Effect of various collection sites on the amount of microplastics found in falling precipitation

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Abstract

Plastic use has increased exponentially since the 20th century. Due to their durability and low cost, they are used in packaging, medical devices, and machinery. Plastic degrades over time into smaller microplastics (<5mm), but is not removed entirely. Microplastics (MPs) in the marine environment are entrained into the atmosphere. Then, MPs precipitate through rain or snow and flow into soils and landfills. MPs enter the body through inhalation or food consumption. Accumulating these MPs has been found to affect the human body negatively. MPs have been found in precipitation in various locations around the world, including rural areas, although this is not consistently observed. This study focuses on whether sites of precipitation collection impact the number of MPs found in the samples. Samples were collected in four different areas: under a tree canopy, in an open field, on a roof, and next to a building at Shattuck-St. Mary's School in Faribault, Minnesota. Precipitation samples were analyzed by simultaneous transmitted polarized light microscopy (PLM), darkfield reflected light microscopy (RLM), and fourier transform infrared spectroscopy (FTIR). No microplastics were found in any locations for rain samples. However, 243.54 MPs were detected from snow samples analyzed. MP detection may be affected by the volumes collected, preceding precipitation, environmental conditions, and the way samples were analyzed. The process and equipment used for MP analysis can also impact MP detection. Therefore, standardized protocols for analyzing and quantifying MPs from the falling precipitation are needed.

INTRODUCTION

First invented in 1907 by Leo Baekeland, plastics have been used ubiquitously since the end of World War II. Plastics are made from natural gas or oil and refined into propane and ethane. When heated, they form ethylene and propylene. These polymers, composed of linked hydrocarbon monomers, can form different types of plastics used for different purposes. Polyethylene terephthalate (PET) is used for packaging or textile production, and polypropylene (PP) is used for machinery, pipes, medical devices, and cables. Polyvinyl chloride (PVC) is applied to the creation of medical devices. Moreover, DVD cases are made out of polystyrene (PS). Plastic usage has dramatically increased in the man-made product market since the early 20th century because plastics are lightweight, low-cost, resilient, flexible, and durable (Figure 1).

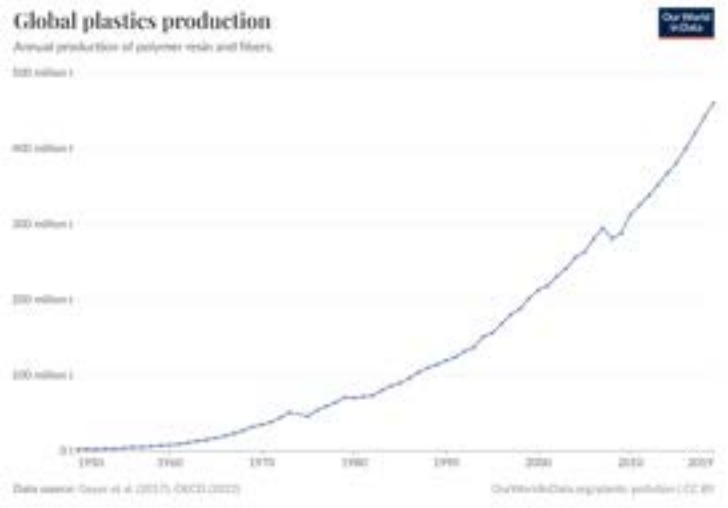

Figure 1. Global Plastics Production of million tons from 1950 to 2019 (Ritchie)

Small amounts of certain plastics such as beta-hydroxybutyrate (BHB), polyhydroxybutyrate (PHB), lactide, and Polylactic Acid (PLA) are biodegradable as they come from biomass or renewable resources. Conversely, polyethylene (PE) and Nylon 11 can be produced from renewable resources, but they are non-biodegradable due to their carbon-carbon structure and hydrophobic features. Most plastics are not biodegradable due to the presence of inorganic materials such as PET; therefore, they take a long time to break down. Recycling efforts have increased to manage the accumulation of discarded plastics. Surprisingly, however, Maier (2023) showed that curbside recycling leads to more total household plastic consumption. The only method of destroying plastic is by thermal incineration. However, incineration can release deleterious chemicals into the air. While recycling and incineration make up for the disposal of 21% of plastic waste, the vast majority (79%) of plastic waste is discarded in the environment in general dumps or landfills (Figure 2). Plastics' resilience to breaking down enables plastics to accumulate in the environment in locations such as oceans, lakes, rivers, soils, and air.

