The threat of landfill leachate contamination for groundwater and well water sources.

By

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Abstract:

As Earth's population hits eight billion, waste management or the proper disposal of solid material is crucial for the sanitation and environmental health of the planet. Landfills have been used as a tool for waste management for centuries. Modern landfills are engineered to bury solid waste and protect the soil and subsurface groundwater from contamination through the mechanics of plastic and clay liners. The contamination associated with landfills includes high levels of methane release, which is a hazardous greenhouse gas, and leachates, commonly known as "trash juice". Leachates are the liquid by-product of buried waste from developed moisture, which, if secreted into the soil and groundwater, can cause significant pollution to aquifers, leading to contaminated drinking water for those using private wells as a source of freshwater. Leachates often contain multiple contaminants, including lead, iron, Per- and poly-fluoroalkyl substances (PFAS), and other heavy metals (Han et al., 2016). Michigan has approximately 126 active and closed landfills. Closed landfills can continue threatening groundwater due to leachate pollution 25 years post-closure (Kjeldsen et al., 2002; Renou et al., 2008). It is known that approximately 45% of Michigan residents use private wells as their primary source of drinking water (Steinman et al., 2022). Private wells near a landfill can cause adverse health effects to many residents who rely on those wells for freshwater, due to leachate pollution. The research associated with this study aims to evaluate the groundwater quality of well sites near landfills across Michigan and determine the extent of leachate pollution affecting these freshwater sources. From this, analyze the available water quality data to understand whether leachate pollution is more likely to occur in wells near landfills. The geographic information system software ArcGIS assisted in visualizing the location of landfills in relation to private wells and the United States Geological Survey (USGS) well sites in Michigan. USGS well sites were included in this research due to the lack of private well water quality data. This analysis discusses the increased risk specific Michigan communities face by living near a landfill and the public health risks associated with leachates. We also discussed ways to decrease the use of landfills and sustainably dispose of waste material to protect and mitigate harm to our freshwater drinking sources.

Introduction:

Our planet is approaching its highest global population yet, with approximately 8 billion people currently and an expected 11 billion by 2050 (Current World Population). As the human population grows, the expectation is that much more waste will be generated (Alves, 2023). Landfills historically have been used as a form of waste management dating back as far as 3,000 B.C. (Rihn, 2016). As the total population increases solid waste globally, better waste management efforts and innovations are imperative to protect the environment. Countries globally face many challenges in implementing sanitary and effective waste management systems (Ferronate & Torreta, 2019). Open dumpsites, burn pits, and unlined landfills represent the difficulty in managing waste disposal infrastructure, found in many developing nations. Countries like Ghana and India grapple with the weight of electronic waste (e-waste) as new technology continues to be mass-produced and discarded yearly (Tamba et al., 2021). Open dump sites are common in developing countries as they are a cost-effective disposal method for many countries that do not have adequate waste collection systems (Peter et al., 2019). "Roughly 40 percent of the world's waste ends up in open dumpsites, particularly in cities found in middle and lower-income countries" (Open Dumping). However, modern landfills are the predominant form of waste management for developed countries due to stricter regulations and enforcement for sanitary disposal (Srivastava, 2013). Modern landfills are often highly engineered facilities with systems in place to protect the surrounding soil and groundwater. These environmental protection systems include a gas collection system to absorb the methane produced from a landfill, and a leachate collection system. Leachates are a highly concentrated liquid that forms as rainwater percolates through the waste, dissolving harmful chemicals and materials, and then infiltrates the groundwater" (Lee et al., 1993). Leachate pollution can contribute to fatal health effects for humans and surrounding biodiversity from contaminants like PFAS, lead, iron, arsenic, and other heavy metals. Regulation of leachates has not always been consistent in developed countries, and many countries still suffer from polluted freshwater due to landfill contamination. A South African study found that "More than half of the participants (56%) living close to a landfill indicated fear of their health in the future" (Njoku et al. 2019). Similar research across the European Union identified leachate pollution from wells near small municipal solid waste landfills and found that the "deterioration of the chemical status

in the quality of the groundwater within the landfill area was a consequence of the lack of efficiency of the existing drainage system, which may result from the 19 years of its [the drainage system] use" (Przydatek G & Kanownik W, 2019). Their research indicates that the drainage systems utilized in these municipal landfills to remove leachates from landfills were not sufficient to mitigate leachate pollution from reaching nearby wells. Such findings highlight the ongoing environmental risks associated with landfills despite advancements in modern engineering.

The research associated with this study aims to evaluate the groundwater quality of well sites near landfills across Michigan and determine the extent of leachate pollution affecting these freshwater sources. The study also aims to recommend better regulatory measures pertaining to waste management and groundwater.

Waste Management and Landfills across the United States

Landfills are the predominant method for managing municipal solid waste throughout the United States (_Sustainable Materials Management_). Most citizens' interaction with waste management often extends no further than the routine weekly trash collection provided by their local city or county. This minimal involvement is attributable to the development of a robust waste management infrastructure in the United States following the enactment of the Resource Conservation and Recovery Act (RCRA) in 1976. The RCRA became the nation's primary law to govern the disposal of solid and hazardous waste (History of the Resource Conservation and Recovery Act). Before the RCRA, open dump sites, trash dumping in surface water bodies, and unlined landfills were common practices in the United States. Currently, waste management responsibilities broadly fall under the guidance of individual states. Despite many improvements in waste management since the inception of RCRA, the volume of waste generated annually continues to escalate, causing more difficulty in managing sanitary disposal practices (Anuardo et al., 2022)

In 2021, 51,990,037 cubic yards of total waste was disposed of in Michigan (Report of Solid Waste Landfilled in Michigan). The EPA found that 4.9 pounds of trash is collected per person per day (National Overview: Facts & Figures). With such high amounts of trash being disposed of daily, how are landfills able accommodate such vast quantities of waste? Michigan

law mandates that all landfills are registered and approved by the state, accompanied by an application fee ranging from $1,500 to $3,000, depending on the landfill type. There are three main types of landfills: Type 1 for hazardous waste materials, Type 2 for municipal solid waste, and Type 3 for industrial waste (How landfills work). Type 1 facilities collect hazardous materials, encompassing byproducts of industrial waste, which may include specific solvents and chemicals. Type 2 landfills, the most common type, primarily handle municipal solid waste, accepting a wide range of materials, including furniture, food waste, and other commonly discarded items. Type 3 landfills, on the other hand, specialize in industrial waste, such as construction and demolition debris sourced from roads, bridges, and construction sites. Each type of landfill must comply with federal and state regulations, which require incorporating environmental protection systems such as drainage systems and plastic or clay liners to protect soil and groundwater. (Requirements for Municipal Solid Waste Landfills). These liners create a "dry tomb" to prevent moisture and leachates from infiltrating the subsurface. The drainage system pumps the leachate from below the landfill back to the surface to be discarded. Often, the leachate pumps only go as deep as the first layer of liners leaving some pollution to collect deeper within landfill (Adamcová et al. 2017; G. Lee et al. 1991). In Michigan, a bottom liner layer is not required if the site's soil material is already equipped with at least 10 feet of natural low permeability clay (How landfills work). The construction of a landfill, from its liners to the pipes, is essential to protecting groundwater from leachate contamination. While landfills today are heavily civil-engineered operations, contamination is always possible (Madon et al., 2020). As moisture develops from the precipitation that falls onto the landfill and seeps into the ground, it combines with the deteriorating trash, producing heavily toxic chemicals. The toxic chemicals can cause corrosion of the landfill liners and subsequently leak the leachates into our groundwater (Madon et al.,2020). In a 1993 study, approximately 75% of the then 55,000 landfills in the United States were found to have polluted water near them (Lee et al., 1993). The number of landfills has drastically decreased since then, with an estimated 1,250 municipal landfill facilities in the United States as of 2022 (Tiseo, 2023).

