Land use and meteorologic influences on atmospheric deposition of microplastics in urban watersheds

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1. Introduction and project background

Anthropogenic microparticles, which are human-derived particles that are < 5 mm and include microplastics and other materials (e.g., semi-synthetic or natural microfibers from textiles), present ubiquitous threats to human and ecological health (Athey and Erdle, 2022; Rochman, 2018). Though early research on microplastic contamination focused on aquatic environments, research in the last decade has begun to explore other portions of the 'microplastics cycle', including the atmosphere, where airborne microplastics can be suspended and transported over large distances (Allen et al., 2021; Zhang et al., 2020). Both microplastics and other anthropogenic microparticles are prevalent in the atmosphere, and, in some cases, semi-synthetic or non-synthetic microfibers in the air are at higher concentrations than synthetic microfibers (Finnegan et al., 2022; O'Brien et al., 2023).

Fallout of airborne anthropogenic microparticles might be a significant source of these pollutants to various landscapes, with driving factors of spatial variation including land use and climate and driving factors of temporal variation including short-term weather fluctuations and varying human activity levels in populated areas (Beaurepaire et al., 2024; Dris et al., 2016; Leonard et al., 2024). Despite the potential significance of the atmosphere as a transport mechanism for microplastic movement in the environment as well as a concerning exposure mechanism for humans and other organisms, evaluations of atmospheric microplastics are still relatively limited (Abbasi et al., 2023; Wright et al., 2020; Zhang et al., 2020). Only a few studies have assessed atmospheric microplastics in North America, with no research yet conducted on microplastic deposition from the atmosphere in the central United States. Early North American studies have focused on remote areas (e.g., protected park areas; Brahney et al., 2020) and urban areas either much smaller (e.g., population < 1 million in suburban Tempe; Chandrakanthan et al., 2023) or larger (e.g., population > 20 million in Mexico City; Shruti et al., 2022) than St. Louis metro's population of ~2.8 million (Allen et al., 2022).

The goal of our research is thus to characterize microplastics and other anthropogenic microparticles in atmospheric fallout, assessing both spatial and temporal factors influencing their deposition in the St. Louis, Missouri, region. This report summarizes the major findings from one year of atmospheric deposition sampling near Deer Creek at the Litzsinger Road Ecology Center (LREC). We compare these findings to anthropogenic microparticle deposition rates at an urban site on Saint Louis University's (SLU) campus to understand spatial variation in atmospheric fallout.

2. Methods

2.1. Field methods

To assess anthropogenic microparticle deposition in the St. Louis region, we collected total atmospheric fallout (i.e., both wet and dry deposition) near Deer Creek at LREC from April 2023 to April 2024 and at a site on SLU's campus from June 2023 to April 2024 (Fig. 1A). Atmospheric fallout was collected with a steel funnel inserted into a glass bottle that was stationed at each of the sites (Fig. 1B-C) for approximately week-long intervals (Dris et al., 2016). Following the week-long deposition time, any contents stuck on the funnel for each site were rinsed into the glass sample bottle using a small volume (100 mL) of filtered distilled deionized (DDI) water. Bottles were then immediately capped to reduce contamination and transported to the laboratory for microparticle extraction.

