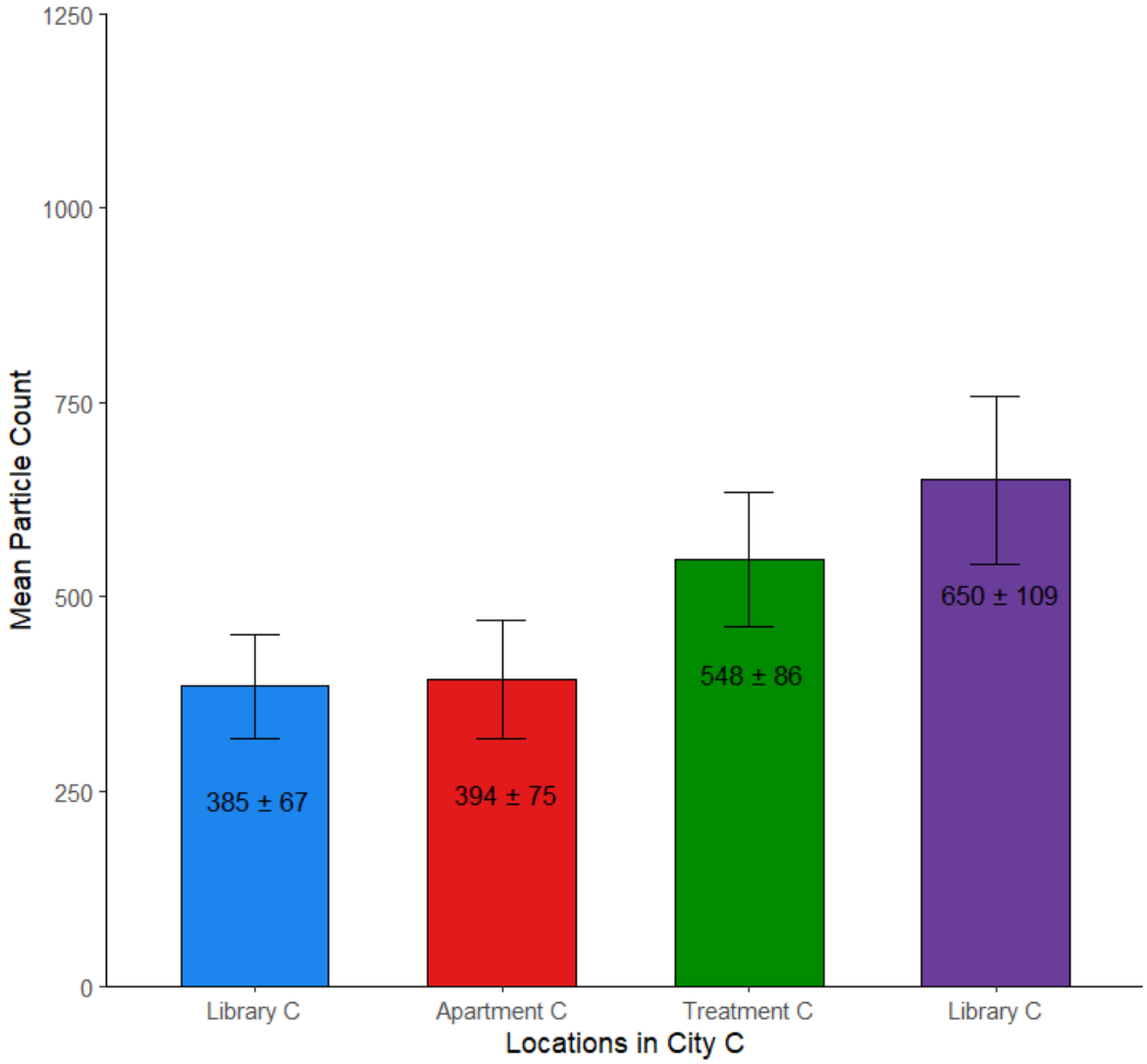

Figure 6. . The mean (±s.e.) particle count from the locations sampled in City C.

