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Tracing Microplastics in Municipal Potable Water Across Residential Buildings

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TRACING MICROPLASTICS IN MUNICIPAL POTABLE WATER ACROSS RESIDENTIAL BUILDINGS

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by

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ABSTRACT

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SEPTEMBER 2023

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Limited research on microplastics makes it increasingly difficult to measure the potential dangers of their toxicological effect on humans and the environment. Today, evidence has revealed that microplastics have been located in highly remote areas of the world. There are few studies that examine the movement of microplastics within urban landscapes and even fewer that observe different communities within cities. To this end, a study was devised that utilized filtration, dehydration, and Laser Direct Infrared Spectroscopy to monitor drinking water microplastics found in residential buildings across different communities.

Houses and apartments of low and high-income at different distances from the nearest water treatment plant were considered. Comparisons between format differences between housing units were made possible by creating a ratio between rent and the square footage of the unit. Samples were extracted from kitchen faucets for their high impact on cooking and human consumption. While there was no significant difference between distance, income level, and building structure some factors had a stronger influence on microplastic count than others. Using a general linear model, it was found that distance

had the greatest effect on microplastic count followed by building type and then income levels. The greater the distance from a water treatment plant the fewer microplastics one was exposed to. Microplastics were found to be more abundant in apartments as opposed to houses. A weak positive correlation between income level and the number of microplastics was found but was not significant enough to state that income played a role in microplastic count. This can be interpreted as microplastics having no discrimination on one's socioeconomic status. As everyone, no matter their background is affected by microplastics, it is recommended that more research be conducted to confirm whether other building types and other factors have an influence on microplastic exposure.

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CHAPTER 1

INTRODUCTION

Defining Plastic

Plastic is a type of synthetic material derived from polymers. While most plastics are manufactured with synthetic material, they can also come from natural sources such as cellulose in plants [1]. The creation of plastics brought technological advances with their durability, malleability, and other properties like their lightweight nature. Since their invention approximately a century ago, at least 9 billion tons of plastic have been produced since the 1950s, and half of that was in the past 20 years [2] [3]. Their ever-growing dominance in society has been attributed to their involvement with nearly all parts of life including food storage, medical devices, infrastructural materials, transportation, and more. With attention being brought to climate change, efforts have been implemented to handle the pollution of plastics. However, something that escapes the human eye is an emerging pollutant whose potential dangers remain undefined; microplastics.

Plastics can be broken down into three major size categories: macroplastics, microplastics, and nanoplastics. Macroplastics are plastics that are larger than 5 mm or 5,000 µm, microplastics (MPs) are smaller than 5,000 µm but larger than 1 µm, and nanoplastics (NPs) are those smaller than 1 µm [4] [5] [6]. One of the major concerns of MPs comes from their decomposition rate and size. Being made of synthetic materials means their decomposition rate in the environment is significantly longer than natural materials. Their small size makes it more difficult for detection and cleanup efforts as

opposed to macroplastics [7] [8] [9]. MPs have been found in all kinds of ecosystems meaning their accumulation and potential risk have outgrown their slow decomposition rate.

1.1 Literature Review

Types of MPs

While the field of MPs is on the rise to gaining more attention, current research has been able to find information on the characteristics and behaviors of this contaminant. MPs can come in a variety of shapes and sizes. These shapes are beads, foams, films, fibers, and fragments [10]. Beads also known as pellets or spheres are characterized by their round bodies. They are commonly found in hygienic and beauty products such as toothpastes, cleansers, and body washes as a means of exfoliation [11]. Foams are another subset of microplastics that are classified by their bubble-like appearance and generally derive from polystyrene (PS) but can come from other polymers as well [12] [13]. Films are thin sheet layers often used in agriculture and even in food preservation [14] [15]. Mulch films and plastic wraps for covering food are sources of these MP films. Fibers are thread-like spindles that can form when articles of clothing are worn or washed [16] [17]. Lastly fragments have no consistent shape like the other groupings and therefore encompass all irregularly shaped MPs [18]. While many of these shapes are more commonly associated with a specific point source, it should be noted that the presence of different shaped MPs can also be found where a specific shape dominates abundance.

Sources of Microplastics

Each of these MP shapes can have different or overlapping origins, but these sources share similarities. MPs can originate from two major sources; they are primary and secondary sources. Primary sources involve intentional manufacturing of MPs and their applications in industries while secondary sources arise from the decomposition of macroplastics or other MPs into smaller particles [19] [20]. Secondary sources are much more dominant than primary sources due to the abundance of existing plastics to break down from. The unintentional creation and abundance of secondary MPs is one of the many reasons why more research is being done to find out how MPs reach and affect the places where they reside.

The Fate of Microplastics

Weathering and erosion of existing plastic particles can allow MPs to be found from factories, appliances, and vehicles and in the air we breathe, rivers we draw drinking water from, and the oceans where our food comes from. According to Geyer, between 2015-2019, 8.3 billion tons of plastic were produced where 6-7% was recycled, 8% was incinerated, 30% was still being used, and 55% was sent to landfills [21]. While plastic sits at these landfills their range of effect continues to increase from there. In soils and seas, weathering and erosion continue to occur resulting in MPs breaking away from these landfill sinks. These MPs can be mistaken for as prey and consumed ending up in the bodies of land and sea animals [22]. Over time this concentration grows and spreads through more animals through a process called bioaccumulation. This process works its way up the food chain where predators will consume prey that have ingested MPs and

continue all the way into the bodies of larger creatures such as sea turtles [23]. One study by Marte Haave reports polyvinyl chloride (PVC) and PS being found within the stomach, intestines, liver, and muscles of seabirds, otters, cod, and flounder [24]. Studies have noted that MPs can be taken up through root systems and have been found along the vascular system [25] [26].

Humans are no exception to being exposed to MPs as they have been found in fecal matter and in the gastrointestinal systems[2] [27]. Humans can take up MPs through three routes: ingestion, inhalation, and dermal contact [28]. MPs can enter the human body through ingestion of foods carrying MPs, but also through the MP leaching of food containers/bottles. Choudhary reports that a 1 L water bottle's cap released about 10,000 MPs of polypropylene (PP) and polyethylene terephthalate (PET) on average [29]. Inhalation of MPs in humans has been proven with several studies noting that PP, PET, and polyethylene (PE) were the most abundant in human lungs [30] [31] [32]. While there exists few evidence of dermal absorption of MPs, it has been noted that NPs could pass through the skin through face creams or medicines [33].

Microplastic Toxicity

Speculations on how MPs could affect human anatomy have been drawn from toxicological effects that MPs have on animals and plants. Several studies examined the interaction between MPs and plants where they found that MPs hindered the growth and development of plants [25] [26]. In Jia Li's study, they noted that MPs had direct and indirect effects. MPs directly affected plants mechanically by blocking pores, reducing light intake, and causing physical damage to roots. MPs indirectly affected plants by

altering soil properties, increasing the bioavailability of other contaminants, and affecting microbial communities in a way that gave less favorable growing conditions.

Toxicological responses to MPs have been observed by studying animals that have ingested MPs. A study in 2020 observed how amphibians, specifically *Physalaemus cuvieri*, reacted to PE MPs over a weeklong period [34]. They found signs of dilating blood vessels, hypertrophy, and congestion across the 40 tadpoles they studied. Another study observed *Daphnia magna*, a type of plankton, and reported mortality and immobilization when exposed to PP, PE, PVC, and PVC/PE over the duration of 1 to 4 days [35]. Similar experiments have been conducted in other animals such as fish, clams, and earthworms and have found similar effects ranging like inhibiting animal metabolic functioning and cytotoxicity [36] [37] [38].