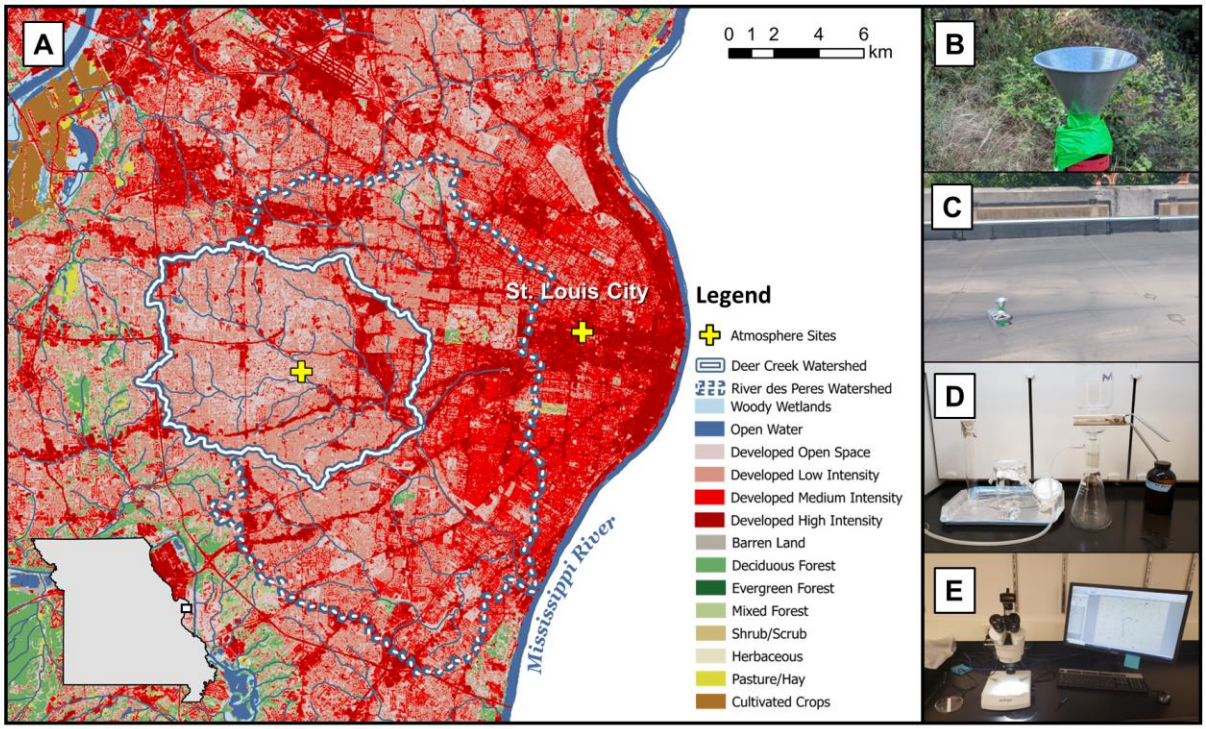

Figure 1. The atmospheric sampling sites in St. Louis on a (A) land use/land cover map (Dewitz, 2023), with the location in Missouri shown on the inset map. The Deer Creek watershed is outlined in solid white. Photos of (B) the sample collection apparatus at the suburban LREC site, (C) the sample collection apparatus at the urban SLU site, (D) the glass filtration system, and (E) the microscope set up for visual identification.

2.2. Laboratory analyses

Upon return to the laboratory, the samples were filtered through an all-glass filtration apparatus (Fig. 1D). Resulting filters were dried and the anthropogenic microparticles were visually identified (Fig. 1E) with criteria intended to isolate synthetic, semi-synthetic, and non-synthetic materials of human origin (e.g., dyed cotton fibers; Athey and Erdle, 2022). Our visual identification process had a lower size limit of 100 µm. The deposition rate for each sample in particles/m^2/day was calculated by dividing the anthropogenic microparticle quantities for each

sample by the area of the opening of the sampler systems (0.021 m^2) and the sampling interval in days (Zhou et al., 2017; Liu et al., 2022). Material types were analyzed using a Thermo Fisher Scientific Nicolet iN5 Micro-Fourier Transform Infrared (μ-FTIR) spectrometer for a ~7% subset of the microparticles (n = 65). Resulting spectra from the μ-FTIR analysis process were corrected with atmospheric suppression and compared to spectral libraries to determine the best match for material type. Only matches > 70% were accepted. When microparticles matched with cellulose but not a specific anthropogenic cellulosic material (e.g., cotton) or a specific natural cellulosic material (e.g., tree or grass fiber), they were classified as "undefined" if they were undyed or "anthropogenic" if they were dyed with a humanmade color.

To reduce contamination throughout the sample collection and processing steps, we covered all open sampling containers with aluminum foil, pre-filtered all working solutions, triple rinsed surfaces and glassware with filtered DDI water, and filtered samples under a fume hood. Bright green cotton attire was worn during sample handling, and bright green duct tape was used to attach the funnels to the sampling apparatuses to allow easy identification of contamination from any non-glass or metal items (Fig. 1B-C). Sampler blanks were collected using a clean steel funnel and glass bottle apparatus rinsed with 100 mL of filtered DDI water. They were then processed alongside the samples. Laboratory filtration blanks were obtained by filtering 1 L of prefiltered DDI water alongside atmospheric samples to assess any background contamination from the laboratory methods. Both blank types were used to calculate a limit of detection (LOD) for our method, which was the average of the blank values plus three standard deviations (Dawson et al., 2023; Table 1). Any deposition samples with microparticle quantities below the LOD were corrected to 0 prior to calculating the deposition rate, resulting in a deposition rate of 0 particles/m^2/day for those sample periods.