The advancement of federal waste management regulation has been significant since the inception of the RCRA. During the Industrial Revolution, the United States witnessed unprecedented industry, infrastructure, and consumerism growth, resulting in widespread pollution, substantial waste generation, and even rivers catching fire due to industrial pollutants.

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In response to these environmental hazards, policymakers recognized the urgent need to safeguard public health and the environment by establishing regulatory frameworks towards the end of the 18th century. The Solid Waste Disposal Act of 1965 is considered the first solid waste management Act for the United States. In 1976, the EPA amended this act with the Resource Conservation and Recovery Act. The RCRA's inception allowed states to control and manage their waste while remaining accountable for its environmental impact (Municipal Solid Waste Landfills). Michigan dealt with a similar trajectory in implementing a policy for waste management. In the 1970s, Michigan's nine million residents produced an estimated 26,000 tons of general waste and 130 tons of hazardous waste daily. Michigan's Solid Waste Management Public Act was passed in 1978, which mandated stricter landfill regulations (Solid Waste Management). The 1982 amendment of Michigan's Solid Waste Disposal Act defined "disposal" as "the discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including ground waters" (Solid Waste Management). Solid waste was defined differently as "Any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities, but does not include solid or dissolved materials in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges" (Slater, 1986). These definitions clarified the necessary policy enforcement for industries operating in waste disposal (Slater, 1986). Legislation about solid waste has continued to be amended, updated, and changed at the federal and state levels for decades.

Despite legislative efforts, challenges persist. Landfill leachates contain many chemicals that can harm groundwater quality, including emerging compounds not regulated by the EPA (Eggen et al., 2010). This poses significant health risks, as even trace amounts of pollutants can be harmful over time. For leachate contamination, "the variability of the chemical composition of the leachate depends on many factors, including, in particular, the original composition of the deposited waste and its various chemical substances, and the chemical and biochemical reactions that may occur when the waste decomposes" (Fatta et al., 1999). Largely ignored are the "wide

variety of chemicals that are known to have significant adverse impacts on domestic water supply water quality. It is widely recognized by professionals in the water quality management field that the chemicals included on the Priority Pollutant list [does not] represent a consensus list of the most important chemicals posing the greatest threats to surface and groundwater quality" (Jones-Lee et al., 1993). Belevi and Baccini (1989) estimated that unlined sanitary landfills in a wet climate could leach hazardous chemicals, such as lead, at concentrations above drinking water standards for several thousand years. While studies have shown that the rate of contamination decreases after 20 years, trace amounts of hazardous chemicals found from leachate can remain harmful (Han Z et al., 2016). Indeed, leachate pollutants can persist in groundwater long after the landfill has ceased operation (Kjeldsen et al., 2002; Renou et al., 2008). "It is being found that many such contaminants continue to leach from contaminated aquifer material in concentrations of concern for drinking water, for exceedingly long periods, in some cases projected for tens to hundreds of years" (Bredehoeft, 1992; AGWSE, 1992; Rowe, 1991). In fact, John A. Cherry (1990) reported that landfills constructed by the Romans over 2,000 years ago still produce leachate.

The EPA post-closure care requirement of municipal landfills says, "The required post-closure care period is 30 years from site closure, but this can be shortened or extended by the director of an approved state program" (EPA, Requirements for Municipal Solid Waste Landfills). While modern landfills employ advanced engineering to mitigate environmental risks, widespread groundwater contamination remains a concern. The research regarding the danger within landfill leachates underscores the urgent need for comprehensive legislation and practices to safeguard groundwater resources and public health relating to landfills.

Contaminants of Concern

Studies have identified chemicals in landfill leachates at nanogram (ng) or microgram (µg) per liter levels, these included "chlorinated alkyl-phosphates such as tris(1-chloro-2-propyl) phosphate (TCPP), N-butyl benzene sulfonamide (NBBS), the insect repellent diethyltoluamide (DEET) and personal care products such as the non-steroidal anti-inflammatory drug ibuprofen, polycyclic musk compounds and per-fluorinated compounds (PFCs), which were found to have ineffective removal methods". PFCs and Per- and poly-fluoroalkyl (PFAS) have been used for over 50 years in household products such as non-stick coatings in cookware, stain and water-

resistant coatings and fabrics, and more. PFAS has only recently become of significant concern as its resistance to natural degradation is slow and can exist in the environment for decades. In Michigan, a 2019 study identified landfill locations with perfluoroalkyl and polyfluoroalkyl substances (PFAS) levels. The study found on a statewide basis, that "the 35 landfills contribute approximately one million gallons of leachate to water resource recovery facilities, with approximately 0.01 lbs./day of PFOA and 0.003 lbs./day of PFOS" (PFOA and PFOS Impact on Water Resource Recovery Facility Influent, 2019). The first national drinking standard for PFAS pollution was implemented in 2024 during the Biden-Harris Administration (Biden-Harris Administration Finalizes First-Ever National Drinking Water Standard). Historically, EPA regulations have fallen short when considering the long-term effects of drinking polluted water. Even with trace amounts of these contaminants found, they can still be harmful and damaging to human health. Ignoring the reality trace amounts of a pollutant throughout years can decline a person's health (Shetty et al., 2023).

Consumerism and Overconsumption - Circular Economy as a Solution to Waste Management

Unfortunately, landfills are needed due to increased consumerism and the overconsumption culture found in developed countries. Billions of dollars are spent on food and retail yearly in the United States. In 2022, food spending by U.S. consumers, businesses, and government entities totaled $2.39 trillion (Food Prices and Spending). In 2020, approximately 62.5 million tons (56.7 million metric tons) of food waste was disposed of across the United States municipal solid waste landfills (Quantifying Methane Emissions from Landfilled Food Waste). Furthermore, much of the food in local grocery stores is packaged in plastic material. "U.S. plastic waste generation is projected to surpass 140 million metric tons by 2060. Plastics account for roughly 12 percent of the United States municipal solid waste generation, with plastic containers and packaging as the main source of plastic waste" (Plastic waste in the U.S). Plastic, food, and other common sources of waste, including products obtained from retail shopping, such as clothing and beauty products, fill our landfills due to a culture of over-consumption in the United States and other more affluent countries. This substantial amount of waste continues to necessitate alternative solutions for waste management. Global efforts to decrease waste and "reduce, reuse, recycle" are promoted but not often practiced due to the perceived lack of economic incentives for industries.