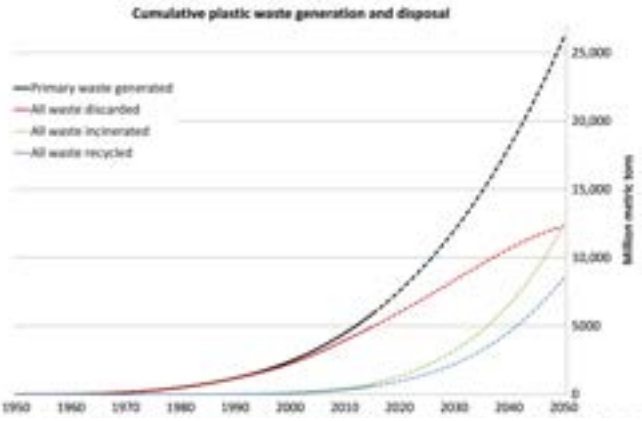

Figure 2. Cumulative plastic waste generation and disposal (in million metric tons). (ResearchGate)

Environmental conditions such as sunlight, wind, and waves cause plastic to degrade into smaller pieces. Plastic decomposition is differentiated by particle size: macroplastic (>1cm), mesoplastic (1-10mm), microplastic (<5mm), and nanoplastic (<1um) (Figure 3). Microplastics can be categorized as primary or secondary microplastics. When microplastics (MPs) are degradation products of plastics that are originally designed for commercial purposes or usage, they are called primary MPs, while secondary MPs derive from larger plastics. About 80% of MPs consist of fiber, such as textile products, carpets, and synthetic fabrics. Other components of MPs include microbeads (facial scrubs and toothpaste), pellets (recycling facilities and polymeric manufacturers), and films (plastic bags and plastic packaging). Microplastics have even been found in tap water, sea salts, and beer. Chemicals such as phthalates, polybrominated diphenyl ethers (PBDEs), and tetrabromobisphenol A (TBBPA) are also found in MPs. Microplastics can be degraded through enzymatic processes, photolysis, thermal stress, hydrolysis, aging processes, and mechanical stress. Due to the size of microplastics and nanoplastics (MNPs), they are easily transported and have been observed both in the human body and the environment.