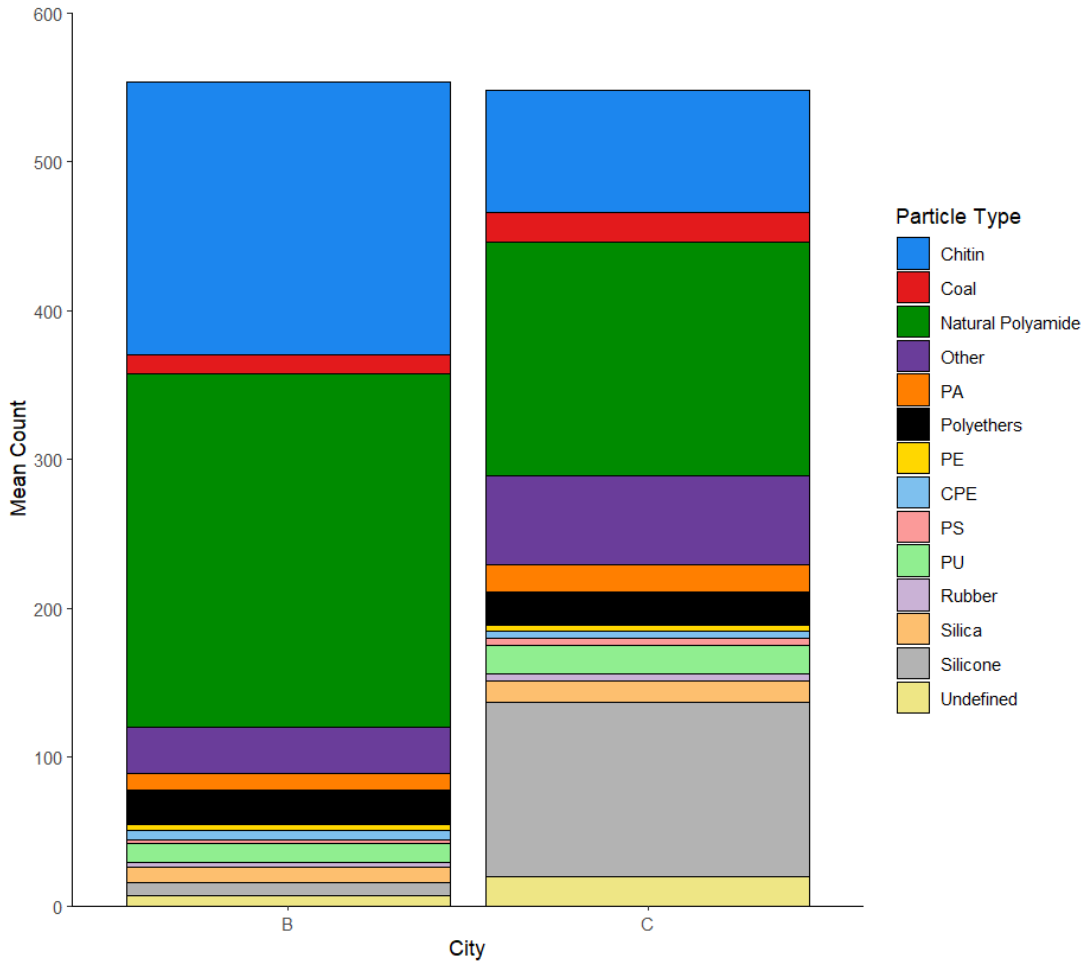

Figure 7. The mean particle type of City B and C respectively post-treatment tapwater.