The physiological effects MPs have on human health have been difficult to determine due to the infancy of the research. While more studies on the physiological effects MPs have on the human body are being done, some observations have been made. In one experiment, scientists subjected human colon and intestinal cells to four different sizes of PS MP and NP beads (0.1, 0.5, 1, 5 μm) over the course of 24 hours [39]. They determined that PS MPs and NPs showed low toxicity levels in the colon and intestinal cells resulting in cell membrane damage, oxidative stress, and lowered cell functioning. While this study is one of the few who have observed direct human cell interactions, more research should be conducted to confirm these findings. Despite this the speculations from the way other animals and plants have reacted to high concentrations of MPs and the onset of more research should raise questions as to who among the human population is most affected.

Mobility of MPs

From the Great Lakes of the United States to the beaches of Asia and rivers of the United Kingdom, MPs have a hold on the entire world [40] [41] [42]. It is no surprise that many of these studies focus on aquatic environments as they tend to be sinks and major transport ways due to runoff and urban sewer discharge [43] [44] [45]. Something that papers have started to examine is how MPs behave in drinking water sources. Drinking water is an essential resource that every human requires for daily consumption. With great volumes of water being consumed, the importance of having clean and safe water becomes pressing. MPs can be found in drinking water supplies through a multitude of ways. Some of these include run off from urban areas, accidental industrial spills, waste treatment effluent, agricultural runoff, littering, and deposits from atmospheric MPs through precipitation or erosion [46] [47] [48].

While the presence of MPs in drinking water brings about potential risks to human health, the mechanisms present can add more reason to not underestimate MPs. Weathering and erosion are natural vectors that allow MPs to be more mobile in the environment and adsorb contaminants. Adsorption is the physical adhesion of atoms or molecules onto a solid surface which can often result in a thin film of adsorbent around the solid. Depending on the size, composition, and shape, each MP particle can have different surface properties that affect adsorption. MPs can be considered a potential risk because of their ability to act as transporters for contaminants [49] [50]. MPs are made of polymers that can contain a mixture of hydrophilic and hydrophobic or water-repelling functional groups like methyl groups. The addition of hydrophilic or water-loving functional groups like carboxyl groups can make the polymer slightly hydrophilic

allowing them to attract hydrophilic compounds such as heavy metal oxides or hydrophilic organic contaminants (HOCs) [51] [52] [53]. Some studies found that HOCs and heavy metal contaminants can sorb onto spherical or fibrous-shaped MPs like polyamine [54]. HOCs are a class of organic compounds that have an attraction to water because of their hydrophilicity. Examples of HOCs include antibiotics, pesticides, and polychlorinated biphenyls (PCBs) which are known to be highly carcinogenic [53]. Heavy metals are metallic elements with a much greater density than water [55]. Mercury, lead, and arsenic are some examples of heavy metals that have known dangers to human health such as causing cancer in lungs, liver, and skin and even death [56]. HOCs pose a threat to public health because these compounds can enter and dissolve within water bodies such as fresh or groundwater used for drinking water. For heavy metals their bioavailability increases because MPs can transport them into the stomachs of animals where the acidic conditions cause desorption and uptake of those heavy metals into tissue [26] [57] [58].

Concentrations of MPs in Drinking Water

The concentration of MPs within drinking water systems varies depending on the location as well as the type of source water. One study in the Netherlands reports they found <1.000 MPs/m^3 in ground water while surface water varied between 65,000-90,000 MPs/m^3 [59]. Another study in Belgium finds 5.59 MPs/L within their drinking water [60]. Huge variability in sampling drinking water MPs as well as the differences in living standards across countries means that every reported concentration of drinking water MPs needs to be supported by other researchers before a stable reading can be reached for a given area. Drinking water supplies differ from oceans and rivers in that the water is

treated before it is released for consumption. These drinking water treatment plants can introduce chemicals or utilize filtering processes to remove contaminants from the drinking water. It should also be noted that within drinking water the more common morphology of MPs tended to be fibers, beads, fragments, and films [61] [62].

Instrumentation for Identifying MPs

To detect MPs traditional spectroscopic techniques that analyze MPs such as Fourier-transform Infrared (FTIR) and Raman must be employed. FTIR is a traditional spectroscopic technique that provides information on the composition and chemical bonds of a sample. FTIR has some advantages such as a quickly obtained spectrum and high resolution compared to other methods. FTIR covers a broad wavelength range of 4000-350 cm^{-1} and while it can detect peaks pertaining to MPs, the range is too broad for changes in polymer structure to be detected [63]. Additionally, certain infrared-absorbing materials like metal oxides can absorb some of the infrared light which can make readings difficult [64] [65].

Current knowledge gaps in microplastics among different communities

Several knowledge gaps exist within the field of drinking water MPs. First is the effectiveness of drinking water treatment plants. Many drinking water treatment plants are not equipped with the tools to fully remove MPs from drinking water [66]. This is in part due to high construction costs and the infancy of the research. Should water treatment plants be reconstructed to account for MPs filtration and removal, more harm may be done to the drinking water due to leaching of MPs from construction. One question that arises from this dilemma is what can be done to current water treatment

plants. Are current water treatment systems as effective at removing MPs or could the MPs go undetected because of the absence of a standardized sampling and analytical procedure? Another question that arises from this is how the MPs will be stored and disposed of. Having the MPs sent to a landfill will only contribute to the issue, while improper storage of MPs may lead to accidental spills.

Another knowledge gap in the field of MPs is the lack of standard procedures and methods of reporting concentrations of MPs [48]. Because the field of research is still infant, many scientists have utilized different filtration and extraction methods, analytical tools, and have reported varying concentrations of MPs. This variability is fueled by the research community's desire to explore the most effective methods for varying bodies of water. Perhaps in the future, the sampling procedures can be standardized and accounted for both low volumes and high volumes of drinking water. As for reporting concentrations of MPs, the difficulty arises when one tries to compare their results to other similar studies. Current efforts are aimed at having multiple experts communicate with one another in conferences such as the one held by the World Health Organization in 2019 [67].

Current research is aimed at tracking MPs within the environment and examining physiological effects on humans. The focus of detecting and locating where MPs could be in preparation for the potential risks that MPs may have. By having more research focused on the extent of the effect of MPs, once the toxicological effect of MPs is found, then public health officials can have a better understanding on how to approach the issue. This focus on detection of MPs is because of the lack of known toxicological effects on humans. Locating the sinks of MPs could provide clues for their behavior. Some studies

have analyzed drinking water pathways, but even fewer have observed drinking water MPs with respect to differing socioeconomic areas [68] [69]. The need for this arises from the correlation that contaminants and poorly water systems in lower income communities have. Haloacetic acids (HAAs) are chemical compounds that are formed when chlorine and other drinking water disinfectants come into contact with organic matter. Examples of HAAs include dichloroacetic acid and dibromoacetic acid which are known to have toxic effects on the human nervous system and metabolism [70]. In low-income areas, older infrastructure and poor water quality can leach organic material which can form HAAs. Similarly older water pipelines can be made of materials that are known contaminants such as lead. This gives one reason to believe that other contaminants such as MPs may also be more present in these communities due to poor infrastructure and water quality.

Other studies are also limited in the sizes of MPs that they detect and so our study will look to utilize the extensive MP library on Agilent's Laser Direct Infrared spectral instrument to identify particles ranging from 20 to 500 μm [71]. Doing so will allow the categorization of MPs to examine if socioeconomic factors, categorized under low and high-income, influence MPs within communities. Another limitation to current research is the lack of research focused on drinking water MPs within the United States. Several studies have been produced in European and Asian countries and so this paper hopes to shed light on the current state of MPs within US drinking water [59] [60].