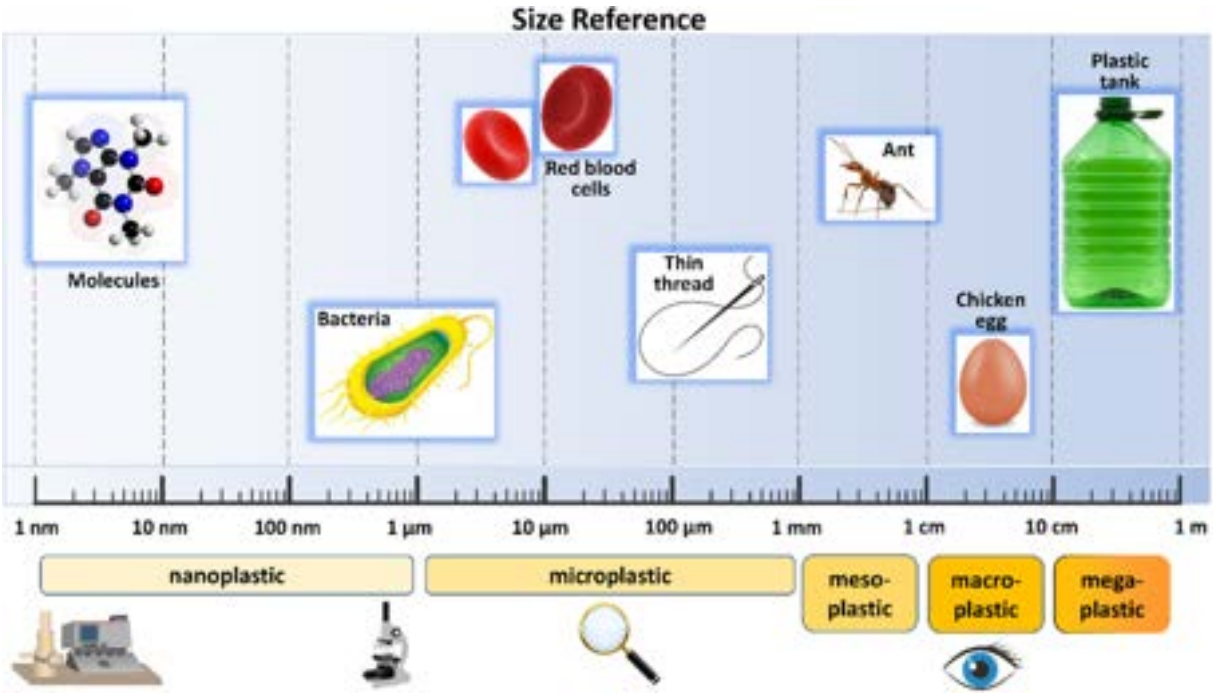

Figure 3. Size classification of plastics (ResearchGate)

According to studies on exposure routes of microplastics and nanoplastics (MNPs), MNPs enter the human body through food consumption, skin, sweat glands, hair follicles, and inhalation from the air. Consequently, MPs have been found in tissue throughout the human body including in the placenta, sputum, testicles, penile tissue, lungs, and nose. Once MNPs accumulate in organs, they can cause several serious problems in the body, including stimulation of Endocrine-disrupting chemical (EDC) release which may lead to developmental abnormalities. Endocrine-disrupting chemicals may interfere with reproduction by altering sex hormones and disrupting feedback mechanisms. Microplastics may also lead to oxidative stress that can potentially contribute to triggering cardiovascular diseases by apoptosis in endothelial cells. Microplastics also increase the potential for other health issues such as asthma, allergies, respiratory lesions, and even lung cancer. In addition, MPs have been shown to decrease pregnancy duration and result in adverse birth outcomes. Microplastics can clearly have negative effects on the human body; therefore, it is necessary to observe the sources of MPs that humans and other organisms are exposed to.

The environment is a re-emission source of plastics. There are a variety of sources of MPs that result in their being suspended into the atmosphere. These sources include plastics in road dust, marine environments, and agriculture. Approximately 84% of deposited MPs in the environment come from dust formation from worn tires, brakes, and road surfaces, all of which contain plastic. Turbulence in the wake of vehicles allows these plastic particles to resuspend into the atmosphere. Microplastics in marine environments can be aerosolized through wind or wave action. As a result, plastics that flow into the marine environments accumulate and possibly draw into sea spray, triggering an increase in evaporation. Plastic particles placed at the top of the marine layer are easier to mobilize into the atmosphere. Precipitation is formed when water vapor condenses; MPs suspended in the atmosphere flow into the lakes, oceans, or rivers as it rains or snows. Around 98% of MPs in human wastewater are retained in biosolids which are composed of organic matter recycled from sewage. These biosolids are reapplied to fields as fertilizer. This is the entry of MPs to the soil. Microplastics in soils are carried into the atmosphere by wind or they flow into the marine environments by agricultural wastewater. The plastic cycle is repeated over time. The global plastic cycle is more influenced by historical plastic emissions rather than the plastic emissions of the current years. Since the size of MPs is small, they are easily transported in the atmosphere and end up in precipitation in many different locations such as the Pyrenees mountains (Allen et al., 2019), Dongguan (Cai et al., 2017), Arctic regions (Bergmann et al., 2019), Hamburg (Klein and Fisher, 2019), San Paulo (Amato-Lourenco et al., 2022), Antarctica (Aves et al., 2022), New Zealand (Fan, 2022), and England (Kyriakoudes, 2023). These particles may enter the atmosphere through plastic aerosolization which is the process of MPs being transported from water bodies into the air.