Table 1. Microparticles found in our blanks and the calculation steps for our method LOD.

Date	Blank Type	Total Microparticles (count)	Clear Fiber (count)	Blue Fiber (count)	Black Fiber (count)	Blue Fragment (count)
2023-07-21	Sampler Blank (Field)	5	4	1		
2023-06-15	Sampler Blank (Laboratory)	3	3			
2023-09-05	Sampler Blank (Field)	3	2		1	
2024-03-13	Laboratory Filtration Blank	3	2			1
2024-03-13	Laboratory Filtration Blank	3	1	2		
2024-03-27	Laboratory Filtration Blank	4		4		
2024-07-01	Laboratory Filtration Blank	3	2	1		
2024-07-05	Laboratory Filtration Blank	3	3			
	Average	3.38				
	Standard Deviation	0.74				
	Limit of Detection (LOD)	**6**				

2.3. Meteorologic data sources

Meteorologic data were collected from an Automated Surface Observing System (ASOS) unit located at St. Louis Lambert International Airport (STL; accessed at https://mesonet.agron.iastate.edu/ASOS/). Daily or sub-daily air quality data were collected from

the United States Environmental Protection Agency's (USEPA) AirNow repository (https://www.epa.gov/outdoor-air-quality-data/download-daily-data). Ozone, PM-2.5, and PM-10 data were obtained for the Blair Street station (295100085). Additional PM-2.5 data were obtained from the Ladue station (291893001), which is closer to our LREC monitoring site, but ozone and PM-10 data were not available from this station.

2.4. Data analysis

Statistical analyses were performed in R using non-parametric tests (i.e., Spearman's and Wilcoxon tests, where $\alpha = 0.05$). Figures were created using ArcGIS Pro Version 3.0.3., Microsoft Excel, and R.

3. Results and discussion

3.1. Anthropogenic microparticle deposition in the St. Louis region

At the suburban LREC site, the anthropogenic microparticle deposition rate varied over time (Fig. 2), with an average and standard deviation of 39.5 ± 46.0 particles/m^2/day (Fig. 3). However, deposition rates could be as high as 154.8 particles/m^2/day (see Fig. 2 in August 2023). Several samples from the LREC site were below the LOD (n = 18).