The United Nations has taken action to manage the global waste impact with its "Global Waste Management Outlook," which assessed the governance issues from countries around the world concerning proper and sustainable disposal of solid waste (Global Waste Management). It was found that the cost of managing waste in an environmentally sound manner sooner can be 5-10 times more cost-effective than in future years of attempting to "clean up" the waste later. The United Nations goal is to adopt a global "circular economy" where waste is reimagined as a "resource" and a life cycle assessment from production to disposal is considered with the hope of more recycling, reusing, and reducing (Global Waste Management). A circular economy must be considered starting with the extraction of raw materials, to the manufacturing of varying products, all the way to the final disposal place of produced products. While landfills have been modernized to ensure better environmental safety, the engineering and government mandates are not widely practiced enough, leaving room for long-term groundwater contamination. Leaving sources of freshwater at risk of becoming a polluted and non-viable resource. Fortunately, a move in the right direction is occurring. As of 2024, Landfills and the treatment or disposal of waste are considered the last resort in EGLE (Figure 1) and the EPA's Sustainable Materials Management Hierarchy (EGLE 2024, EPA 2024). In addition to not constructing as many landfills and dealing with the negative attribution of their existence, we should also find effective ways to reduce the amount of waste we produce.
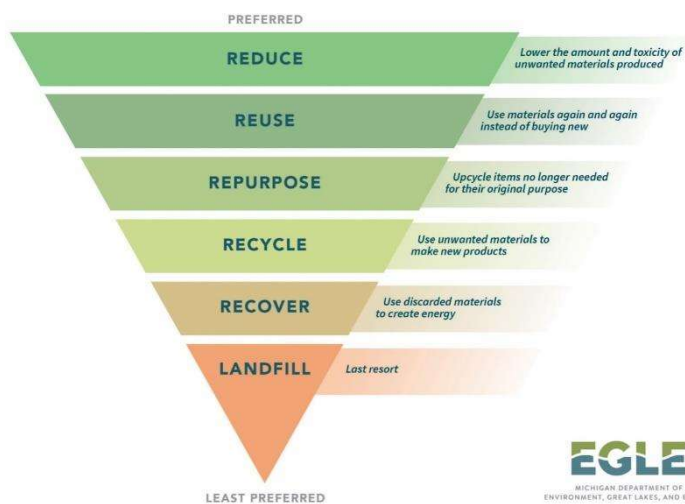
Figure 1: Michigan Department of Environment- Sustainable Materials Management

Groundwater Contamination

The Earth comprises 78% water, most of which is in our saltwater oceans. From this, humans rely on a very minimum percentage of available freshwater. Of the available 3% freshwater, 60% is stored in glaciers and ice caps, with the remainder found in surface and groundwater sources. Groundwater, which accounts for 30% of available freshwater, plays a crucial role in replenishing Earth's aquifers through the water cycle (Where is Earth Water?). Aquifers are defined as "a body of porous rock or sediment saturated with groundwater" (Aquifers). As precipitation falls onto the ground, water infiltrates back into the soil and the porous rock layers. Aquifers supplies much of the world with their daily drinking water.

Across the world, groundwater is used as a primary source of drinking water, especially in arid desert regions. "At the global scale, it [groundwater] supplies one-third of total water withdrawal to cater for nearly 85 and 50% of rural and urban needs, respectively" (Kumar and Shah, 2006). Groundwater aquifers across the United States are essential as a drinking water source, especially in dry-temperature states with a low percentage of available surface freshwater. In the United States, roughly 165 million Americans rely on subsurface freshwater for their daily needs (Heggie, 2020). Forty-three million Americans get their drinking water from private wells (Domestic Supply Wells). Total groundwater withdrawal within the Great Lakes basin was approximately 1510 million gallons per day (MGD) about 25 years ago and has increased considerably since then (Estimated water use in 1995). As of 2019, the most significant usage of groundwater in Michigan was for the public water supply (208.9 MGD), followed closely by irrigation (208.5 MGD), and then industry (85.8 MGD) and livestock (21.4 MGD) (Water Use Program). The Great Lakes Commission reported that 40.8 billion gallons of water were withdrawn from the Great Lakes basin in 2022, with 1,267 million gallons per day recorded. (Great Lakes Commission). The Great Lakes Compact is a legally binding international agreement between eight U.S. states and two Canadian Provinces whose land area encompasses the entire Great Lakes basin. Yearly, the compact reports the amount of surface and groundwater extracted to supply citizens across the basin. The parties recognize their collective responsibility to manage and restore the lakes for future generations (Water Law Explanation).

The EPA oversees public water systems under the Safe Water Drinking Act signed by Congress in 1974, setting standards for contamination levels and treatment processes.

Unfortunately, private wells are not regulated under the Safe Water Drinking Act, leaving citizens open to the risk of pollution in the water they consume daily from their private wells (Understanding the Safe Drinking Water Act). The EPA identifies contaminants in drinking water that may pose health risks and establishes maximum contaminant levels for regulation, considering the feasibility of treatment methods. They set a maximum contaminant level goal for each contaminant and determine how "feasible" the treatment to remove the pollution would be. SDWA defines feasible as "the level that may be achieved with the use of the best technology, treatment techniques, and other available means, taking cost into consideration" (Understanding the Safe Drinking Water Act). When it is not economically or technically feasible to set a maximum level, or when there is no reliable or economical method to detect contaminants in the water, this leaves a considerable margin of allowed pollution, and as mentioned, even trace amounts of specific pollutants with daily consumption can be fatal (Water Contamination and Diseases). Gaps in regulation for groundwater leave an opportunity to endanger millions of humans from contaminated drinking water.

Unfortunately, in Michigan and globally, "groundwater historically has been an understudied, underfunded, and underappreciated natural resource" (Steinman et al., 2022). A recent USGS-led assessment of the Great Lakes basin stated that "little to no groundwater quantity or quality information is available to help manage water availability" (Steinman et al., 2022). The lack of groundwater data could be attributed to the "high cost of data sampling and collection provides a challenge to the implementation of water quality monitoring programs" (Saalidong et al., 2022). The Michigan Water Use Advisory Council, as recently as 2018, codified a series of recommendations to advance and improve conservation, data collection, modeling, research, refinement, and administration of Michigan's water withdrawal assessment process (Steinman et al. 2022). Also, the lack of data can be related to the "Reasonable Use Doctrine" used often in east coast states. The reasonable use doctrine permits "a landowner to make use of groundwater beneath their property so long as their use does not 1) unreasonably interfere with the rights of neighboring landowners to reasonable use groundwater from beneath their property; 2) decrease the value of the neighboring land for legitimate uses; and 3) unreasonably impair the quality of the groundwater" (Lusch et al. 2011). Leaving the responsibility of ensuring safe groundwater quality to the landowner. The reasonable use doctrine in Michigan dates to 1917 with the Schenk v. City of Ann Arbor case. In this case, the

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Michigan Supreme Court held that the City of Ann Arbor had no greater rights to use groundwater than a private landowner. The plaintiffs were awarded damages for the cost of digging their well deeper. Additionally, the controversial trial of the Nestlé water bottle industry became one of the most public acknowledgments of big companies extracting Michigan groundwater for extremely low rates by taking advantage of the reasonable use doctrine (House, 2020). The public became aware of Nestle's actions, leading Michigan residents to feel defrauded and fight for change and legal action. The idea is that since groundwater is not owned by a single state or person, if Nestlé owns the well it uses to extract water, they are allowed to do so. Extracting is exactly what Nestlé continues to do, with a permit that allows 576,000 gallons of water daily (House, 2020). Many Michigan residents believe Nestlé should be taxed for extracting so much groundwater. Only 18 states in the United States tax water-bottling factories (Wayne State University, 2016). The debate is that if the bottled water industry is taxed for selling our shared groundwater, should farmers also be taxed for using the same groundwater to sell their produce? Since irrigation is a huge source of groundwater usage, if a tax were created to charge companies like Nestle, farmers would have to follow suit (Lusch, 2011). The use of groundwater for industry and agriculture is essential for those businesses but the depletion and contamination of said groundwater puts human life in danger. As debates ensue over-extraction laws, the repercussions of a lack of legislation on this matter will lead to empty aquifers, low-level streams, and dry wells. Groundwater as a resource need much more regulation and safety. Public health safety for all using groundwater is as essential as the groundwater itself. Ensuring sustainable use of groundwater necessitates the actions of government, industry, and the individual.