Another limitation of these papers is the exclusion of the color of MPs. MPs have varying colors due to manufacturers wanting to have appealing aesthetics for their products. Because of this coloration, different colored MPs are more susceptible to

photodegradation, a process that weathers MPs with UV radiation. MPs that lean towards blue do not absorb UV light as much as more red leaning MPs and because of this they take significantly longer to degrade than red MPs [72].

Our paper aims to show that MPs received in one's drinking water will be significantly higher in lower-income areas as these areas are often closer to and have poorer management of waste facilities [73]. It is expected that increasing one's income and therefore the general wealth of the surrounding community will decrease the MPs one can expect in their drinking water. To this end, we have conducted a study that focuses on observing differences in MP counts among different types of residential buildings in different communities.

CHAPTER 2

METHODS

2.1 Location and Calculations

In the observed town, sampling was taken from 10 different locations; 5 houses and 5 apartments that were considered low or high-income housing for that area. For every site, 4 replicates were collected to account for variation in sampling and extraction. Building type and income level, designated by a single bedroom's rent costs, were chosen to observe if the distribution of MPs was influenced by socioeconomic factors. Income designation was determined through the following calculations:

High = monthly rent of home/apt. > avg. monthly rent of all homes/apts.

Low = monthly rent of home/apt. < avg. monthly rent of all homes/apts.

The ratio below was calculated to equalize the residential buildings to overcome structural differences between them.

Rent/Sq. Ft. Ratio = Monthly rent of building Sq. Ft. of unit

The other factor recorded was distance in relation to the town's water treatment plant nearby. Similar to the income level of residential buildings, the average distance from residential buildings to the treatment plant was compared. This calculation was done to determine the distribution of MPs as a function of distance.

2.2 Drinking Water Sampling

While there is no set standard for how MPs should be sampled and extracted for analysis, filtration and digestion in water samples is the most common method to date allowing for the removal of unnecessary biological background elements [74] [75] [76]. To determine the optimal volume needed to accurately portray the MPs found in a sample, a preliminary study utilizing MilliQ water in 1L, 2L, and 4L was conducted. 2L was the optimal volume as 1L and 4L resulted in significantly lower MP concentrations. Other studies have also utilized similarly high volumes of samples as well as replicates [77] [78]. To ensure consistent sampling, cold tap water was run for 30 seconds prior to collection. Studies have shown that colder temperatures released fewer MPs in polyethylene bags than hotter temperatures [79] [80]. For all collections, cold water was used to avoid temperature having an inconsistent influence on particle count.

2.3 Extraction of MPs

A vacuum filtration with 10 µm stainless steel filters (McMaster-Carr 92715T85) was used in order to extract MPs from the drinking water samples and to analyze particles within the size range of 1 µm-25 µm. After carefully sonicating the filters for 30 seconds in MilliQ water to remove MPs from the sample, the MilliQ-MPs solution was filtered and sonicated again with pre-filtered HPLC-grade methanol [81]. Afterward, the methanol-MPs solution was placed into an oven at 60°C where aluminum foil with 6 holes covered the beakers. The holes allowed methanol to evaporate out of the beaker. When the methanol was completely evaporated, the MPs were then reconstituted with 1 mL of MilliQ water, sonicated for another 30 seconds, and then transferred onto Kevley

slides for LDIR analysis. Kevley slides are IR-reflective coated glass slides that allow infrared light to be reflected back into the LDIR's detector [82]. Other studies have employed similar techniques when extracting MPs from liquid samples [83] [84]. Blank samples were created by having 2L of MilliQ water pass through the steps of the procedure.

2.4 Laser Direct Infrared Spectroscopy

To overcome some of the limitations for traditional analysis instrumentation, Agilent's Laser Direct Infrared Spectroscopy (LDIR) machine was used. The LDIR's quantum cascade laser allows for large areas of a sample to be scanned in less than 1 second. The LDIR uses a quick, low resolution scan to identify particles that absorb light compared to the reflectance of the slide. It then collects a full spectrum of each particle found to identify the polymer by matching with its library [71] [81]. The LDIR also operates within 1800-975 cm^{-1} allowing it to be highly specific within the fingerprint region of the IR spectrum, unlike the FTIR's broad wavelength range of 4000 - 350 cm^{-1} [71].

Other studies have excluded cellulose derivatives (cellulose acetate, cellulose chemically modified, and cellulosic) from their analyses as their reasoning was that these particles came from natural sources such as wood and fruits so they will also be excluded from our study [85] [86]. Two groupings called polyesters (alkyd varnish, polycarbonate, polyethylene terephthalate, polylactic acid) and others (acrylates, acrylonitrile butadiene, calcium stearate, ethylene vinyl acetate, polyacetal, polybutadiene, polycaprolactone, polyether, polyimide, polyisoprene chlorinated, polymethylmethacrylate, polypropylene,

polyvinylchloride) were made as their individual MP counts were <1% of the total sample composition.

2.5 Quality Control

Working under a laminar flow hood was recommended in order to reduce contamination of the samples during the extraction procedure [87]. Metal tweezers, glassware, nitrile gloves, and cotton attire were used during extractions. Plasticware was limited to prevent any materials from leaching into the samples which could have led to inaccurate MP representations [88].

CHAPTER 3

RESULTS

The units for numbers in the figures represent the particle count. Figure 1 shows the average particle count for each site. Figure 3 shows the average house particle count was 1874 ± 318 and for apartments 2299 ± 283. Average particle count for income levels were also displayed in Figure 3 with 2119 ± 1258 for low-income housing and 2055 ± 1461 for high-income housing. Figure 4 shows a distribution of particles found among all homes; the top 5 most common particles were undefined, natural polyamide, chitin, polyamide, and polyurethane. Similarly, apartments also retained undefined, natural polyamide, chitin, and polyamide as their 4 most common particles with the addition of polystyrene instead of polyurethane. Figure 5 shows the particle distribution across the different income levels; for both low and high-income housing, the 5 most common particles were undefined, natural polyamide, chitin, polyamide, and polyurethane.

CHAPTER 4

DISCUSSION

Except for House 2 which had around 50 particles less, all samples had significantly higher particle counts than the MilliQ blank averages. House 2's deviation could be attributed to contamination that occurred during the sampling or extraction procedure making it an outlier. [89]. Even among identical samples, high variability occurs between replicates. A general linear model was utilized in Table 2 to compare building types and income levels through an ANOVA test. While there were no significant differences between building types, income levels, or even across the two factors, Table 2 showed there were differences in the strength of the influence each factor had on MP counts based on the adjusted sum of squares value. It's shown that in descending order of influence, distance followed by building type and income level affected how many MPs were found in one's drinking water.

4.1 Low Income vs. High-Income

Income level denoted by the cost of one's housing expenses was examined to see if socioeconomic factors influenced one's exposure to drinking water MPs. No correlation existed between low or high-income homes as shown in Table 1 but according to Table 2, income levels did have a slight effect on the sizes of particles found. In Figure 8, lower-income residences found a greater number of the smallest class of MPs 0-30 µm while higher-income residences found greater numbers of the larger classes of MPs within size classes 30-50, 50-100, 100-200, 200-300, and 300-500 µm. Within this study, income levels had no significant influence on MP abundance, but further examination

should be conducted in order to verify if socioeconomic factors do affect the size of particles found.

4.2 Houses vs. Apartments

Houses were found to have fewer average MPs than apartments with 1874 ± 318 and 2299 ± 283 particles being found respectively. Despite this, no significant difference existed between building type and the MP abundance. Table 1 shows a positively weak correlation value of ~0.31 between building type and particle count [90]. Alongside the GLM in Table 2, building type had a more direct effect on the MP count than income level. This could be explained by the materials used in the construction of homes and apartments. If older houses were constructed using more traditional natural materials like cast iron, then it is likely its materials would leach less MPs than PVC piping for apartments. The location of houses is typically further from urban areas as opposed to apartments that are centralized in those urban areas. One outlier from this trend is Apartment 3, which when compared to its counterparts had significantly fewer MPs again, possibly due to contamination during the sampling or extraction procedure. For future iterations of this study in this area, one should examine if Apartment 3 continues to act as an outlier when the sample size is expanded to encompass more apartments.