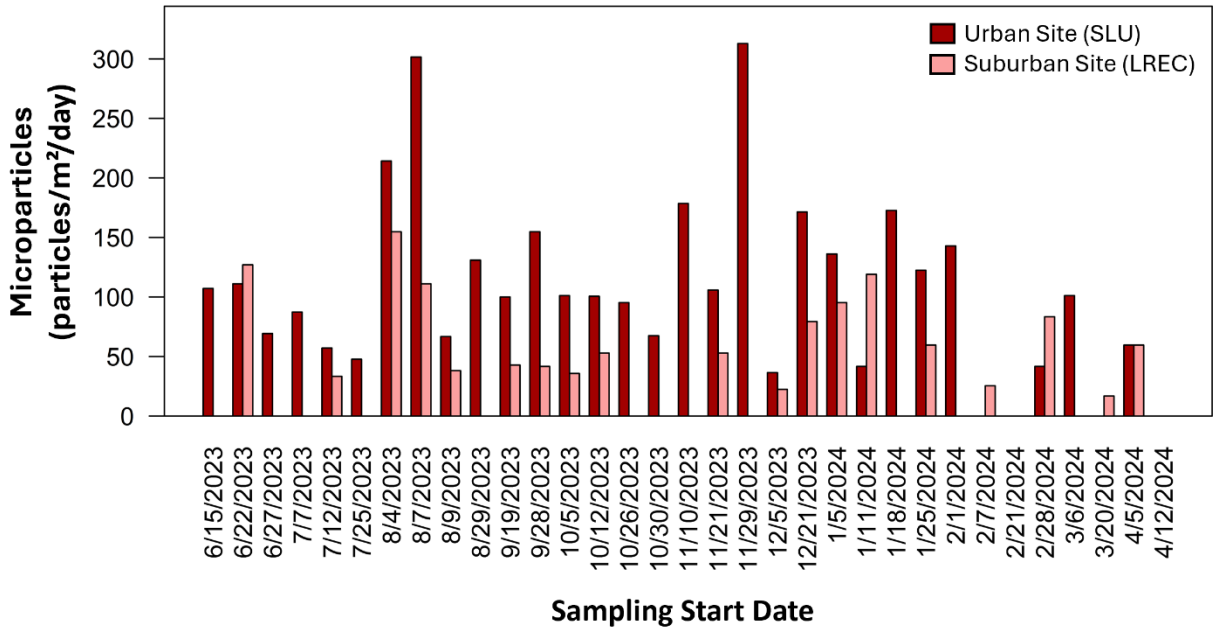

Figure 2. A comparison of anthropogenic microparticle deposition rates for the two sites between June 2023 and April 2024.

The urban SLU site had significantly higher anthropogenic microparticle deposition rates (average = 101.7 ± 72.1 particles/m^2/day) than the suburban LREC site (Figs. 2-3). It also featured only four samples below the LOD and a peak deposition rate of 312.9 particles/m^2/day (Fig. 2). No

relationship between anthropogenic microparticle quantities at the sites for overlapping sampling dates was observed (Spearman's $\rho = 0.14$ and $p = 0.44$).

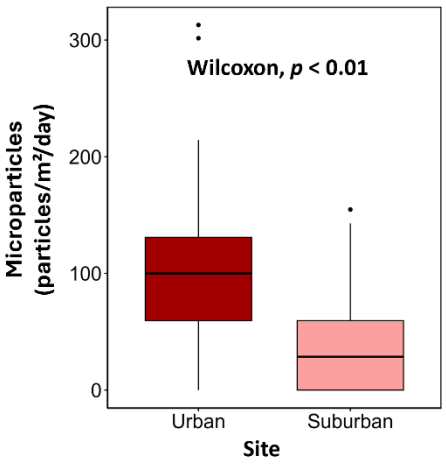

Figure 3. A comparison of the average microparticle deposition rate at each site, which shows significantly higher deposition at the urban SLU site compared to the suburban LREC site.

We found that > 90% of the materials deposited at the two sites were microfibers, and most were blue and clear in color. The average anthropogenic microparticle sizes at each site were essentially identical at 1158.3 ± 743.2 µm for the urban SLU site and 1110.8 ± 818.5 µm for the suburban LREC site. Correspondingly, the anthropogenic microparticle size distributions were similar between the two locations.

We found that the urban SLU site had a higher percentage of microplastics at 49% (compared to non-synthetic microparticles) than the suburban LREC site, which featured 41% microplastics (Fig. 4). Cotton and polyethylene terephthalate (polyester, or PET) were the most observed material types at both sites, including matches to specific PET types such as label fibers from shipping labels (Figs. 4-5).

Material types found in a subset of microparticles from the blanks were mostly cotton ($n = 3$) and one particle was PET ($n = 1$).

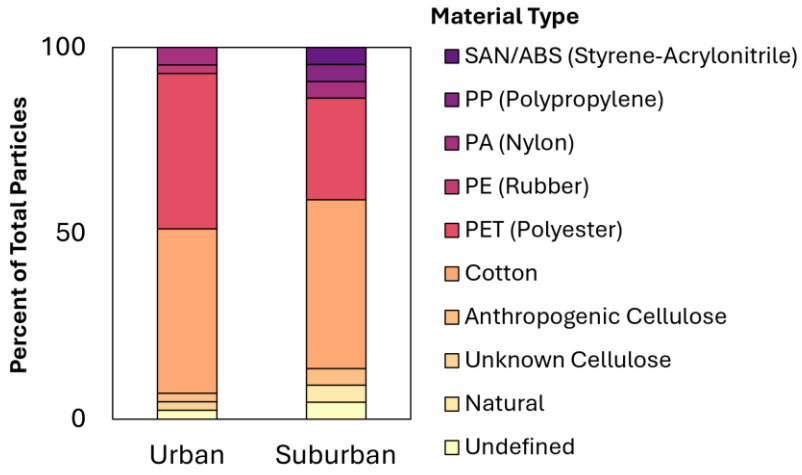

Figure 4. The material types identified at the urban SLU site and suburban LREC site using µ-FTIR.

