SI 305 | Project Assignment: Final Report
Paige Wiaduck

Summary
As urbanization accelerates and the demand for potable water rises, Per- and Polyfluoroalkyl Substances (PFAS), are potential contributors to the declining quality of water sources. This analysis highlights the relationships between PFAS and some infectious diseases, as well as the PFAS concentration levels and sources. Notably, the strongest, positive correlation is associated with PFAS and the nucleocapsid and spike genes of respiratory disease SARS-CoV-2. The greatest PFAS concentrations are PFPeA and PFHpA and their respective sources: food packaging, couches, and carpets. The analysis highlights the potential health risks of consuming PFAS-contaminated water, as it can harm the immune system and infectious diseases are found in wastewater

Problem Diagnosis
Urbanization is the increase of human population concentration. This process involves the land transformation to accommodate residential, commercial, industrial, and transportation purposes as a result of urban growth.[1] As populations multiply, many people within an area share a water supply. It is essential to serve the public by understanding the underlying factors behind the different diseases present in a population. Many factors contribute to public health, and scientists explore how and why it may be affected negatively. The accessibility to clean drinking water is a benefactor to the standard needs of living and ensuring positive public health.

Common contaminants in city water systems are perfluoroalkyl substances (PFAS), also known as 'forever chemicals.' These chemicals are typically in items like non-stick cookware and fast-food boxes. Contamination occurs from manufacturing facilities, landfills, and fire-fighting foam runoff, either infiltrating groundwater or bodies of water. Their durable design makes it hard for PFAS to break down, leaving them to cycle throughout the environment and contaminating natural resources like water.[2] The prevalence of these substances carries concerns with human consumption. For instance, around 45% of tap water has one or more types of PFAS.[3] Residents are continuously exposed to these chemicals in their daily activities like cooking, cleaning, bathing, and drinking. Research involving the exposure to PFAS indicates that these chemicals suppress the immune system and increase the vulnerability to recurrent

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[1] ORD US EPA, "Urbanization - Overview," Collections and Lists, November 3, 2015, https://www.epa.gov/caddis-vol2/urbanization-overview.
[2] "Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water | American Association for the Advancement of Science (AAAS)," May 2, 2023, https://www.aaas.org/epi-center/PFAS.
[3] "Tap Water Study Detects PFAS 'Forever Chemicals' across the US | U.S. Geological Survey," accessed October 27, 2023, https://www.usgs.gov/news/national-news-release/tap-water-study-detects-PFAS-forever-chemicals-across-us.

infections.[4] Studies have observed higher exposures to PFAS are associated with more infections, furthermore supplementing the risk of chronic diseases or mortality.[5] This risk may have consequences on residents of all ages, especially ones living in city areas for a long duration of time. Therefore, these chemicals pose a dangerous risk on the public health for many communities nationwide.

Nowadays, 80% of Americans live in metropolitan areas, and the issue of pollution is a reality evident in urban streams.[6] Specifically, Ann Arbor water is taken locally, where "approximately 85% of the water comes from the Huron River."[7] As water cycles between the treatment plant, residential use, and the Huron River, the City of Ann Arbor and the WasteWaterScan regularly record and monitor the water to evaluate public health. Relying on the Huron River for water, it is plausible that the city's water supply could influence the well-being of the residential population. An exploration in water quality has the potential impact for researchers, government officials, and local residents to take action.

Research Questions

1. How do the PFAS found in drinking water relate to the likelihood of having infectious and non-infectious diseases in wastewater?
2. On average, which PFAS are the most contributing factor to prevalent infectious and non-infectious diseases per season?
3. How does urbanization affect our drinking water quality in the means of PFA types and their sources?