Previous research has mainly focused on precipitation in Europe and large cities in the United States. More research is needed to identify and quantify MPs in falling precipitation in smaller towns. Since exposure to MPs is detrimental to human health, observing MPs in pure rain and snow in rural towns is necessary to explore. Cui et al., (2023) examined precipitation in Faribault, Minnesota (population 24,000) on January 16th, 2023, and observed MPs, including fibers and acrylic fragments, in rain samples. However, no MPs were found in 300 ml of falling snow. Since there were three precipitation events on January 9th, 11th, and 15th with 0.55 inch, 0.09 inch, and 0.1 inches of snow, respectively, before the snow collection, it was hypothesized that the precipitation might have washed out the MPs from the air, resulting in no MPs in the

snow sample. In a separate study (Moon 2023) investigated this, as well as whether the small volumes of precipitation collected in Cui et al., (2023) may affect whether MPs are detected. However, no MPs were detected in five 400 ml rain or snow samples. No precipitation was detected for 5 days before the snow collection. It's possible that the location of sampling sites may impact whether MPs are observed in precipitation. Klein (2019) observed more MPs under tree canopies in rural areas compared to urban areas. Therefore, we examined whether MPs are observed when larger precipitation samples are collected from a variety of locations including the center of a track field, on a roof, under a tree canopy, and next to a building.

Method

Four plastic-free stainless steel bowls were used to collect precipitation in the small city of Faribault, Minnesota. The bowls had a diameter of 18.5 inches with a height of 5.5 inches. To ensure there were no MPs in the bowl, we used a 25 ml glass syringe containing a mesh with an opening of 25 microns to filter out tap water. Then, MP-free water was used to wash out the stainless steel bowls. A chicken poultry net was used to cover the bowls when they were placed outside for the experiment. Before collection, the bowls were placed at room temperature upside down, covered with aluminum foil so that no other substances could enter the bowl.

The rain samples were collected from October 24 to 25, 2024. Four bowls were placed in four different areas: the roof, the middle of a track field, under a tree canopy, and next to a building. The bowls were covered with chicken poultry that had an opening size of 12 mm^2 to prevent leaves or other materials from coming in. Tent stakes for each side of the mesh put the bowls in place. Falling rain was collected overnight. Samples were poured into six jars that were provided by EMSL, each containing 500 mL. The snow samples were collected from 10 am on December 19 to 10 am on 20th, 2024. Four bowls were placed next to the building. The bowls were covered with mesh. To reduce contamination, when placing and getting the bowls back, the sample collector stood against the wind. Approximately 2 L of snow was collected throughout the experiment.

After collecting the precipitation overnight, the collected samples were stored in the refrigerator to minimize heat and other microorganisms from growing. Approximately 2.25 L of rain samples and six snow samples (400 mL each) were sent to the Environmental Molecular Sciences Laboratory (EMSL) for identification of the amount of MPs in the samples. All of the samples were analyzed by EMSL using Simultaneous Transmitted Polarized Light Microscopy (PLM), Darkfield Reflected Light Microscopy (RLM), and Fourier Transform Infrared Spectroscopy (FTIR).