The prevalence of microfibers in the deposition samples suggests that degradation of textiles and the subsequent release of microfibers from clothing might be a key source of microplastics into St. Louis's local atmosphere (De Falco et al., 2020). The higher levels of this microparticle morphology found at the densely populated urban SLU site support this idea.

3.2. Temporal variation in anthropogenic microparticle fallout and its relationship to atmospheric conditions

Microparticle deposition at both sites was significantly and positively correlated with the average relative humidity during each sampling period (Fig. 6). Other meteorologic (e.g., precipitation) and air quality (e.g., PM-2.5) parameters that we checked did not correlate with anthropogenic

microparticle deposition. We hypothesize that the correlation between anthropogenic microparticle deposition and relative humidity is due to the adsorption of atmospheric moisture onto these microparticles when humidity levels are high. This process can enhance the deposition of airborne microparticles (Leonard et al., 2024; Yuan et al., 2023).

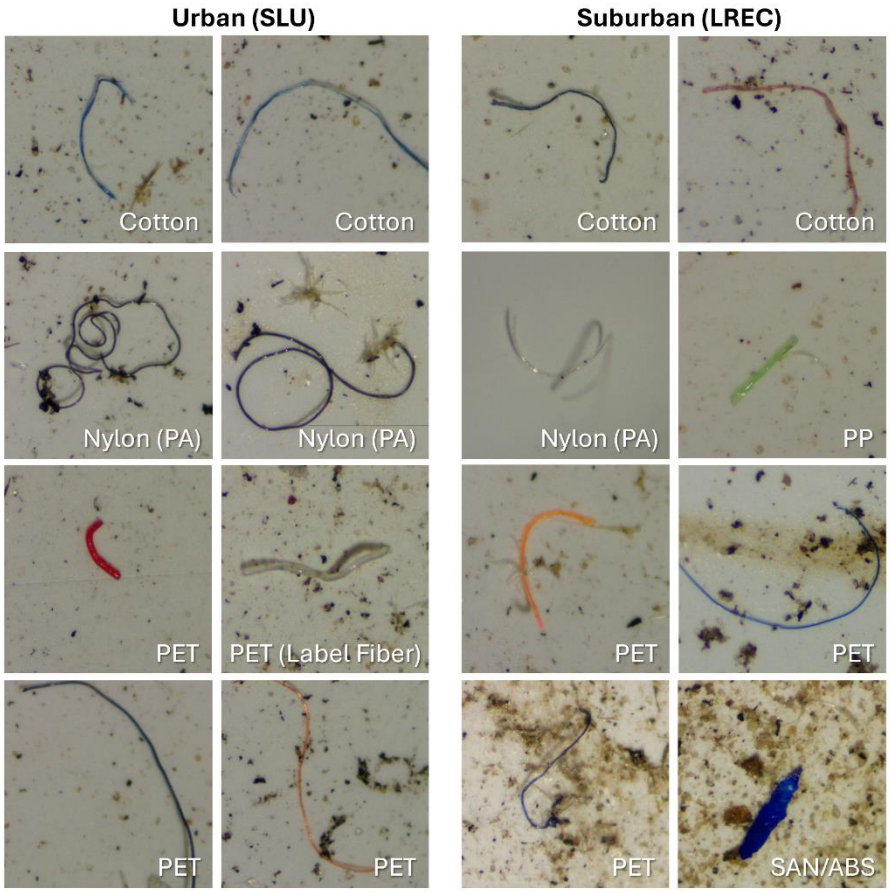

Figure 5. Examples of various material types identified at the urban SLU site (left) and suburban LREC site (right) using μ-FTIR. Figure 4 defines the polymer abbreviations.