Analysis for RQ1

Present your findings

In research question one, the analysis focuses on the relationship between PFAS in drinking water and infectious diseases in wastewater. Due to the lack of data on non-infectious diseases, the evidence is limited to these specific relationships. The likelihood of each infectious disease is calculated using Pearson's r-statistic and p-values, with individual linear regressions plotted. While there are limitations and uncertainties, such as the inability to establish causation and oversimplification of health conditions, the correlations still provide insights. Overall, the sums

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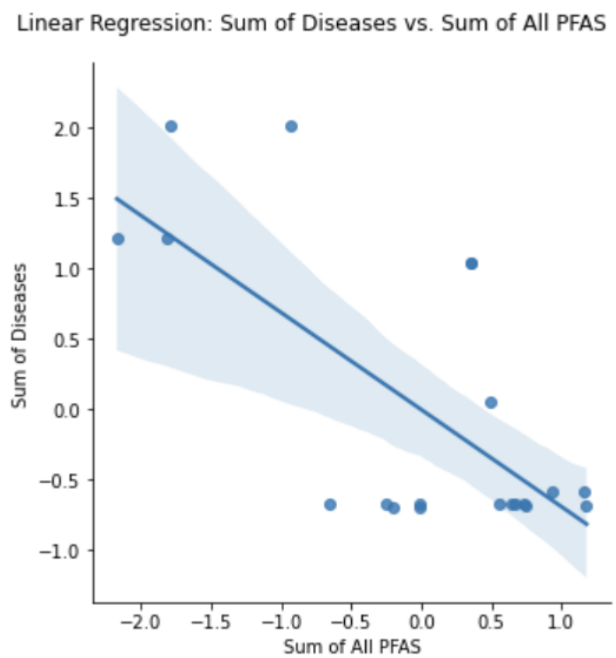
[4] Catherine M. Bulka, Vennela Avula, and Rebecca C. Fry, "Associations of Exposure to Perfluoroalkyl Substances Individually and in Mixtures with Persistent Infections: Recent Findings from NHANES 1999–2016," *Environmental Pollution* 275 (April 15, 2021): 116619, https://doi.org/10.1016/j.envpol.2021.116619.

[5] Catherine M. Bulka, Vennela Avula, and Rebecca C. Fry, "Associations of Exposure to Perfluoroalkyl Substances Individually and in Mixtures with Persistent Infections: Recent Findings from NHANES 1999–2016," *Environmental Pollution* 275 (April 15, 2021): 116619, https://doi.org/10.1016/j.envpol.2021.116619.

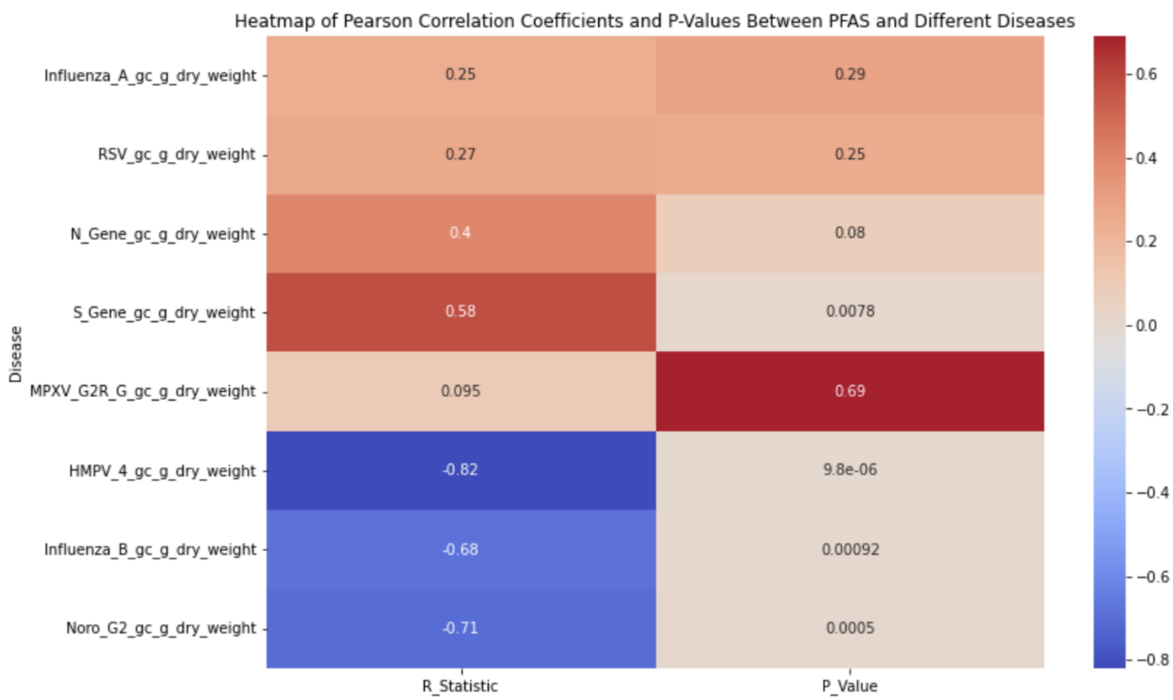
[6] "Effects of Urban Development on Stream Ecosystems in Nine Metropolitan Study Areas across the United States | U.S. Geological Survey," accessed October 27, 2023, https://www.usgs.gov/publications/effects-urban-development-stream-ecosystems-nine-metropolitan-study-areas-across.