Results

	Collection Information											MP Analysis Information				
Sample Name	START of Collection: Start Date	START of Collection: Start Time	END of Collection: End Date	END of Collection: End Time	Total Time (hrs)	Type of Precipitation	Location	Sample Volume (mL)	Temp Range (°F)	Wind Range	Preceding 5 days PRT Events (inch)	Sample Volume: Analyzed (mL)	Sample Volume: %	Microplastic Particles: # found	Microplastic Particles: Concentration (MPs/Liter)	Microplastic Particles: Description of MPs Found
SSMRW1	11/7 (2022)		11/8			Rain	Track	500	27-48	20-22	0.12	400	80	8	0.015	Acrylic,PET (2 MP range between 5-10µm, 4 MP range between 1000-5000µm)
SSMRW21	1/18 (2023)		1/19			Snow	Track	400	4-23	15-20	0.2	300	75	0	-	-
1	2/14 (2024)	5:00 PM	2/14	7:10 PM	2hr 10m	Rain	Track	500	7-28	14	0.09	400	80	0	-	-
2	2/14 (2024)	7:10 PM	2/15	2:12 PM	19hr 2m	Snow	Track	500	7-28	14	0.09	400	80	0	-	-
SSM1	4/1 (2024)	1:35 PM	4/2	9:25 AM	19hr 50m	Rain/Sleet/Snow	Track	500	27-49	13-22	0	500	100	0	-	-
SSM5	4/15 (2024)	12:33 PM	4/17	9:25 AM	20hr 52m	Rain	Track	500	33-56	15-26	0.03	500	100	0	-	-
SSM4	4/7 (2024)	12:00 PM	4/8	9:26 AM	21hr 26m	Rain	Track	500	30-52	17-23	0.45	500	100	0	-	-
1a+1b	10/24 (2024)	5:29 PM	10/25	10:30 AM	17hr 01m	Rain	Roof	700	32-55	15-18	0	180	25.7142	0	-	-
2a+2b	10/24 (2024)	5:29 PM	10/25	10:30 AM	17hr 01m	Rain	Track	800	32-55	15-18	0	370	46.25	0	-	-
3	10/24 (2024)	5:29 PM	10/25	10:30 AM	17hr 01m	Rain	Tree	250	32-55	15-18	0	60	24	0	-	-
4	10/24 (2024)	5:29 PM	10/25	10:30 AM	17hr 01m	Rain	Courtyard	500	32-55	15-18	0	190	38	0	-	-
51,52,53,54,55,56	12/19 (2024)	10:00 AM	12/20	10:00 AM	24hr	Snow	Courtyard	1500	11-28	15-21	0.01	410	27.333	243.54	0.594	Fiber,morphologies (87.56 MP range between 50-100µm; 145.95 MP range between 100-500µm)

: Cui et al (2023)

: Rain sample analysis by location

: Snow sample analysis

Table 1: Sample collection data [Cui et al, 2023, Moon, 2023 (unpublished), current study]

EMSL Rain Sample Analysis

No MPs were detected in rain samples from all four locations (Table 1). Results indicate that the location of the precipitation collection was irrelevant to whether MPs were detected. In addition, increasing the volume of the precipitation sample collected didn't affect whether MPs were observed in the samples. Precipitation at various locations was collected in greater volumes compared to Cui et al. (2023) and Moon (unpublished). It should be noted that from October 24 to 25th, 2024, sample volumes analyzed were less than 50% of the total volumes sent to EMSL. When questioned, EMSL indicated that less water was analyzed in samples containing a large amount of debris. Therefore, only partial volumes were analyzed by EMSL. The following figures (Figures 4-7) show other particles found in the rain samples such as mold, mineral grains, or dust.

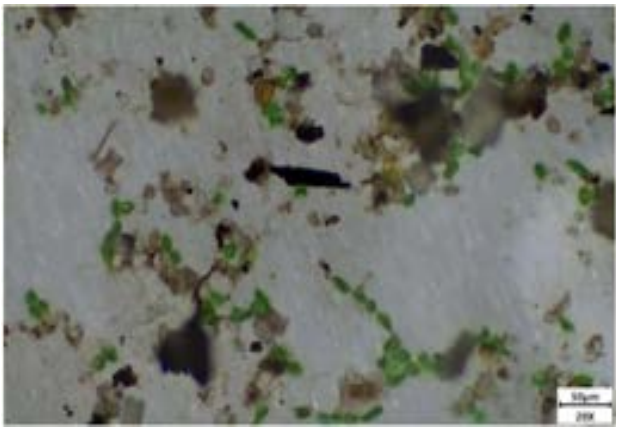

Figure 4.

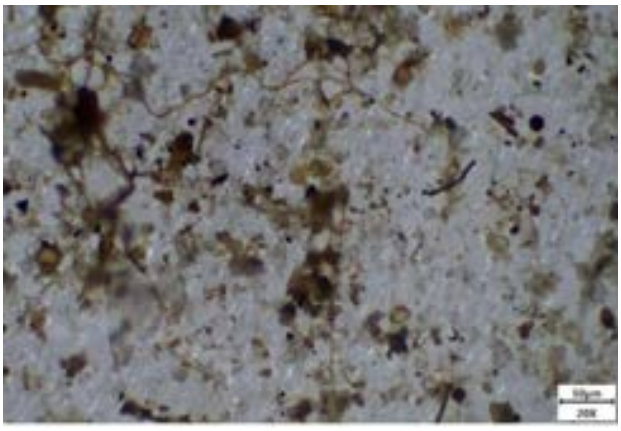

Figure 5.