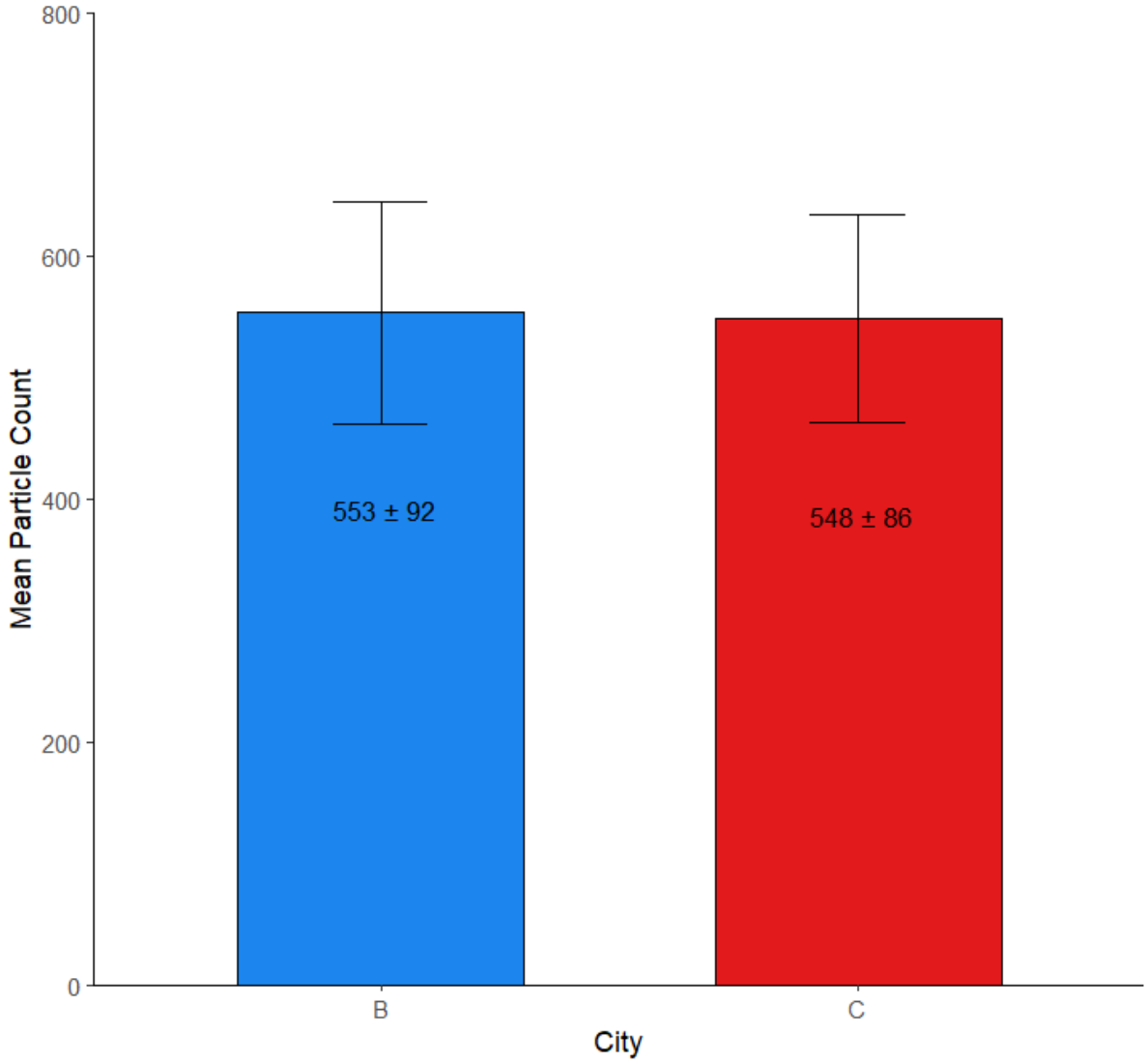

Figure 8. The mean (±s.e.) particle count of the City B and C respectively post-treatment tapwater.