[7] "Water Supply, Treatment, and Distribution," accessed October 27, 2023, https://www.a2gov.org:443/departments/water-treatment/Pages/Water-Supply-and-Treatment.aspx.

of PFAS and infectious diseases show a negative relationship, contrasting to some relationships viewed individually. The most prominent infectious diseases are respiratory illnesses like SARS-CoV-2's RNA from its nucleocapsid and spike (N Gene and S Gene). SARS-CoV-2 has the strongest positive linear relationship and significance from its Pearson r statistics and p-values. Similarly, Influenza A and Respiratory Syncytial Virus (RSV) have positive correlations, but a lower significance. This is weaker evidence than SARS-CoV-2, but important to consider. On the other hand, Human metapneumovirus (HMPV), Influenza B, and Norovirus show negative linear relationships. The monkeypox virus (MPXV) is unique with almost no linear relationship, indicating its rarity in the presence of PFAS in drinking water. The general negative link between PFAS and diseases may be influenced by the absence of linear correlations or strong negative linear correlations at specific infectious diseases' individual levels.



The negative relationship between the sum of all diseases in wastewater and the sum of all PFAS in drinking water suggests a weak possibility that when PFAS are present in drinking water all diseases are present in wastewater.



This heat map shows the strength and significance denoted as the Pearson r-statistic and p-value for individual infectious diseases in wastewater and the sum of PFAs in drinking water.