Microscopic images showing algae, mold, diatoms, pollen, organic dust, char, and mineral grains in samples collected on the roof (Figure 4) and in the middle of the track field (Figure 5)

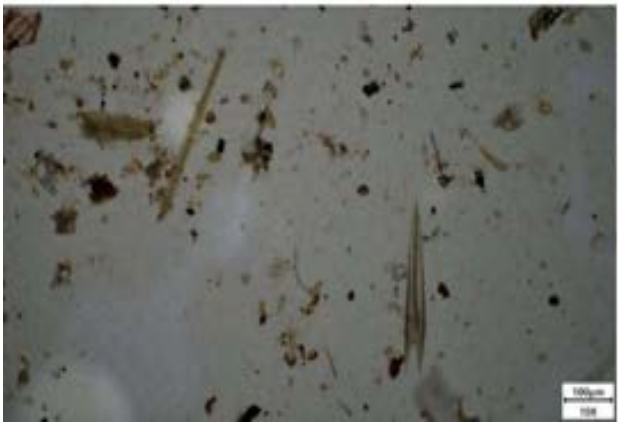

Figure 6.

Figure 7.

Microscopic images showing plant fragments, insect fragments, pollen, mold, diatoms, organic dust, and mineral grains in samples collected under the tree (Figure 6) and next to the building (Figure 7).

EMSL Snow Sample Analysis

Approximately 1.5 L of snow was collected on December 19 to 20th, 2024; however, only 410 mL of the sample was analyzed by EMSL. Approximately 243.54 MPs were detected from the snow samples (Table 1).

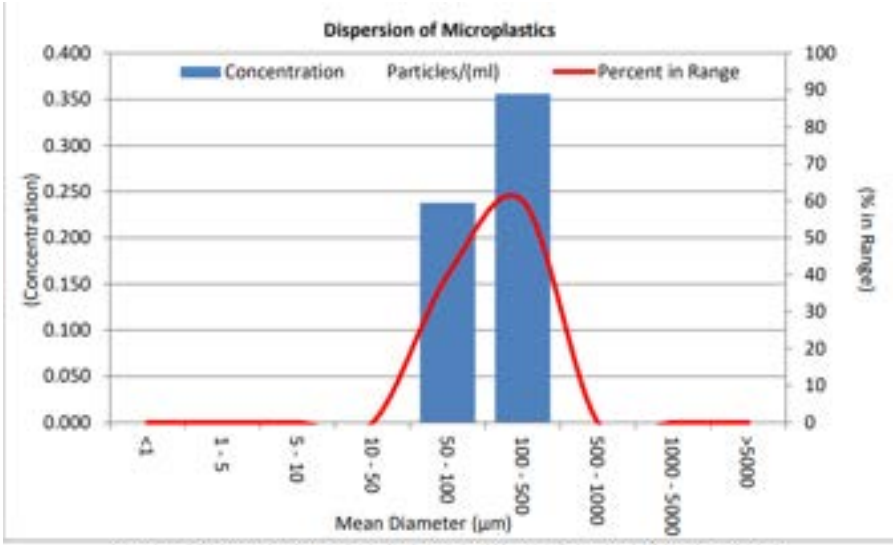

Figure 10: Histogram showing the particle size distribution of MPs in snow samples

Figure 10 shows the size distribution of the MP particles that were observed from the snow sample. Approximately 98 MP particles were observed with a size of 50 µm - 100 µm. The other

146 MP particles were larger, which had a size of 100 µm to 500 µm. Figure 11 is an image of the MP particles that were found in snow samples.