Public Health Threats and Environmental and Economic Injustices in Waste Management Practices

Global studies have concurred that the proximity of landfills can adversely affect nearby residents' health (Njoku et al., 2019; Han Z et al., 2016). Specifically, "groundwater contamination from landfill leachates appears most prominently within 200 meters from the landfill, with prominence of the pollution lasting for the first 20 years from the inception of the landfill" (Han Z et al., 2016). Landfill pollution which encompasses gaseous emissions and leachates, poses significant dangers when ingested. Leachates commonly contain heavy metals,

including iron, lead, and arsenic. In high concentrations heavy metals can affect the nervous system, leading to neurotoxicity and neuropathies with adverse symptoms such as memory disturbances, sleep disorders, anger, fatigue, head tremors, blurred vision, and slurred speech. Moreover, exposure to high lead levels can damage the dopamine system, glutamate system, and N-methyl-D-Asphate (NMDA) (Njoku et al., 2019). About 7.2 million Americans get sick yearly from diseases spread through water ([Surveillance reports for drinking water-associated disease](#)). The top seven outbreaks found in private water systems were Hepatitis A, Giardia, Campylobacter, Shigella, E. coli, Cryptosporidium, Salmonella (tied for 6th), and Arsenic, Gasoline, Nitrate, Phenol, Selenium, *Yersinia enterocolitica* (tied for 7th). Each outbreak can lead to infections, hospitalization, and death ([Surveillance reports for drinking water-associated disease)](#). Impacts can be reduced through water sampling and testing that promote early detection. Since private well sampling depends on the well owner, the CDC recommends these most common household water treatment systems. These include a filtration system which is a device that removes impurities from water using a physical barrier, chemical, and/or biological process. Next are water softeners, a device that reduces the hardness of the water typically using sodium or potassium ions to replace calcium and magnesium ions, the ions that create "hardness". Then, distillation systems boil impure water and collect the steam, which is then condensed in a separate container, leaving many of the solid contaminants behind. Finally, disinfectants involve a physical or chemical process in which pathogenic microorganisms are deactivated or killed. Examples of chemical disinfectants are chlorine, chlorine dioxide, and ozone. Examples of physical disinfectants include ultraviolet light, electronic radiation, and heat ([Well Treatment](#)). These methods of protecting your daily-used groundwater can be costly, leaving the accessibility for clean water practices dependent on the household income.

In addition to the risk to public health relating to landfills, research has found that the home values of those living near a landfill can also be affected. A 1992 study conducted in Minnesota found that the property value of 708 homes was adversely impacted by a nearby landfill. "Given a choice between two sites offered for the same price and identical in every respect, except that one is closer to a landfill, home buyers will choose the site farther away. Only when the closer [home] is offered for less money will families consider the closer site a suitable alternative." (Nelson et al. 1992). Increased traffic, localized air and noise pollution, and land clearing all reduce aesthetic quality for properties near a landfill. Also, littering roads

leading to the landfill is a serious social concern in many communities (Hirshfeld et al., 1992). Oftentimes, the residents found near hazardous waste sites are minority communities. The history of environmental injustice relating to waste management for minority communities' dates to the 1960s in Memphis Tennessee. In 1968, sanitation workers unionized and went on strike refusing to report to work, demanding higher wages and safer working conditions. This protest for better waste management conditions became one of the last speeches Martin Luther King Jr. delivered before his assassination on April 4th,1968. The fight against unsafe waste management practices continued, as seen in the 1979 court case Bean v Southwestern Waste Management Corp in Houston, Texas. African American residents joined together to stop the construction of a landfill 1500 feet from the local public school. The court specifically found that the landfill would affect the entire nature of the community, its land values, tax base, aesthetics, and the health and safety of its inhabitants. Despite this understanding, the community was unable to prevent the landfill placement. This was the first lawsuit of its kind in the country against the dangers of landfills during a time when air and groundwater pollution was not as heavily considered. The fight against the placement of landfills and hazardous sites continued with a nonviolent sit-in protest in 1982 where 500 environmental and civil rights activists were arrested over the construction of a polychlorinated biphenyl (PCB) landfill in Warren County, North Carolina. While halting the landfill construction was unsuccessful, this moment is widely accepted as the catalyst for the environmental justice movement (Environmental Justice Timeline). Despite efforts, minority communities often lacked the political power and resources to prevent the placement of hazardous waste sites, leading to disproportionate exposure to environmental hazards. Studies, such as the United Church of Christ Commission on Racial Justice (UCC) report in 1987, began to highlight the inequitable distribution of hazardous waste sites, with minority communities withstanding the worst of environmental pollution. The UCC report began the national research efforts to integrate the relationship between race and environmental hazards. The UCC report found that over 15 million African Americans, 8 million Hispanics, and half of all Asian/Pacific Islanders and Native Americans resided in communities with at least one abandoned or uncontrolled toxic waste site there (UCC, "Toxic Waste in the United States" 1987). The study also found that while the socioeconomic status of residents appeared to play a significant role in the location of hazardous waste sites, the residents' race was the most significant factor among the variables analyzed. Similar research conducted by the

University of Michigan in collaboration with the University of Montana found a consistent pattern of placing hazardous waste facilities in neighborhoods where poor people and people of color reside. The study was done by comparing the demographic composition of neighborhoods around the time commercial hazardous waste facilities were built and the demographic changes that occurred after the construction of the hazardous waste facility. They studied 319 commercial hazardous waste treatment, storage, and disposal facilities in the United States from 1966 to 1995. It was concluded that there was "a consistent pattern over 30 years of placing hazardous waste facilities in neighborhoods where poor people and people of color live" (Mohai & Soha, 2014). This is because Black and brown communities are considered the "least resistant" from the lack of political power and fewer available resources to prevent the placement of those kinds of facilities. In addition to the phenomenon of "NIMBYism" or "not in my backyard" syndrome where white affluent communities have enough political power to move the placement of a hazardous waste site away from their community (Mohai & Soha, 2014). As long as the environmental hazard was not immediately visible to the predominantly white community and the minority community did not have the political influence to halt the construction, the landfill of hazardous waste facility would be built. This study was an extension to the 2006 report titled "Toxic Waste and Race at Twenty which found that more than half of all people in the United States who live within 3.0 kilometers (1.89 miles) of a hazardous waste facility are people of color (Erickson, 2016).

Environmental justice efforts in Michigan have garnered national attention, notably during the Flint Water Crisis and in Detroit communities in the 48217 zip code, like Delray, considered the most polluted place in the state. Also in Flint, Michigan, the CEO of Oil Chem Inc. Robert J. Massey pleaded guilty in federal court "to a criminal charge of violating the Clean Water Act stemming from illegal discharges of landfill leachate — totaling more than 47 million gallons — into the city of Flint sanitary sewer system over an eight-and-a-half-year period" (Owner of Oil Chem Inc.). "The defendant knowingly ordered the discharge of over 40 million gallons of landfill wastewater, ultimately to the Flint River, putting the environment at risk," said Jennifer Lynn, special agent in charge of EPA's Criminal Investigation Division in Michigan (Owner of Oil Chem Inc.). These incidents highlight the need for consistent research and regulation to protect groundwater quality and public health.

With 10 million residents across the state of Michigan, and 45% of residents relying on private wells, the most important goals of this research were to analyze the distance of a landfill to residential private wells and to understand the federal and state policies that encompass our waste management and groundwater usage, threats and protection. This is to assess the public health threat associated with the risk of polluted drinking water from landfill leachate to those private wells, hoping to open up the conversation concerning better waste management practices and reconstructing the relationship between the trash we produce and quality of life. Having a better consideration of our groundwater, a vital source of freshwater, is an essential part of this conversation. This assessment starts by analyzing the distance between landfills and residential private wells. We can assess the potential threat of groundwater contamination for those most at risk and advocate for better waste management practices. Safeguarding our groundwater resources is crucial for ensuring a sustainable and healthy environment for all.