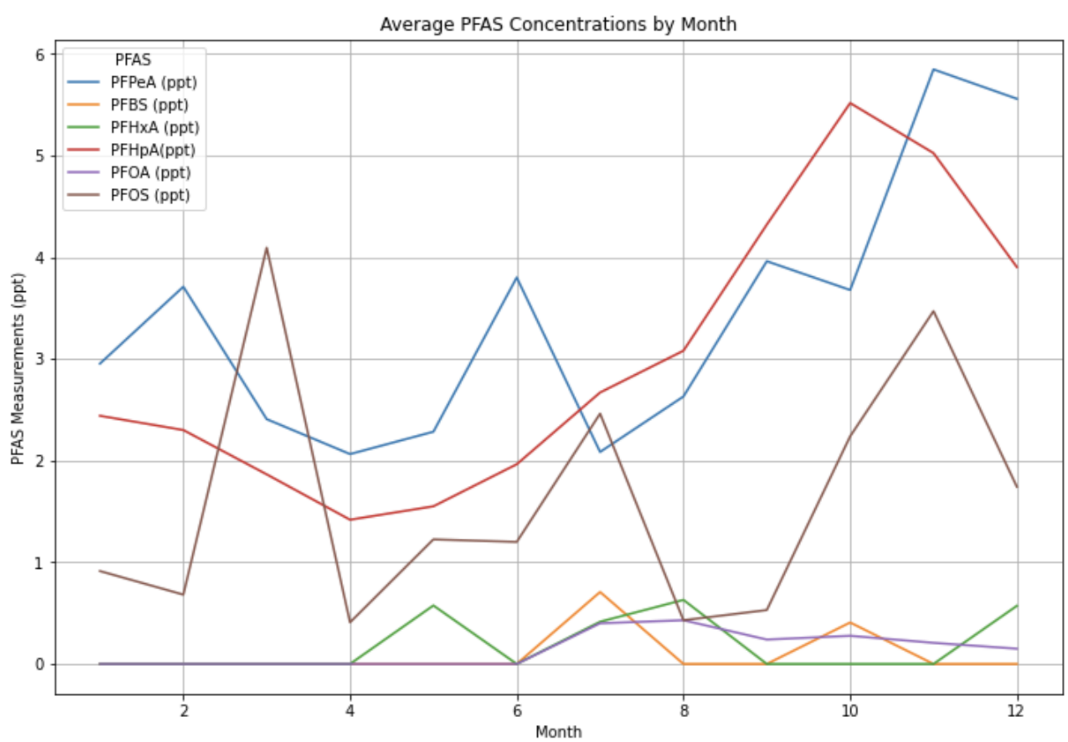
Interpret your findings

The quantitative measures found in research question one reflect the real-world possibility of infectious diseases being found in wastewater when PFAS are present in drinking water. With PFAS ability to suppress the immune system, the statistics from the research seem plausible. The analysis shows the likelihood of infectious diseases is apparent with PFAS contaminating drinking water, especially with some infectious diseases like SARS-CoV-2. This may be due to the varying complexity of biological mechanisms or the sample variability from the data provided. The diseases with a positive relationship give insight towards the possible consequences of intaking PFAS daily. The observed correlations deviated slightly from anticipated expectations, as stronger and positive relationships between the variables were expected more. The findings do support that PFAS water contamination reduces water quality because of its negative health implications from the possible byproduct of infectious diseases collected in wastewater. Knowing which diseases are prevalent can support research questions two and three narrowing down the analyses. Also, the information collected from the first research question can provide guidance towards manufacturers, engineers, and policy makers to improve production processes, product materials, and eco-friendly use of daily products.