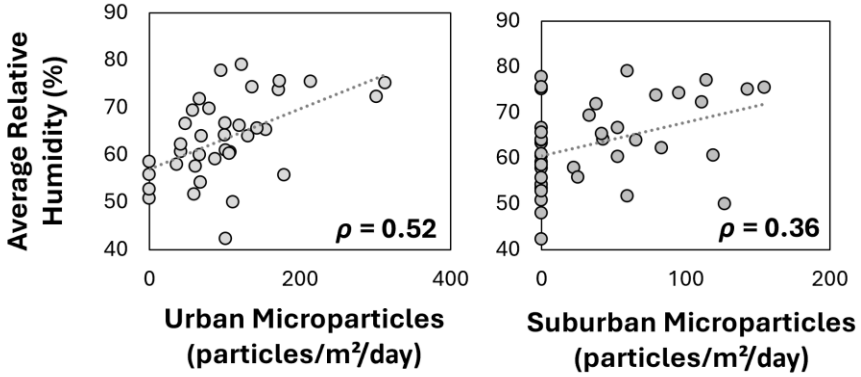

Figure 6. The relationship between the relative humidity averaged over each sampling interval and the corresponding anthropogenic microparticle deposition rate at the urban SLU site (left) and suburban LREC site (right), with Spearman's correlation coefficients (ρ) shown. All correlations were significant at $p < 0.05$.

4. Conclusions and need for future work

Our year of monitoring atmospheric deposition at the suburban LREC site demonstrated that, while atmospheric fallout does deposit up to hundreds of anthropogenic microparticles per square meter per day to the landscape, most of the year saw low deposition rates (< 100 particles/m^2/day) compared to the urban SLU site. We observed mostly blue and clear microfibers comprised of cotton and PET in the atmospheric deposition samples, with higher microfiber levels recorded in the more densely populated urban area. These findings suggest that a key source of airborne microplastics in cities may be the production of microfibers from the deterioration of textiles used for clothing. Once in the air, anthropogenic microparticles may be impacted by atmospheric conditions like humidity that promote the adsorption of moisture, leading to higher fallout of microplastics. Compared to prior studies, we found relatively low levels of anthropogenic microparticle deposition for the > 100-µm sizes we examined. However, previous research demonstrated higher quantities of anthropogenic microparticles in lower size ranges (e.g., 70% of the anthropogenic microparticles observed in atmospheric samples from Brahney et al., 2020, were < 25 µm). We would therefore expect atmospheric levels of breathable microparticles (< 25 µm) to be at higher levels than the deposition rates reported here. This point warrants further exploration as these breathable airborne microparticles could be a threat to human health (Maurizi et al., 2024).

5. Acknowledgements

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6. References

Abbasi, S., Jaafarzadeh, N., Zahedi, A., Ravanbakhsh, M., Abbaszadeh, S., Turner, A. 2023. Microplastics in the atmosphere of Ahvaz City, Iran. *Journal of Environmental Sciences*, 126, 95-102. https://doi.org/10.1016/j.jes.2022.02.044

Allen, S., Allen, D., Baladima, F., Phoenix, V.R., Thomas, J.L., Le Roux, G., Sonke, J.E. 2021. Evidence of free tropospheric and long-range transport of microplastics at Pic du Midi Observatory. *Nature Communications*, 12:7242. https://doi.org/10.1038/s41467-021-27454-7

Allen, D., Allen, S., Abbasi, S., Baker, A., Bergmann, M., Brahney, J., et al. 2022. Microplastics and nanoplastics in the marine-atmosphere environment. *Nature Reviews Earth & Environment*, 3, 393-405. https://doi.org/10.1038/s43017-022-00292-x

Athey, S.N., Erdle, L.M. 2022. Are we underestimating anthropogenic microfiber pollution? A critical review of occurrence, methods, and reporting. *Environmental Toxicology and Chemistry*, 41(4), 822-837. https://doi.org/10.1002/etc.5173

Beaurepaire, M., Gaseperi, J., Tassin, B., Dris, R. 2024. COVID lockdown significantly impacted microplastic bulk atmospheric deposition rates. *Environmental Pollution*, 344, 123354. https://doi.org/10.1016/j.envpol.2024.123354

Brahney, J., Hallerud, M., Heim, E., Hahnenberger, M., Sukumaran, S. 2020. Plastic rain in protected areas of the United States. *Science*, 368, 1257-1260. https://doi.org/10.1126/science.aaz5819

Chandrakanthan, K., Fraser, M.P., Herckes, P. 2023. Airborne microplastics in a suburban location in the desert southwest: Occurrence and identification challenges. *Atmospheric Environment*, 298, 119617. https://doi.org/10.1016/j.atmosenv.2023.119617

Dawson, A.L., Santana, M.F.M., Nelis, J.L.D., Motti, C.A. 2023. Taking control of microplastics data: A comparison of control and blank data correction methods. *Journal of Hazardous Materials,* 443A, 130218. https://doi.org/10.1016/j.jhazmat.2022.130218