Methods

For this analysis, ArcGIS was used to compute and display landfill proximity to privately owned wells and USGS well sites across Michigan. I began by accessing the locations of all landfills in Michigan, which were found through the Environmental Protection Agency (EPA) and The Michigan Department of Environment, Great Lakes, and Energy (EGLE) available landfill datasets. The landfill sites were geographically located by their latitude and longitude and included data like the landfill name, address, year the landfill opened, and the tonnage amount of waste found at the landfill. The datasets represented private and municipality-owned landfills across Michigan. These datasets were available as Microsoft Excel sheets and transformed into an Attribute table through the ArcGIS tool "Excel-to-Table Feature." An Attribute table is the table format of the data from each feature layer on the map. From here I was able to use the "Table to XY point" feature to represent each landfill as a red circle on the ArcGIS map. Within ArcGIS, the "Merge" tool was then used to combine the landfill datasets from EPA and EGLE. Since both datasets included active and closed landfill sites across Michigan, some duplicate landfill locations were found. These duplicates were erased using the "Delete Identical" tool. 126 active and closed landfill sites were found and visually represented within ArcGIS as a feature titled "Landfills".

Next, privately owned wells and USGS well sites were downloaded from EGLE and USGS. EGLE groundwater database "Wellogic" provided six "Water Wells in Michigan" shapefiles, including residential, industrial, and wells used for irrigation locations separated by region across the state. A shapefile is a downloadable file that includes "the geometric location and attribute information of a geographic feature" (What is a shapefile). The six shapefiles are recorded as not containing a complete database of all wells in Michigan due to inconsistency in county records by year. "Beginning January 1, 2000, virtually 100% of new wells constructed are accounted for in Wellogic, however for wells older than 2000 the rate of inclusion varies from county to county and may be considerably lower" (Water Wells). The six private well shapefiles were then merged together as one point-feature layer and titled "private wells" onto the ArcGIS map. As mentioned in the "Groundwater Contamination Leachates" section, private wells do not require water quality sampling. In addition, there are no public records for private well water quality sampling. This led to a limitation in knowing the water quality for private wells across the state. Therefore because of this limitation, I used the USGS well locations to assess their available water quality data, assuming that a USGS well site near a landfill would have leachate pollution rates similar to those of private well locations. The USGS wells geographical locations were downloaded as a shapefile from the USGS website and titled "USGSwells" onto the ArcGIS. The well types are differentiated by purple circles for private wells and gray squares for USGS wells (Figure 2). The landfill and wells datasets were the primary sources for the spatial analysis to determine well locations that are most likely to have contaminated drinking water from living near a landfill. To ensure the geographical location of all points, polygons, and other features are reflective of the same coordinate system, the project tool was used on all existing files to convert each point feature as the "NAD_1983_Michigan_GeoRef_Meters" projected coordinate system. Coordinate Systems are important in ArcGIS when mapping, to ensure accurate positioning of features that are placed based on their geographic locations. For more information on the importance of coordinate systems please refer to (Work with coordinate systems).
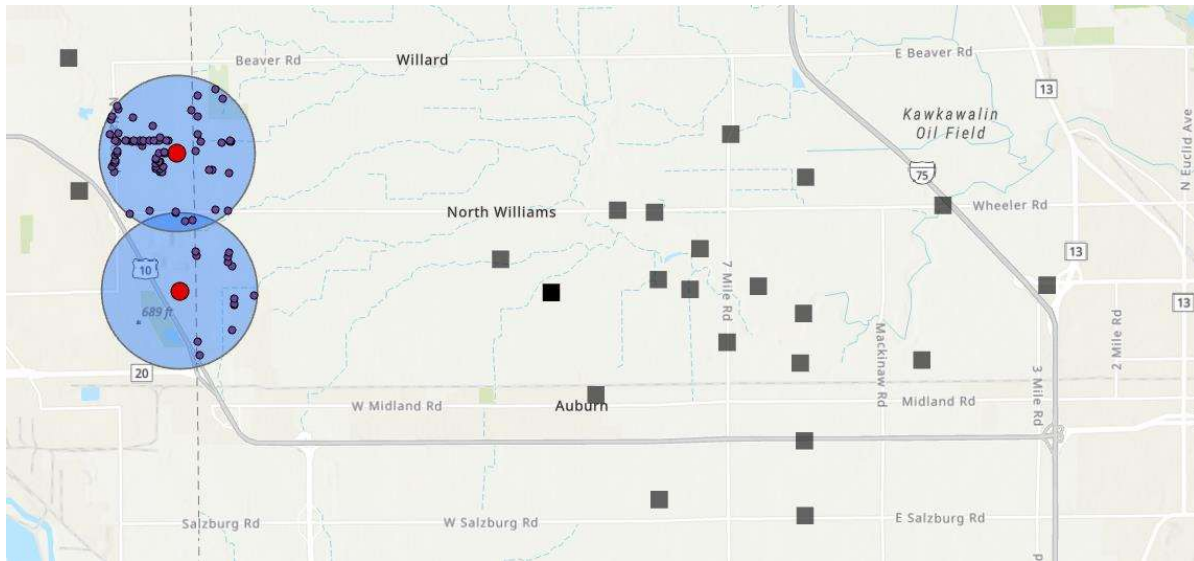
Figure 2: Landfill (red circle), private well in 10 mile buffer (purple circle inside blue circle), and USGS wells (gray squares)

Next, the distance of the nearest USGS well to a landfill was found using the "Buffer" and "Near" tools. As mentioned, water quality data was unavailable for the private wells, so USGS wells were used to compare the contamination rate found at each well to the distance from a landfill. A buffer creates polygons that cover a given distance from a point, line, or polygon feature. The Near tool calculates the nearest distance from one point feature to another. The distance in miles then becomes a column in the Attribute Table. For every landfill, a 10-mile radius buffer was created. This buffer included each USGS well that fell within that 10-mile radius. The 10-mile buffer was chosen to coincide with studies that found the highest pollutant concentration is most prominent the closer to a landfill (Han Z et al. 2016). Also through the movement of groundwater, the span of which a landfill can pollute groundwater reaches far beyond its nearest neighbors. The buffer polygon is then included as a feature layer associated with an attribute table titled Landfill buffer. The Near tool calculated the distance of the nearest USGS wells to a landfill. Some landfills had no USGS wells near them, meaning no near distance was calculated for them. The nearest USGS wells fell within 0-2 miles of each landfill found in the "Near_Dist" column in the attribute table. The attribute table was then exported out of ArcGIS using the" Table to Excel" tool.

The exported attribute table in Excel was titled "USGSwellsExcel.xlsx" including columns such as Near_Dist, which was the distance of the nearest USGS wells to a landfill, the site number for the USGS well sites, the year the landfill opened, and the waste amount found at

each landfill location. Next was to assess the water quality at these USGS well sites. The USGS online database contains water quality sampling records for each USGS well site as a downloadable comma-separated values (CSV) file. This CSV file was then transformed into an Excel sheet with the help of the University of Michigan- Office of Consulting for Statistics Computing & Analytics Research (CSCAR) titled "USGSwaterquality.xlsx". The USGS water quality records included data such as USGS site number, sample date, and containment rates for Iron, Lead, Arsenic, Fluoride, and Zinc which are the heavy metals related to leachates. The contaminants column names were based on their code names from USGS. Please refer to the Appendix for more details on USGS metadata. Each pollutant chosen for this analysis was also compared to the EPA drinking water standard.