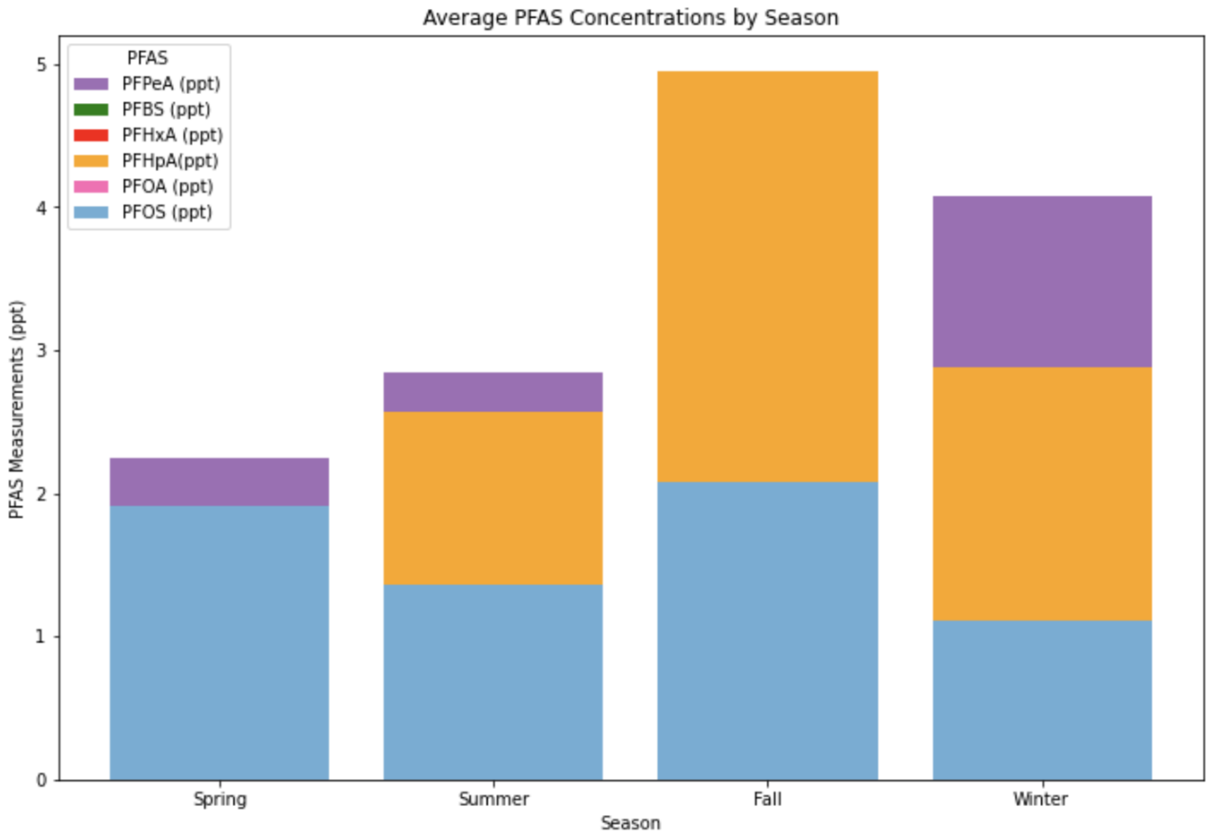
Analysis for RQ2

Present your findings

The PFAS in drinking water will not have any effect on non-infectious diseases per the findings from research question one. Rather, the most prevalent PFAS possibly contributing to the infectious diseases in wastewater per season are PFPeA and PFHpA. In the fall, PFHpA is recorded on average of about 4.95 parts per trillion. In the spring, summer, and winter, PFPeA is recorded on average the most with about 2.25, 2.84, and 4.07 parts per trillion respectively. It is clear that the fall and winter in Ann Arbor, MI have higher recordings of these PFAS on average. This finding also matches the temporal trend of all PFAS which peaks during the fall months, specifically during November. Similarly, PFPeA and PFHpA are the largest overall in October and November in the individual temporal trends. This analysis solely demonstrates the temporal variability of PFAS, so there are some limitations and uncertainties to mention. For instance, PFAS concentrations may change over time from external factors likeweather, human activity, and population changes. Ann Arbor is a college town, so there is a possibility that certain PFAS are higher on average from university activity and an increase in the population from students. These alternative factors may have influence, however, the seasonality from this analysis is still conclusive.



The line plot displays the average PFAS concentrations by month, specifically the large measurements of PFPeA and PFHpA during the fall season.



The bar plot depicts the average concentration per PFA by season, especially the large measurements of PFPeA in the spring, summer and winter seasons and the large measurements of PFHpA in the fall season.