Similar to income level, building type also affected the size of particles one received with apartments retaining more MPs across all size classes. Figure 6 shows that this trend stayed true for size classes between 0-200 μm while in size classes 200-300 μm and 300-500 μm the number of MPs stayed the same between apartments and houses.

These smaller-sized particles could again be connected to the building materials used and the proximity of urban activity.

4.3 Distance and Dilution of MPs

Having the greatest influence on the MPs found in drinking water, distance exhibited a negative relationship with particle count in S.I. Figure 1. This relationship could be explained by the dilution of MPs as they travel along water pipelines, but it should also be noted that a majority of apartments were found near the water treatment plant and houses were found further away from it with the exceptions of House 5 and Apartment 5. While there are current examinations into the type of treatment the water plant uses may explain why there is significantly more MPs post-treatment, it is likely that this relationship arises from the surrounding area of the water treatment plant [68]. The water treatment plant is situated near a college campus and the city's downtown area. Being near an urban center means that runoff and erosion of MPs into drinking water are more likely to happen due to proximity. Something that should be considered in the future is a more diverse arrangement residential building across different distances. Again the high variability of the replicates made it difficult to show a significant relationship between distance and MP abundance.

4.4 Comparing Other Studies

Few studies have conducted similar examinations on residential buildings. Ali, who utilized a sampling volume of 1 L with a 1.5 µm pore size glass filter, reports 380 MPs/L among homes and 90 MPs/L among apartments [91]. It should be noted that the apartments in Ali's study were college campus dorms in Iran as opposed to the off-

campus apartment complexes that our study examines. Additionally, Ali's sample volumes were 1 L instead of 2 L and the use of distilled water instead of MilliQ water could have affected the rinsing steps and MP counts. Another study by Taghipour also traced MPs through treatment plants and consumption taps in residential buildings [92]. With a filter pore size of 5 µm, they found 200 MPs/100 L within 1 apartment, 1 house, and 1 dorm. In water samples before water treatment plants, they found that polyethylene was the most abundant and in post-treatment samples, polystyrene was the most abundant. As the water collected in our study was also after the drinking water had passed through treatment, our MP compositions also support this finding as polystyrene was more abundant than polyethylene across income levels but not building types. The lower MPs count can be explained by the different sample location (Iran) having different conditions that limited MPs exposure. Additionally, the time in which the samples were taken may have also played a role in the MPs discovered as our samples were taken in the Fall and Spring seasons while Taghipour's were taken in the Spring and Winter seasons. As was mentioned before perhaps the hotter seasons were more likely to release more MPs within the water pipelines as opposed to the colder seasons of Winter.

A similar study within the United States conducted by Inga Kirstein notes that in their water samples, the most abundant MPs were polyamine, polyesters, and acrylics [93]. While these MPs align with the most abundant MPs found in our study, the differences can be attributed to the exclusion of certain polymers such as chitin and natural polyamide to focus on more synthetic materials.

4.5 Limitations

One limitation of this study was the limited knowledge of pipeline materials and routes that each residential building used. Without this, it becomes more difficult to determine whether pipeline materials influenced MPs or if another hidden factor was at play. Further examinations into specific building materials could present a relationship with the MPs under more restrictive experimental conditions.

Despite the best efforts, the blanks showed some level of contamination. Rinsing glassware and reconstituting the final samples used 25-50 mL of MilliQ water per sample. Some contamination may be due to the inconsistent volume of MilliQ water used, but this is overshadowed by the high variability among sample replicates, something other studies have noted too [88] [89]. Another limitation was site selection. Site selection was based on the tenant's availability therefore our ability to randomly sample was affected. Something that could be examined in the future is having a randomly selected sample group that is not hindered by availability.

Another limitation to the study was the method by which samples were dried. Without a consistent volume of MilliQ water used the time to fully dry before reconstitution for LDIR analysis varied between sample and replicate. To visually note whether the sample had fully dried off the methanol, the oven door needed to be open which could have introduced more MP contamination through the air and the holes on the aluminum foil. Perhaps the inclusion of a consistent time for drying will allow minimal aerial contamination.

CHAPTER 5

CONCLUSION

The relationship between socioeconomic factors denoted by income level and drinking water MPs was studied. Utilizing a filtration extraction and the LDIR for analysis, it was found that distance from the water treatment plant had the greatest effect on MP count followed by building type and then income level. Apartments found greater numbers of particles while larger-sized particles were found more often in higher-income residences. Despite this all trends between income level, building type, distance, and MP abundance were found statistically insignificant and so future studies should focus on confirming whether these trends hold true or not. Further efforts by local and federal governments should be implemented to prevent drinking water MP contamination across all varying communities equitably.

Future Study

Some revisions should be taken into account should this study be conducted once in the future. First, the sample sites of the study should overcome the limitation of the availability of the tenants. By communicating with the owners of the building, as well as conducting the study in less busier seasons, could open up more locations that can be sampled from. By altering the time of sampling, it should be noted that temperature did have an effect on the MPs released so temperatures of waters should also be considered too. For future iterations of this study, the sampling and extraction methods could be standardized to minimize contamination. Collection faucets varied in sizes and depths at each of the observed locations, so careful planning and preparation prior to sampling

should be done. The introduction of a separate pre-rinsed glass container was used to assist in sampling smaller collection faucets and so its use or the creation of alternative should be continued. During the extraction process, standardized amounts of MilliQ water could also be used in order to account for the additional MPs found within the sample due to rinsing.

Studies on MPs within drinking water will also note the morphology of the particles found. Due to the time constraints of this study a scanning electron microscope or SEM was not used and potential patterns based on the size and shape distributions were unable to be observed. For future studies, not only should a SEM be used but other analytical tools such as the FTIR could be used in order to compare analytical differences between both instruments. The color of MPs was another measurement that some studies chose to include in their study. Perhaps the inclusion of the specific colors found in drinking water can give rise to environmental mechanisms involving UV radiation.

For the discussion of future studies, factors revolving around the building itself should be considered such as date of construction, number of renovations since construction, and other historical events in the infrastructure of homes. Further examination could provide evidence that an individual's socioeconomic status has no bearing on the MPs detected in drinking water. Additionally, as it was found that building type had the greatest effect on the MPs found, future studies should consider different types of residential buildings such as mobile homes, townhouses, and condominiums.

APPENDIX: FIGURES AND TABLES

	Particle Count	Building Type	High vs. Low
Particle Count	1.00	0.31	0.21
Building Type	0.31	1.00	0.20
High vs. Low	0.21	0.20	1.00

Table 1: Correlation values of particle count, building type, and income level.

Source	Adjusted Sum of Squares	P-Value
Distance	12089200	0.160
Building Type	2458697	0.239
Income Level	668732	0.536
Interaction of Building Type and Income Level	620651	0.551

Table 2: General linear model pair-wise comparison of building type and income levels.