For this analysis, the sampling date for each well site would have to be after the date on which the landfill was constructed. This would relate the high heavy metal rates to the potential pollution from landfill leachate. Relating to the hypothesis that a well site in proximity to a landfill would see worse water quality conditions. From there the water quality records for each USGS well site in proximity were graphed using the programming language for statistical computing and data visualization, R software.

Using the converted Attribute tables in Excel, each file was read into R software to begin comparing contaminant rates to distances from a landfill. The distance in miles represented the horizontal line (x-axis), using the Near_Dist column found in the   and "USGSwellsExcel.xlsx" files. The water quality data from the "USGSwaterquality.xlsx" file included rates for Iron, Fluoride, Zinc, Arsenic and pH were placed on the vertical line (x-axis). The pH levels were included based on studies which found heavy metals in water with a low pH tend to be more toxic. The contamination rates were compared to distance from landfill, sample date for USGS wells, and the tonnage amount of waste found at the landfill.

Table 1: EPA Drinking water
Standard for heavy metals & pH

To understand landfill placement based on population size and household income, each county was represented by the median income and total population. This data was available through the Michigan Senate website (Michigan Senate) and EGLE (Egle) as a PDF file. Each PDF file was then transformed into an Excel spreadsheet through Adobe online. Once into an Excel spreadsheet, the data was checked for missing data and accurate transformation from PDF to Excel. The Excel sheets were then downloaded into ArcGIS with the previously used 'Excel to Table' tool. In ArcGIS, the median income and total population were placed as two separate maps. For each map, the symbology was then altered to a gradient color, representing the variation in population density and household income. The gradient color symbology asks to specify a suitable classification method for each data set. The classification methods used for these maps are Natural Breaks (Jenks) which means the "Class breaks are created in a way that best groups similar values together and maximizes the differences between classes" and Quantile which means "Quantile assigns the same number of data values to each class" (Data Classification Methods). Lastly, to visualize groundwater, EGLE's open data provided a shapefile of the Base Flow for Michigan Streams. Baseflow is the estimation of how much groundwater contributes to the surface water levels in cubic feet per second. The baseflow of a stream or river is the amount of groundwater discharged from an aquifer to the watercourse. The classification method chosen for the Baseflow map was Natural Break (Jenks) with a gradient color of blue to represent the increase in cubic feet per second. The landfill locations were then placed on top of the Baseflow layer to represent the proximity of landfills to streams that are largely sourced by groundwater.

EPA	Drinking Water standard
Iron	0.30 µg/l
Zinc	5 mg/L
Arsenic	0.010 µg/l
Fluoride	4.0 mg/L
pH	6.5 - 8.5

Results

Shown in Figure 3 there were 126 active and closed landfills found by county in Michigan. The region with the most landfills were found in the South Central and Southeastern areas, which equates to the largest population size of this region compared to the others. Figure 4 and Figure 5 are the aggregations of landfill locations and USGS well sites across the state. Approximately 3,112 USGS well sites were accounted for, and approximately 948,675 private

wells. Figure 6 illustrates various feature layers, including landfills, USGS wells, and the private wells that fell within the 10-mile radius from Buffer. Hundreds of private wells were found within each Buffer, representing the magnitude of private wells ownership for residents in Michigan. Fewer USGS wells were located within the 10-mile Buffer since there are fewer USGS well sites than private wells. The Base Flow of streams is shown in Figure 7 with a landfill in proximity to a stream, containing a baseflow of 3,210 cubic feet per second.
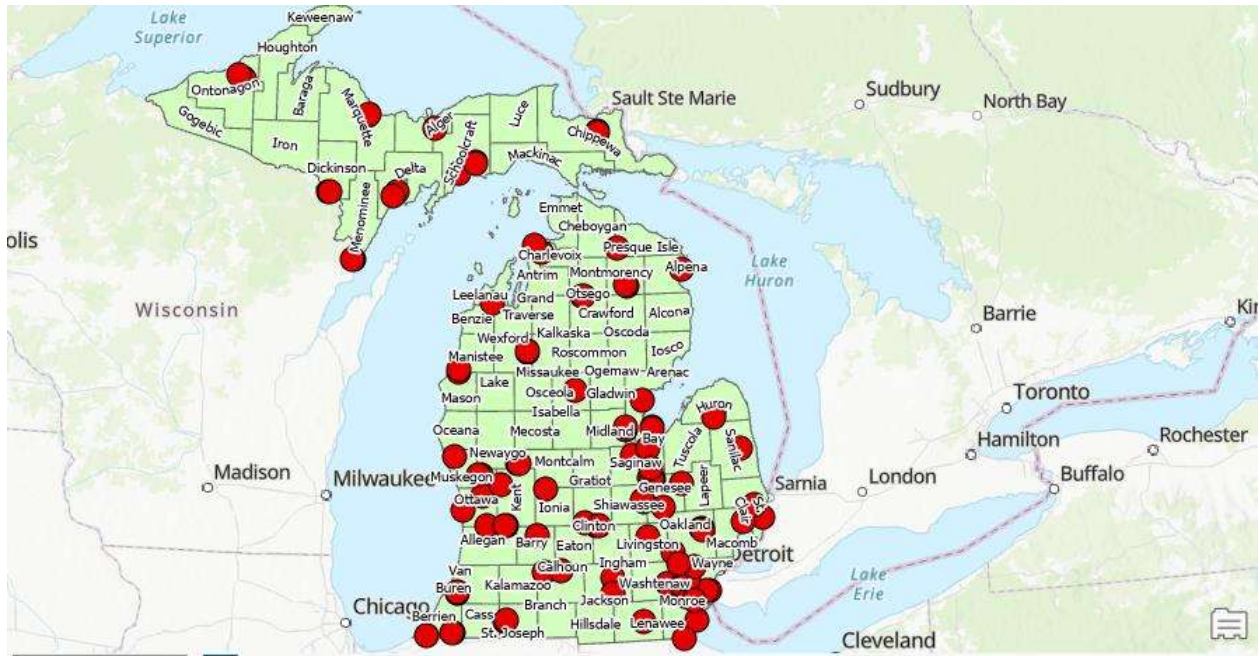