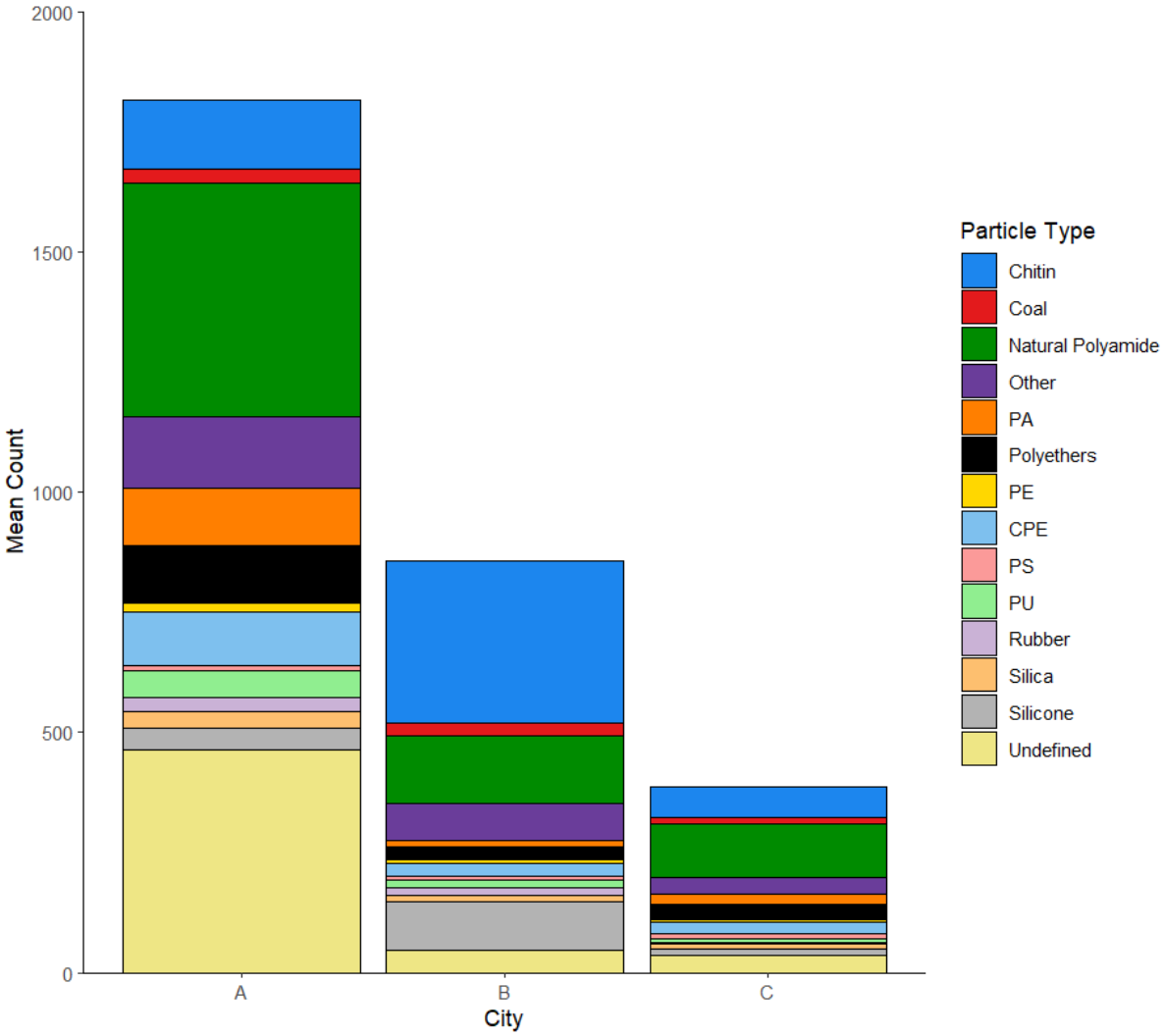

Figure 9. The mean particle type of City A, B, and C library tapwater.