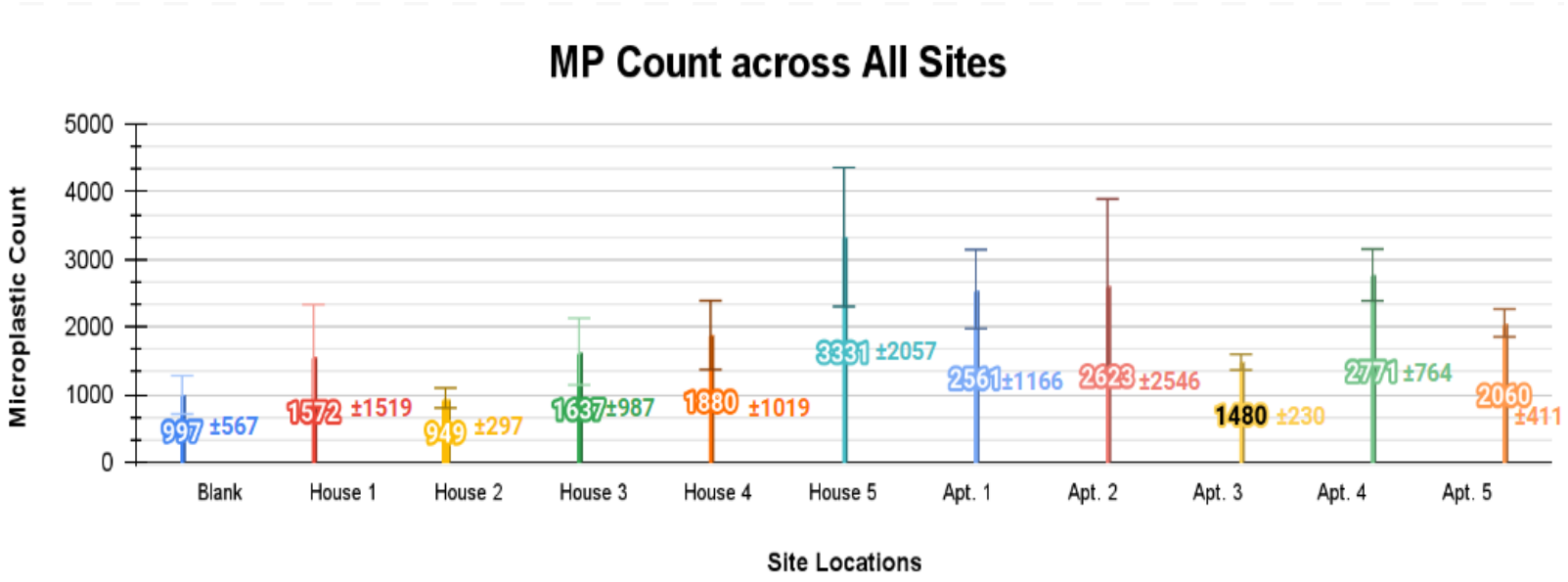


Figure 1: Particle count across all blanks and 10 sites observed. Each bar represents 4 replicates averaged and the error bars are the standard errors of the mean value calculated.

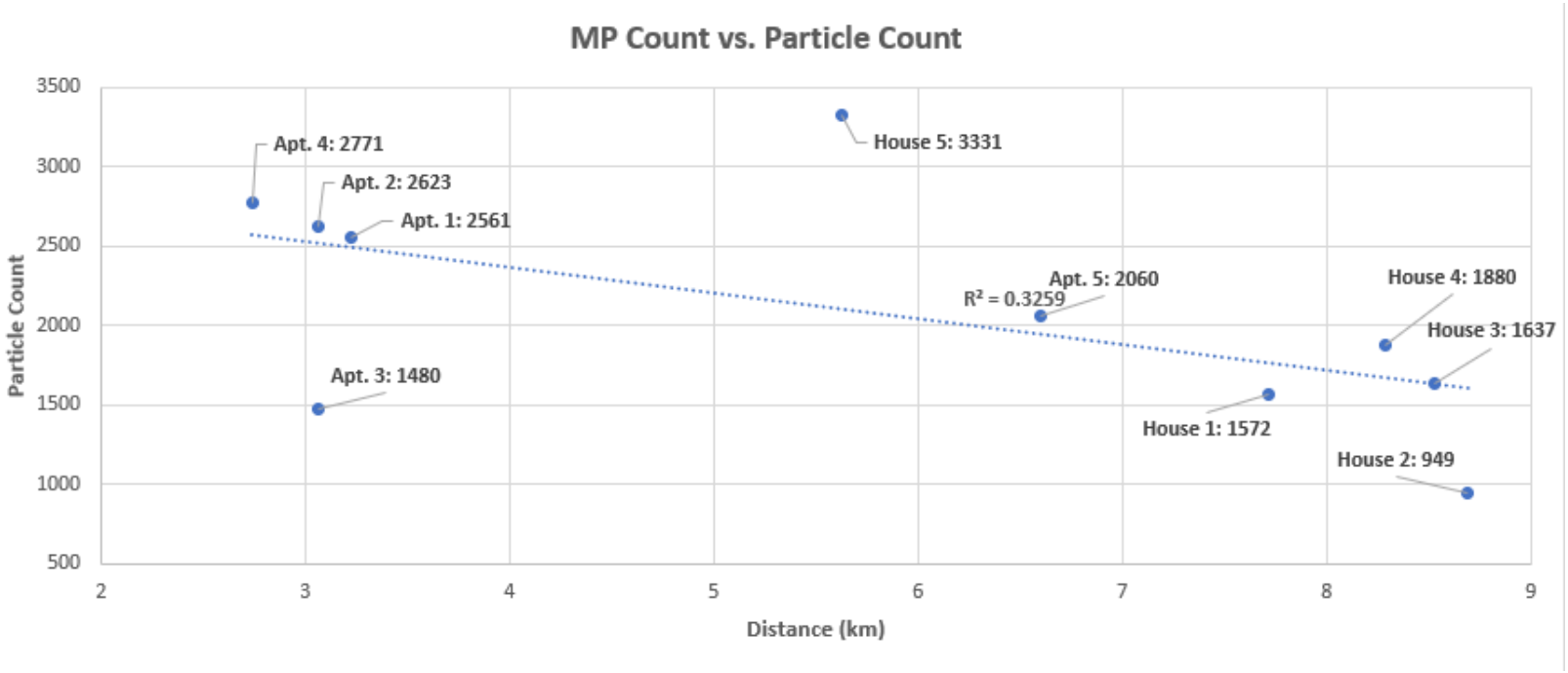


Figure 2: Distance of each site in comparison to the water treatment plant of the town alongside the particle count for each site