Figure 3: Map of Michigan's counties and landfills (red circles)
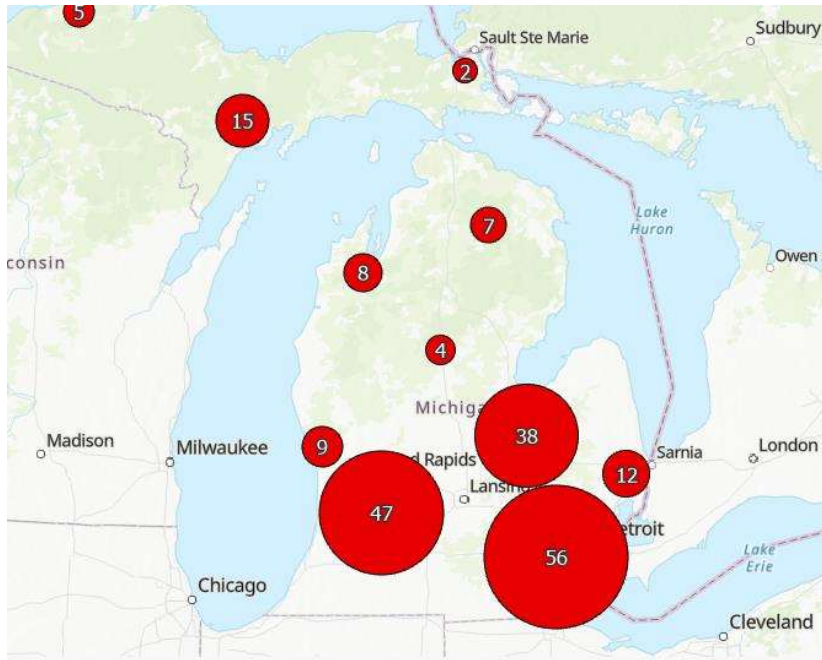
Figure 4: Aggregate of landfill placement across Michigan
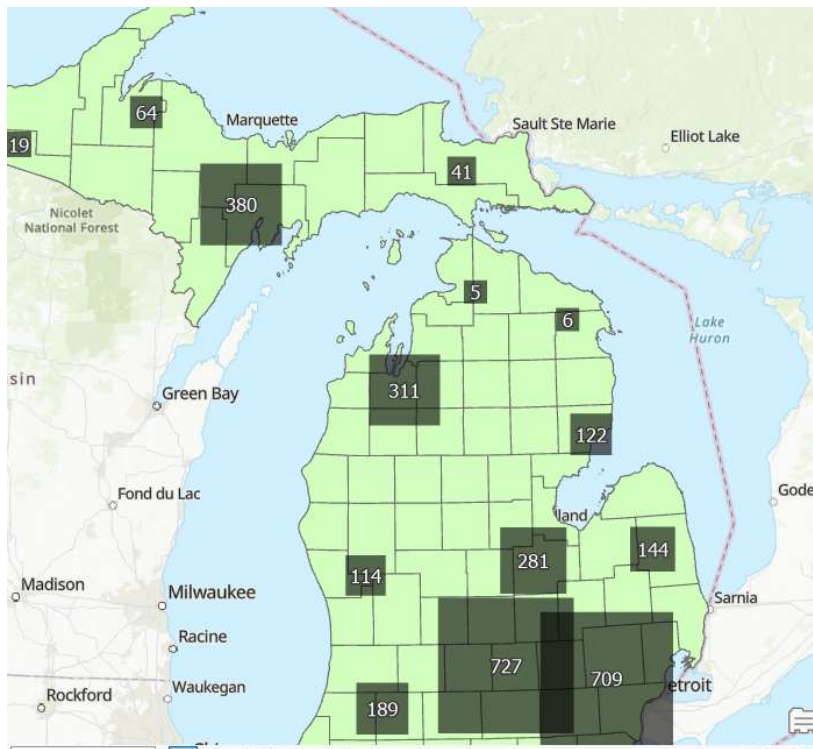
Figure 5: Aggregate of USGS wells across Michigan
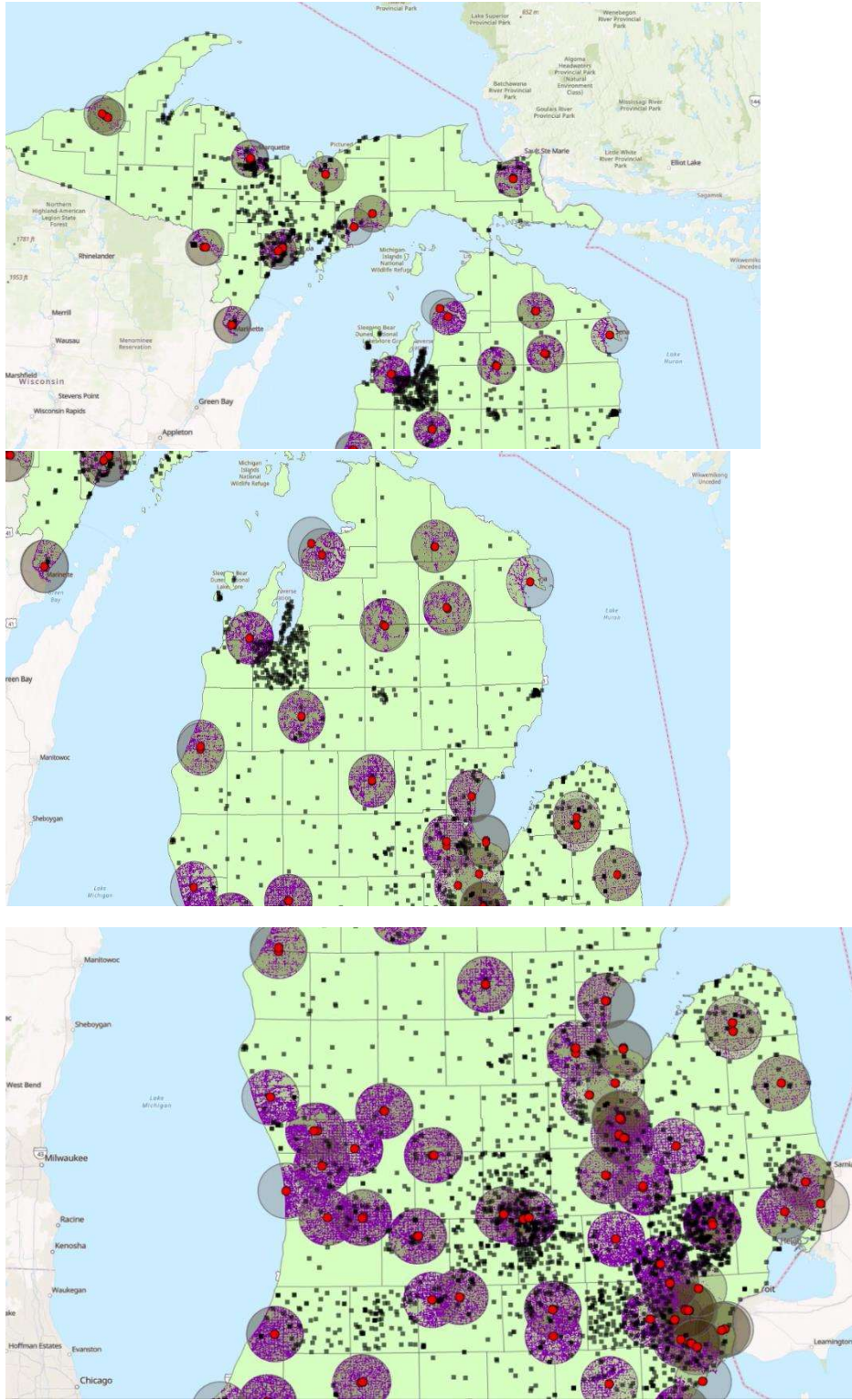
Figure 6: Landfill (red circles), USGS wells (gray squares), and Private wells in a 10-mile radius from Landfills (purple circles)
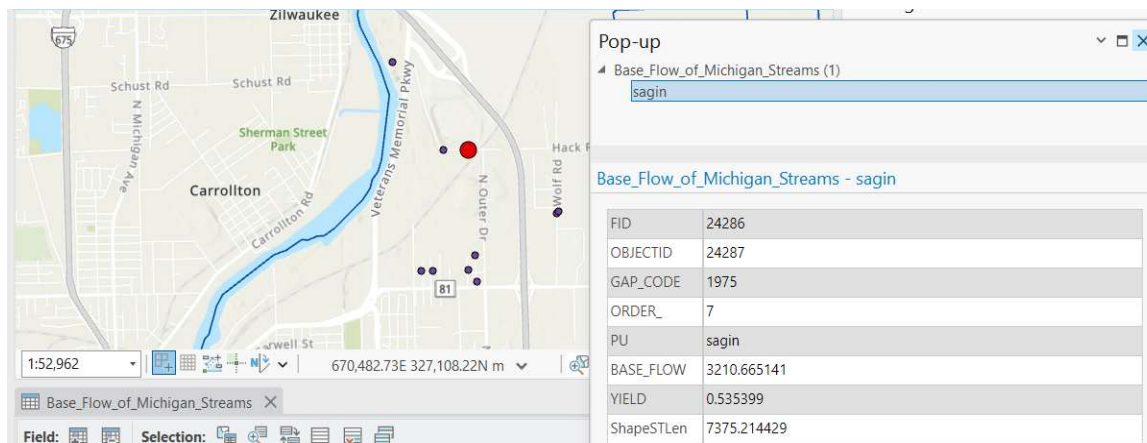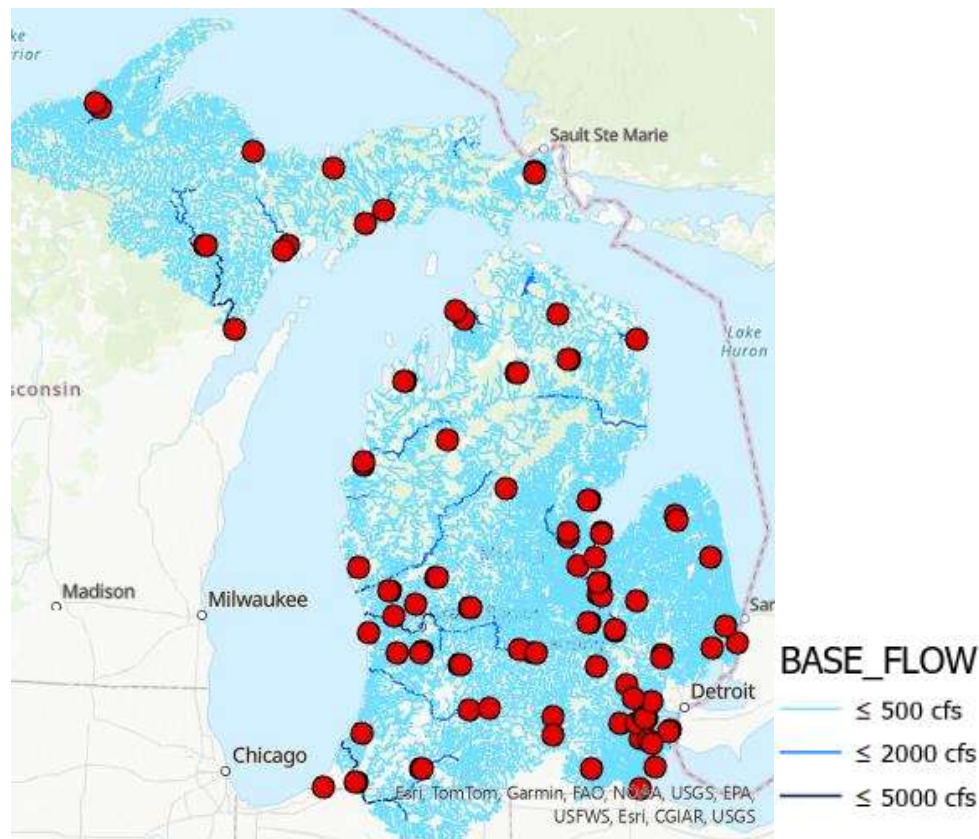
Figure 7: Base Flow of Michigan streams. Stream near a landfill with baseflow of 3,210 cubic feet per second