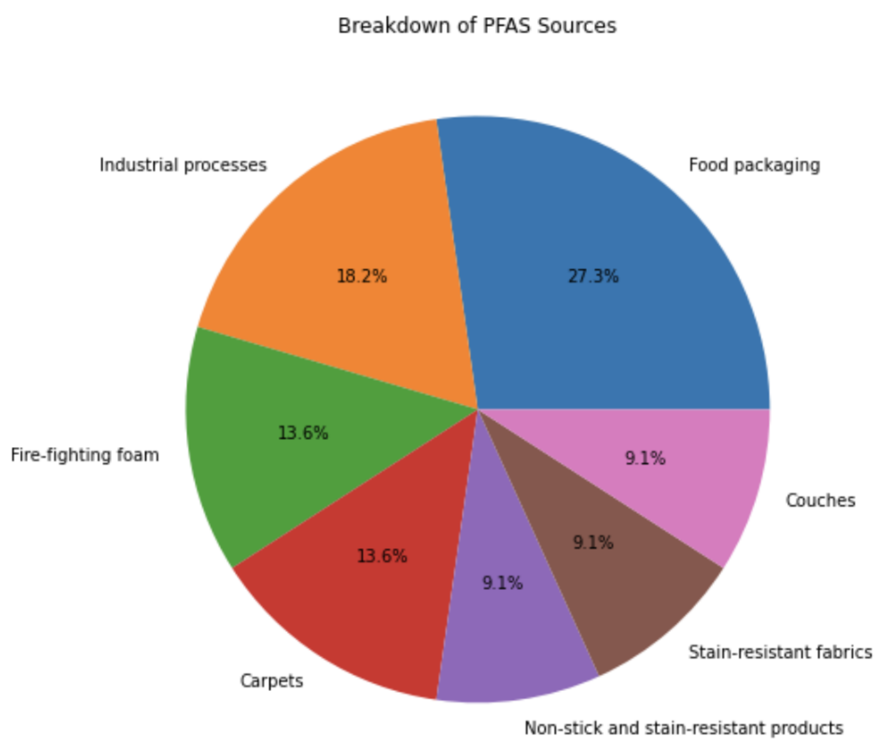
Interpret your findings

The quantitative measures in research question two reflect environmental exposure and health impact in humans. Specifically, this research question analyzes which PFAS are the most prevalent in drinking water and how their variation over time changes in the real world. The findings from this analysis surprised me with the potency of PFPeA (ppt). Although PFHpA had a greater magnitude for the fall time, PFPeA came close with about a 0.46 parts per trillion difference. Anticipating greater variability among the six PFAS, the conclusions drawn from research question two provide valuable information for the subsequent investigation. The two highest contributing PFAS will be used in research question three to define the major sources of these specific PFAS. Similar to research question one, the higher concentration of PFPeA and PFHpA provide evidence to officials to regulate drinking water and the pollution rates in urban areas. This action has the ability to improve Ann Arbor's water pre-treatment for these specific PFAS. Also, this analysis may be evidential to continuous research about PFAS exposure since they are a recently invented chemical.

Analysis for RQ3

Present your findings

The analysis of research question three shows the source distribution of PFAS sources overall, and the distribution between the PFAS with the greatest potency: PFPeA and PFHpA. On average, PFPeA has 3.41 parts per trillion recordances where PFHpA has 3.00 parts per trillion recordances in drinking water. It is clear that PFPeA is the greatest source of PFAS contamination in drinking water, however, the 0.41 parts per trillion difference is little compared to the other PFAS at the averages of 1.62 and about 0.1 parts per trillion. Furthermore, the analysis shows the top sources of PFAS contamination are food packaging, industrial processes, fire-fighting foam, and carpets. The overall PFAS source breakdown follows the expectations with food packaging products as the major source. Focusing on PFPeA and FHpA, their source distribution was equal parts food packaging, couches, and carpets. With this research question's analysis, there are uncertainties and limitations such as the inability to directly differentiate the specific contamination pathways or products. Some sources may overlap in areas like non-stick, stain-resistant fabrics, and couches. Although this analysis provides value for PFAS water contamination, the broad categorical levels are a limitation. The analysis also cannot incorporate external factors such as the efficiency of treatment facilities in removing PFAS, unique human behavior, and the populations' usage of products.



The pie chart shows the overall breakdown of all PFAS sources, denoting food packaging as the largest source.
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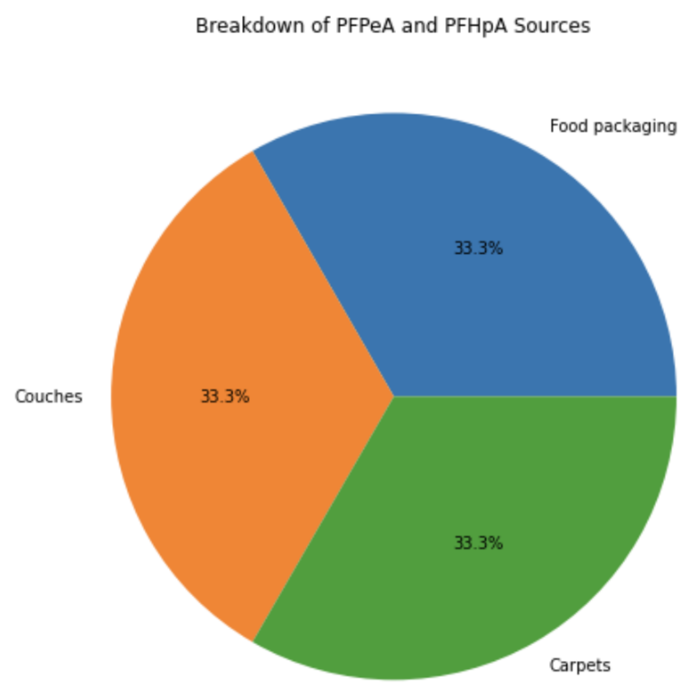