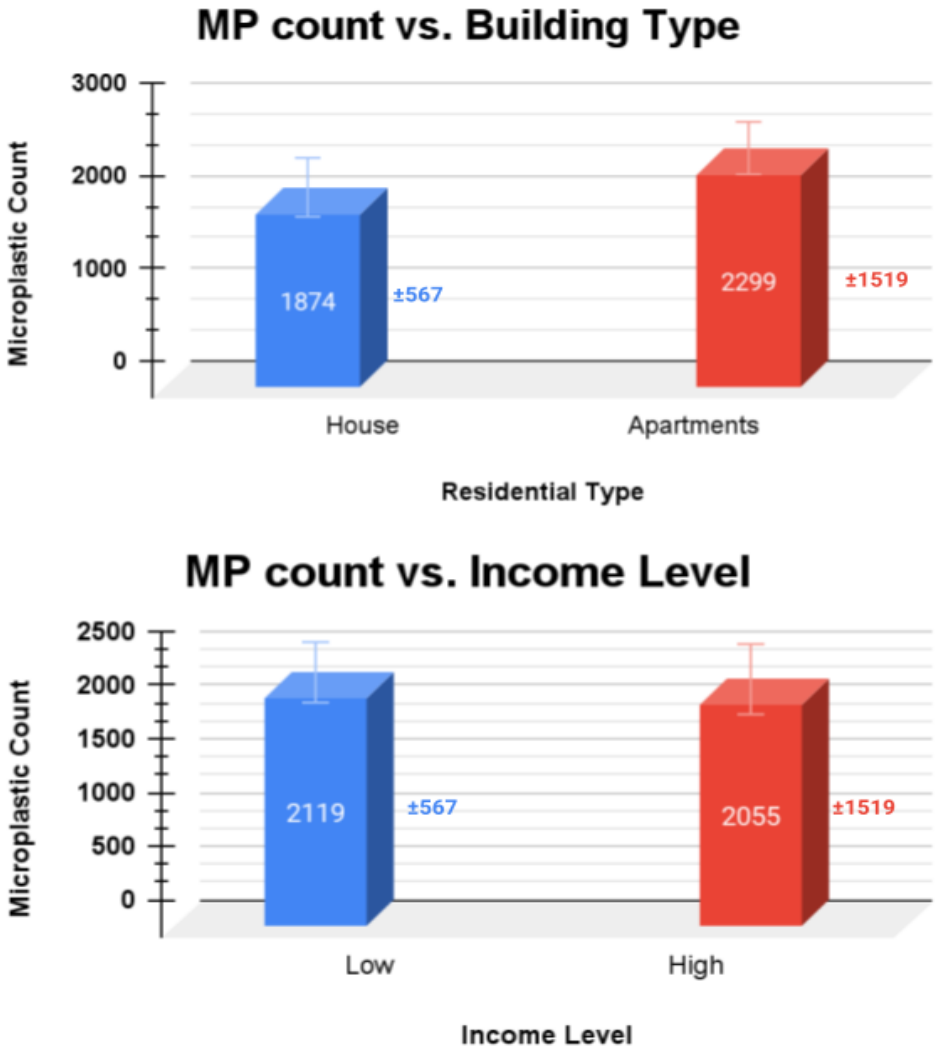


Figure 3: Comparison between particle count, building type, and income level. Error bars represent the standard error of the mean value of all replicates.

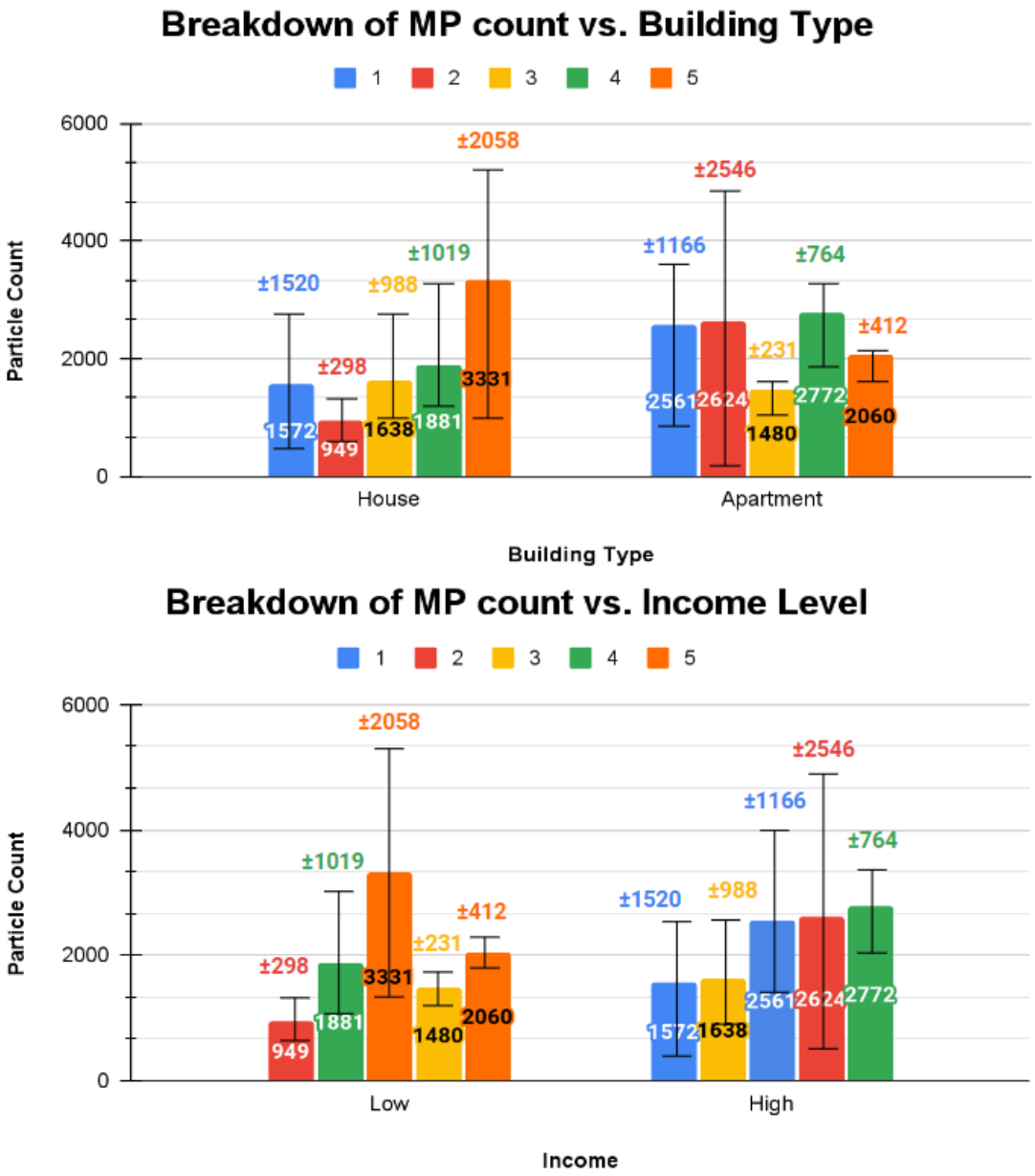


Figure 4: Correlation comparison between building type and income level. Error bars represent the standard error of the mean value of all replicates.