De Falco, F., Cocca, M., Avella, M., Thompson, R.C. 2020. Microfiber Release to Water, Via Laundering, and to Air, via Everyday Use: A Comparison between Polyester Clothing with Differing Textile Parameters. *Environmental Science & Technology*, 54, 3288-3296. https://doi.org/10.1021/acs.est.9b06892

Dewitz, J. 2023. National Land Cover Database (NLCD) 2021 Products: U.S. Geological Survey data release, https://doi.org/10.5066/P9JZ7AO3

Dris, R., Gasperi, J., Saad, M., Mirande, C., Tassin, B. 2016. Synthetic fibers in atmospheric fallout: A source of microplastics in the environment? *Marine Pollution Bulletin*, 104, 290-293. https://doi.org/10.1016/j.marpolbul.2016.01.006

Finnegan, A.M.D., Susserott, R., Gabbott, S.E., Gouramanis, C. 2022. Man-made natural and regenerated cellulosic fibres greatly outnumber microplastic fibres in the atmosphere. *Environmental Pollution*, 310, 119808. https://doi.org/10.1016/j.envpol.2022.119808

Leonard, J., Rassi, L.A.E., Samad, M.A., Prehn, S., Mohanty, S.K. 2024. The relative importance of local climate and land use on the deposition rate of airborne microplastics on terrestrial land. *Atmospheric Environment*, 318, 120212. https://doi.org/10.1016/j.atmosenv.2023.120212

Liu, Z., Bai, Y., Ma. T., Liu, X., Wei, H., Meng, H., Fu, Y., Ma, Z., Zhang, L., Zhao, J. 2022. Distribution and possible sources of atmospheric microplastic deposition in a valley basin city (Lanzhou, China). *Ecotoxicology and Environmental Safety,* 233, 113353. https://doi.org/10.1016/j.ecoenv.2022.113353

Maurizi, L, Simon-Sanchez, L., Vianello, A., Nielsen, A.H., Vollertsen, J. 2024. Every breath you take: High concentration of breathable microplastics in indoor environments. *Chemosphere*, 361, 142553. https://doi.org/10.1016/j.chemosphere.2024.142553

O'Brien, S., Rauert, C., Ribeiro, F., Okoffo, E.D., Burrows, S.D., O'Brien, J.W., Wang, X., Wright, S.L., Thomas, K.V. 2023. There's something in the air: A review of sources, prevalence and behaviour of microplastics in the atmosphere. *Science of the Total Environment,* 874, 162193. http://doi.org/10.1016/j.scitotenv.2023.162193

Rochman, C.M. 2018. Microplastics research—from sink to source. *Science*, 360(6384), 28-29. https://doi.org/10.1126/science.aar7734

Shruti, V.C., Kutralam-Muniasamy, G., Pérez-Guevara, F., Roy, P.D., Martínez, I.E. 2022. Occurrence and characteristics of atmospheric microplastics in Mexico City. *Science of the Total Environment*, 847, 157601. https://doi.org/10.1016/j.scitotenv.2022.157601

United States Environmental Protection Agency (USEPA). 2024. Outdoor Air Quality Data. https://www.epa.gov/outdoor-air-quality-data/download-daily-data

Wright, S.L., Ulke, J., Font, A., Chan, K.L.A., Kelly, F.J. 2020. Atmospheric microplastic deposition in an urban environment and an evaluation of transport. *Environment International*, 136, 105411. https://doi.org/10.1016/j.envint.2019.105411

Yuan, Y., Li, S., Chen, T., Ren, J. 2023. Effects of ambient temperature and humidity on natural deposition characteristics of airborne biomass particles. *International Journal of Environmental Research and Public Health*, 20(3), 1890. https://doi.org/10.3390/ijerph20031890

Zhang, Y., Pu, S., Lv, X., Gao, Y., Ge, L. 2020. Global trends and prospects in microplastics research: A bibliometric analysis. *Journal of Hazardous Materials*, 400, 123110. https://doi.org/10.1016/j.jhazmat.2020.123110

Zhou, Q., Tian, C., Luo, Y. 2017. Various forms and deposition fluxes of microplastics identified in the coastal urban atmosphere. *Chinese Science Bulletin*, 62(33), 3902-3909. https://doi.org/10.1360/N972017-00956