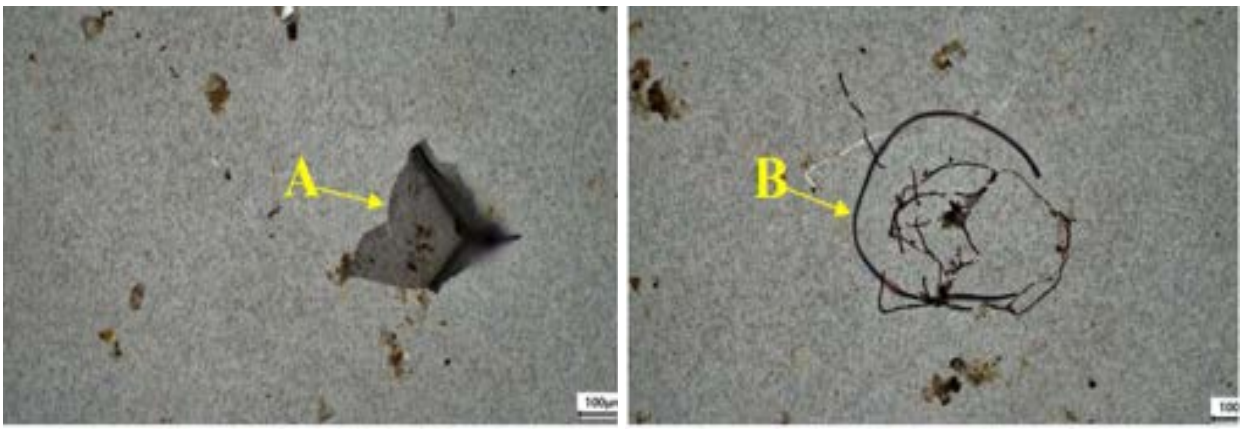

Figure 11: Microplastic images of snow samples showing microplastics of non-uniform (A) and fibrous (B) morphologies

Discussion

No MPs were observed in the precipitation samples from all four locations for the rain sample. Therefore, the results did not support our hypothesis that different sampling sites may affect the amounts of MPs detected in the precipitation. Cui et al., (2023) found MPs in rain samples that had no previous precipitation event, while Moon (unpublished) did not observe MPs in rain samples; precipitation amounts varied.

There were approximately 243.54 MP particles detected in the snow sample. There were no significant amounts of precipitation for the preceding 5 days before snow samples were collected on December 19 to 20th, 2024. In Cui et al. (2023), there were three prior snow events on January 9th, 11th, and 15th. On January 16th, when the snow sample was collected and analyzed afterwards, no MPs were found. It was suggested that prior precipitation events may wash out MPs from the atmosphere. These results indicate that snow may be a better scavenger for MPs. Lei (2004) suggests that snow is more effective in scavenging due to its larger surface area than rain. Therefore, MPs in the atmosphere will be attached to snow particles easily, leading to more MP detection from snow samples compared to rain samples. However, no MPs were observed in the mixture of rain/sleet/snow collected on April 1 with no previous precipitation events. Therefore, it is difficult to conclude whether previous rain or snow influences the amount of MPs detected in the snow samples. It is also possible that there might have been contamination of the samples from the cloth fibers or other small debris from the environment or researchers' clothing. In addition, as snow sampling was only done once, it is hard to confirm which factors may lead to MP detection from the samples. Samples were generally collected overnight for varying durations. If there were accumulations of the precipitation from various dates, samples collected might possibly be impacted by numerous atmospheric conditions, leading to different results. Environmental factors that may have affected our data collection include changes in temperature, wind range, and the duration of the precipitation, all of which could have influenced the sequestration of MPs in the falling precipitation.

There were limitations of this study in that EMSL was the only organization that analyzed precipitation samples. Sending samples to other facilities or lab organizations would allow comparison of the equipment or methods with EMSL and possibly look for the best ways to observe MPs in the samples. Moreover, EMSL partially analyzed the sample volumes, not all of the precipitation samples. It should be noted that from October 24th to 25th, 2024, sample volumes were analyzed for less than 50% of the total volumes sent to EMSL. When questioned, EMSL indicated that less water was analyzed in samples that contained a large amount of debris. This could have led to MPs that weren't detected from the remaining precipitation.

Methods used to collect precipitation and analyze for MPs differ greatly in this area of research. Hence, the next steps of this research should be to devise a standard sample collector. As there are no standardized equipment or methods used for this type of research, there should be a standardized way to collect and analyze the MPs in falling precipitation effectively, including the duration of precipitation sample collection or protocols for making MP-free water.

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