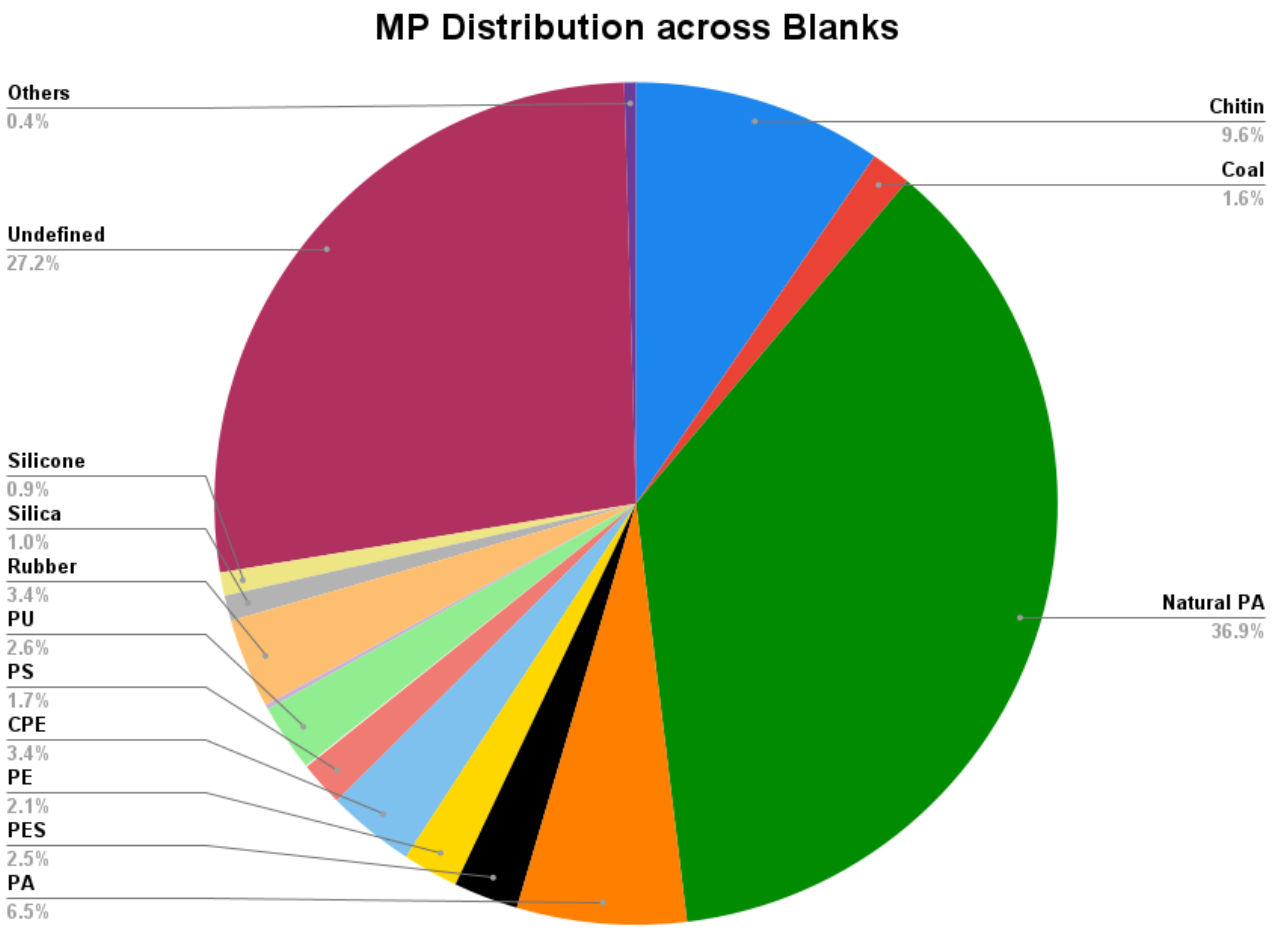


Figure 5: Distribution of polymer types among blanks. Numbers represent the percentage that the given polymer contributed to the average of all blanks.

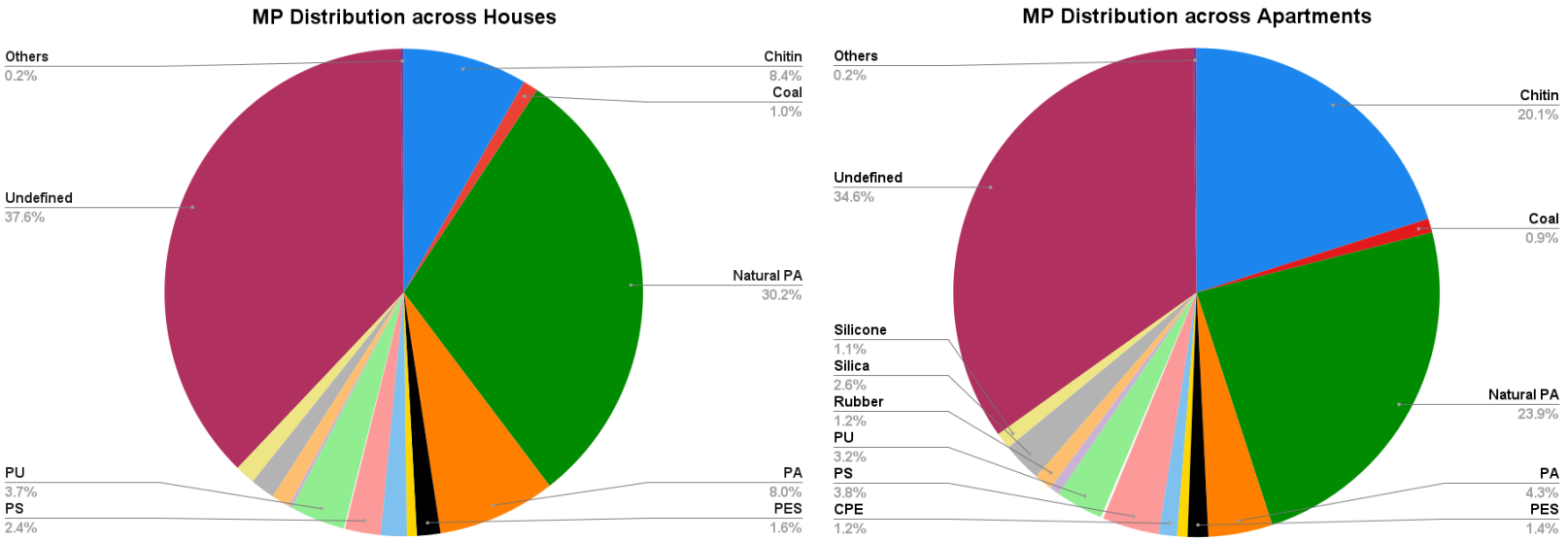


Figure 6: Distribution of polymers among building types. Numbers represent the percentage that the given polymer contributed to the average of all houses or apartments.

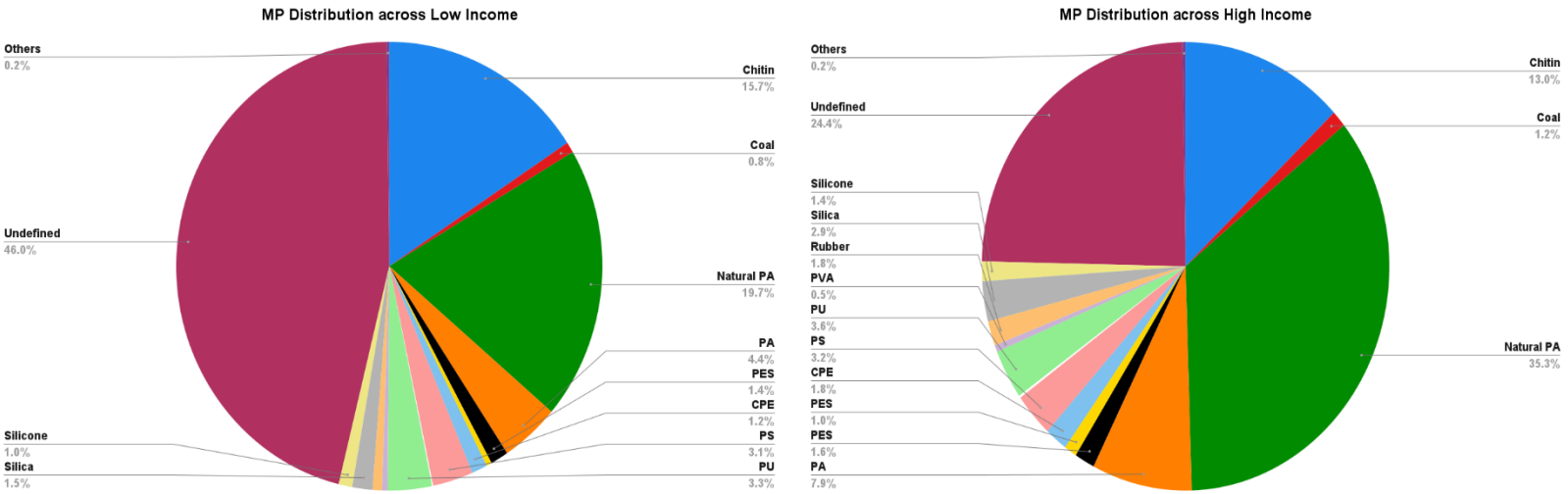


Figure 7: Particle type distribution among income levels. Numbers represent the percentage that the given polymer contributed to the average of all low income or high income buildings.