The pie chart portrays the source breakdown of PFPeA and PFHpA, showing an equal distribution between food packaging, couches, and carpets.

Interpret your findings

The quantitative measures from the distribution of PFAS sources reflects the real-world complexity of drinking water contamination. There are multiple sources for contamination, but this analysis summarizes the challenges of the diverse factors influencing PFAS contamination. The identification of sources and their respective PFAS indicates where contamination may root therefore proving their abundance in the environment. PFPeA and the PFHpA sources being products of a household setting align with the expectations of common source contributors being products used daily by citizens, especially in a densely populated city. On the contrary, the lower rank of non-stick and stain-resistant products conflicted with the expectations as these may include daily-used items such as cookware and cleaning products. This research completes the understanding behind the water cycle by explaining what PFAS enter water, pass through humans, and what ends in the wastewater as a byproduct. Thus, findings are a foundation for further research beyond this exploratory analysis, regulatory considerations, and evidence for decision-making relevant to future PFAS development. Although most PFAS did not exceed the current Michigan Contaminant Levels, the information can still be influential towards lowering the current Michigan Contaminant Levels for PFBS, PFOS, PFOA, and PFHxA, and provide direction for creating legal contaminant levels for PFPeA and PFHpA.[8]

[8] "PFAS Maximum Contaminant Levels (MCLs) and Drinking Water," accessed November 16, 2023, https://www.michigan.gov/PFASresponse/drinking-water/mcl.

Conclusions: Recommendations

Recommendation 1: Sustainable Food Packaging

Audience: Ann Arbor policymakers

The first recommendation is to regulate food packaging to be PFA-free. As Ann Arbor, MI is a highly developed area including residential, commercial, and university areas, the recommendation is for policymakers to implement a regulation for local restaurants and shops to use eco-friendly food packaging that does not contain PFAS. As the analysis portrays that food packaging is a major source of PFAS both overall and for the leading specific PFA contaminants, eliminating the unnecessary packaging in local places will further reduce the possibility of the forever chemicals infiltrating water sources for consumption. With the university, numerous restaurants, and various stores the total commercial consumption of PFA products will drastically decrease. This will control external factors such as human behavior and usage of products that are unsustainable discussed in research question three. This action has the potential to lower the PFAS concentrations found in drinking water sources, therefore decreasing the ability for PFAS to compromise citizens' immune systems and pose negative health consequences.

Recommendation 2: Sustainable Practices in Industrial Processes

Audience: local industries and business, local government officials

The second recommendation is to encourage sustainable practices in industrial processes, especially in regards to manufacturing and pollution. Local government officials overseeing industrial practices can incentivize businesses and industries to refrain from using PFAS in their production processes and stop the release of PFAS into nearby bodies of water through dumping or pollution-like operations. This recommendation will reduce the amount of PFAS being produced and passed to human consumers . The physical volume of waste exposed to water sources that are used for drinking water will decrease too. Developing incentives before regulation will be an easier transition towards the goal to full PFAS abandonment. This process will also slow development of new PFAS if industries deter from their use as a byproduct of the incentivization. Decreasing the overall amount of PFAS used in the industrial practices will actively diminish the consumption of contaminated water. Therefore, human exposure to cleaner water will reduce the possible negative effects on the immune system and negative health implications like infectious diseases.