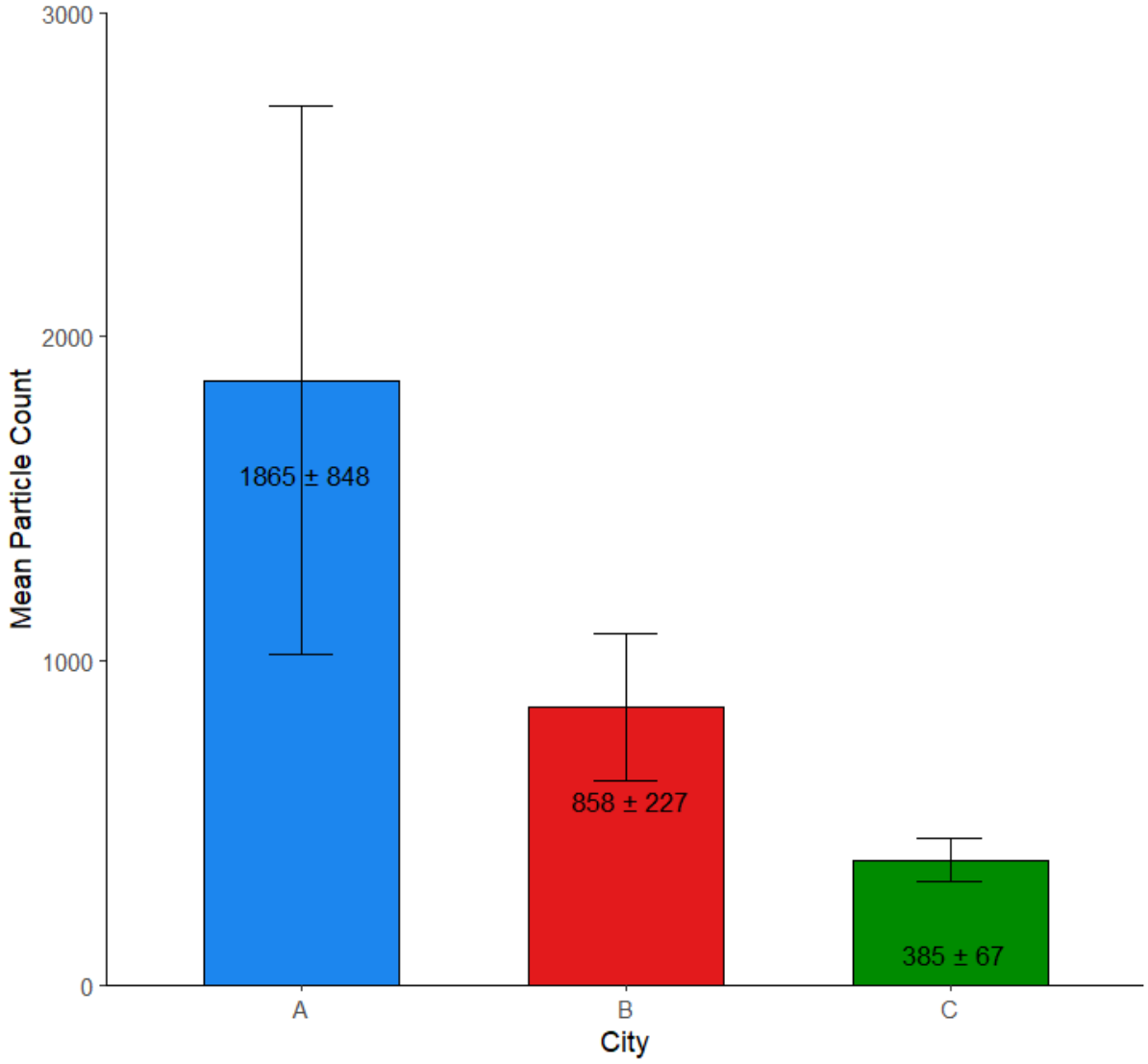

Figure 10. The mean (±s.e.) particle counts from the libraries in each city.