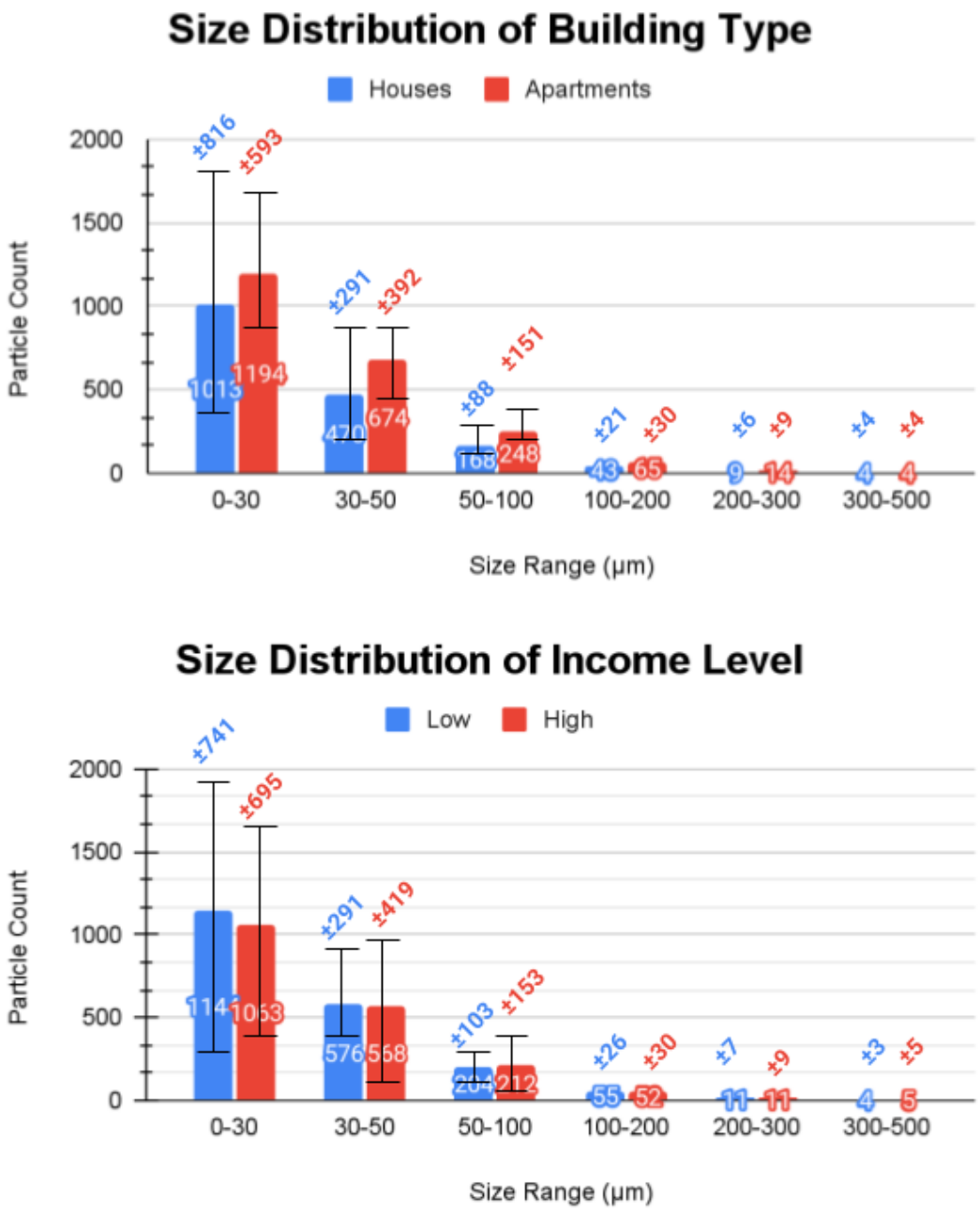
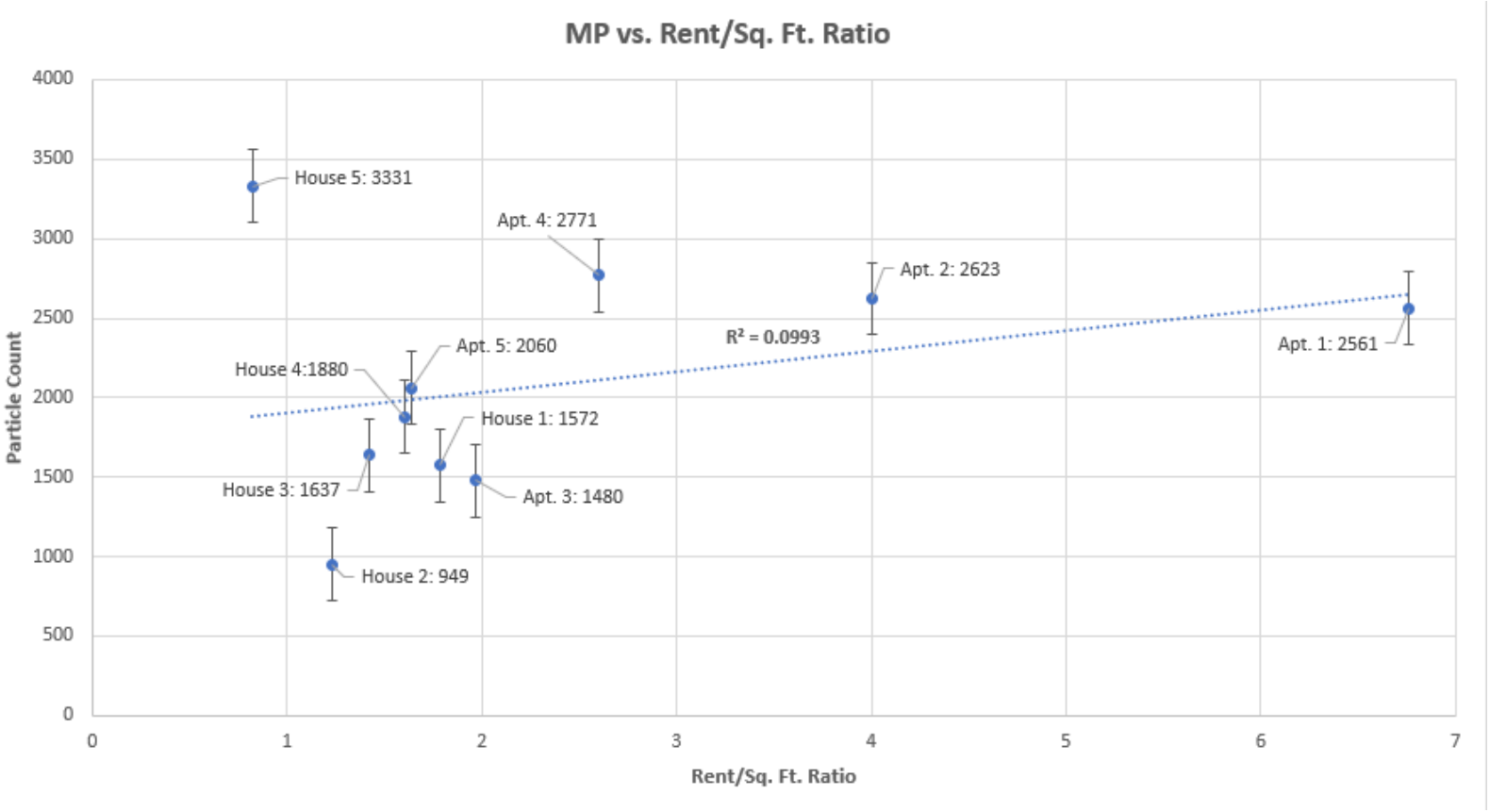


Figure 8: Particle size distribution between building type and income levels. Error bars represent the standard error of mean values. Lower income buildings had more particles than higher income buildings at lower size classes (0-30 µm), but fewer at higher size classes (30-500 µm)



S.I. Figure 1: Particle count and rent price/spacing ratio compared to determine a socioeconomic relationship. Error bars represent the standard error of the mean value of all replicates at a given site.

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