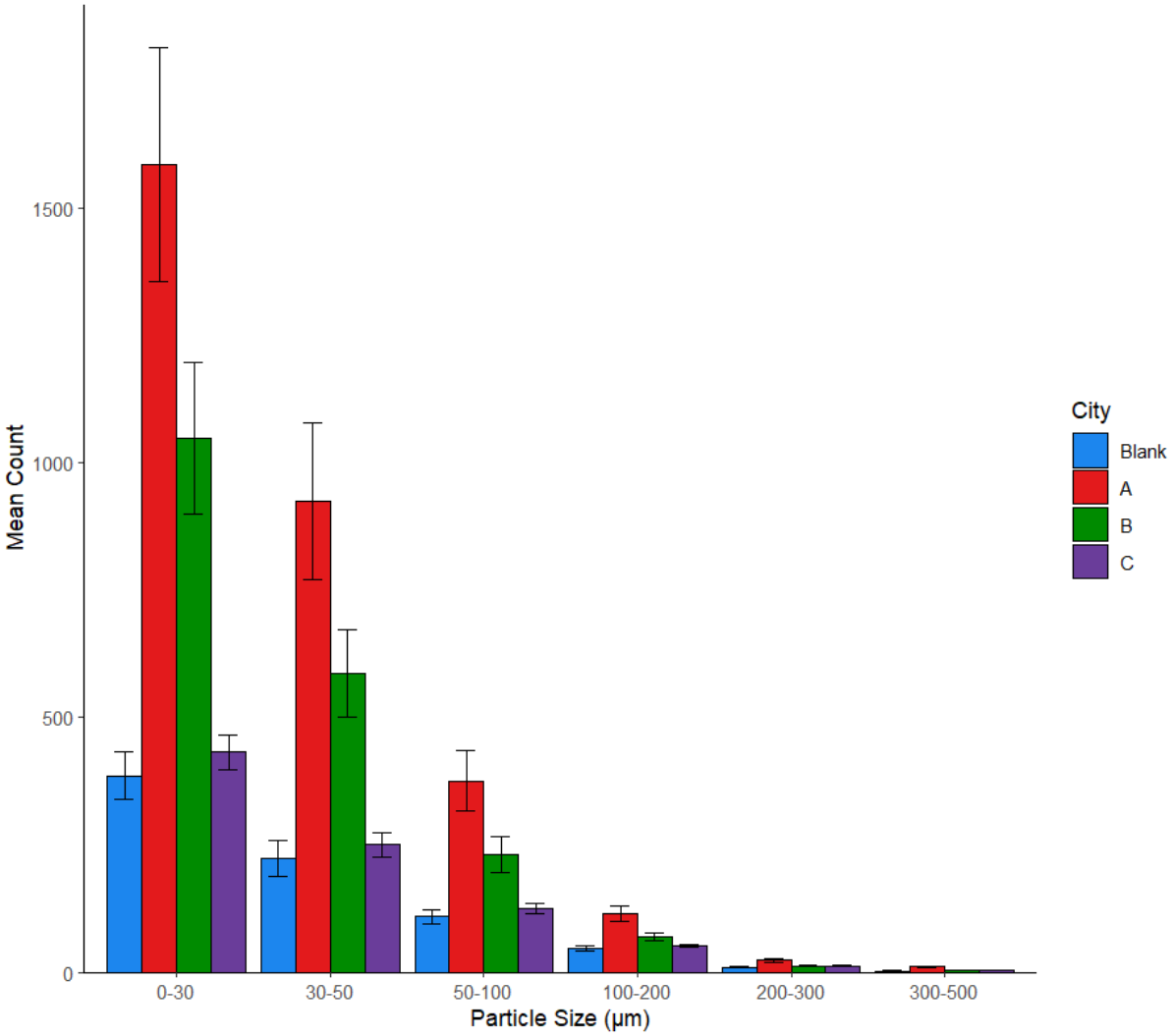

Figure 11. Mean (±s.e.) particle size by city including all particle types observed.

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