Figure 8 represents the duration of landfills across the state, with the red line representing the year 2024. Landfill operations, as mentioned previously, can continue for decades and the EPA requires post-closure monitoring up to 30 years for liners and leachate collection systems. (Closure and Post-Closure Care). Figure 9 shows the results of heavy metals contamination compared to the nearest distance from a landfill. Each point represents an individual USGS well and the containment's recorded sample results. The red line represents the EPA drinking water

standard for each containment. The drinking water standard for pH is also included, represented by two blue lines. The drinking water standard for Iron and Lead is not included since the EPA recognizes no acceptable containment level for lead in drinking water. The standard for Iron is 0.3 milligrams per liter, below the Y-axis range. Zinc, Fluoride, and Iron contain the most USGS wells, which exceed the drinking water standard. Figure 10 shows the containment concentration compared to the year the USGS well was sampled. The seeming increase in USGS well sampling after the 1950s can be related to the United States implementation of the Resource Conservation and Recovery Act in 1976, as previously stated. Despite the regulations to ensure more water quality sampling, the USGS well samples were inconsistent in their frequency for water quality. While the depth of the well was tested to monitor groundwater depletion, the actual quality of water could be tested once every ten years, especially for Lead. Figure 11 compares the Waste amount at each landfill to the contaminant concentration. The waste amount is defined by the tonnage of trash found at a landfill. While there is no direct correlation between the waste amount and contamination rate, this shows that leachate pollution can be prevalent despite the size or amount of waste found at a landfill. The landfill with the largest tonnage of waste in place came from the Arbor Hills Landfill-Washtenaw County, with 70,105,317 tons of trash collected in 2022. The USGS site with the highest pollutant rate of iron was located near Adrian Landfill-Lenawee County in 1986, with 3300 micrograms per liter. The USGS site with the highest pollutant rate of Arsenic was located near Orchard Hill SLF-Berrien County in 1986 at 19.00 micrograms per liter. The USGS site with the highest pollutant rate of Zinc was located near the Smiths Creek Landfill-St. Clair County in 1987, where there were 39000 micrograms per liter. The USGS site with the highest pollutant rate of Fluoride was located near the Huron Landfill-Huron County in 1988 at 3900 milligrams per liter. The USGS site with the highest pollutant rate of Lead was located near the City of Midland Landfill-Midland County in 1987 at 95000 micrograms per liter. The USGS site with the most acidic pH levels was near the Pine Tree Acres Landfill-Macomb County in 2023 with a 2.8 pH level. Based on the USGS water quality metadata, there were minimum sampling records for USGS well near those landfills from the past ten years. The most recent sampling was for one USGS well in 2022 near Orchard Hill SLF with an Iron level of 230 µg/l, Arsenic level of 11.40 µg/l, and Fluoride level of 28.00 mg/l. The most recent levels of heavy metal contamination from USGS wells near Orchard Hill SLF exceed the drinking water standard. These results show the significance in heavy metal

concentration for USGS wells near landfills and how private well owners near a landfill should have extra precautions when using their well for drinking water.
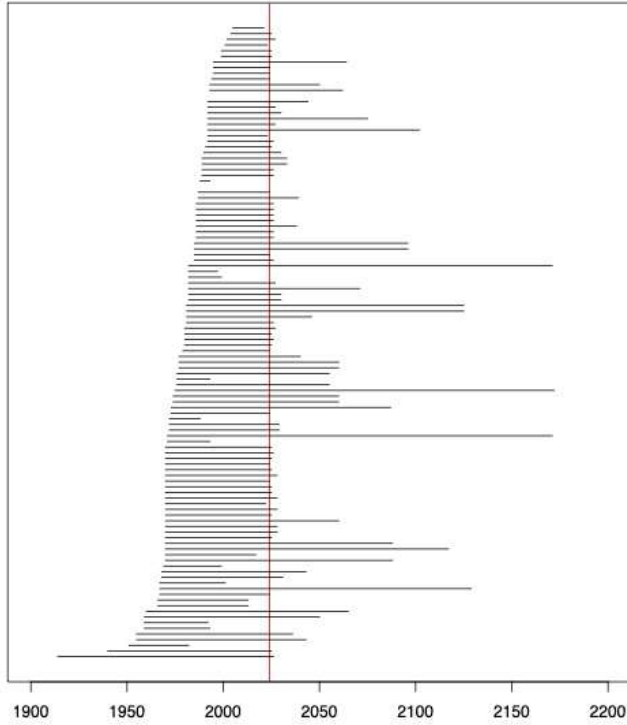
Figure 8: The duration of landfills with year 2024 represented by red line.
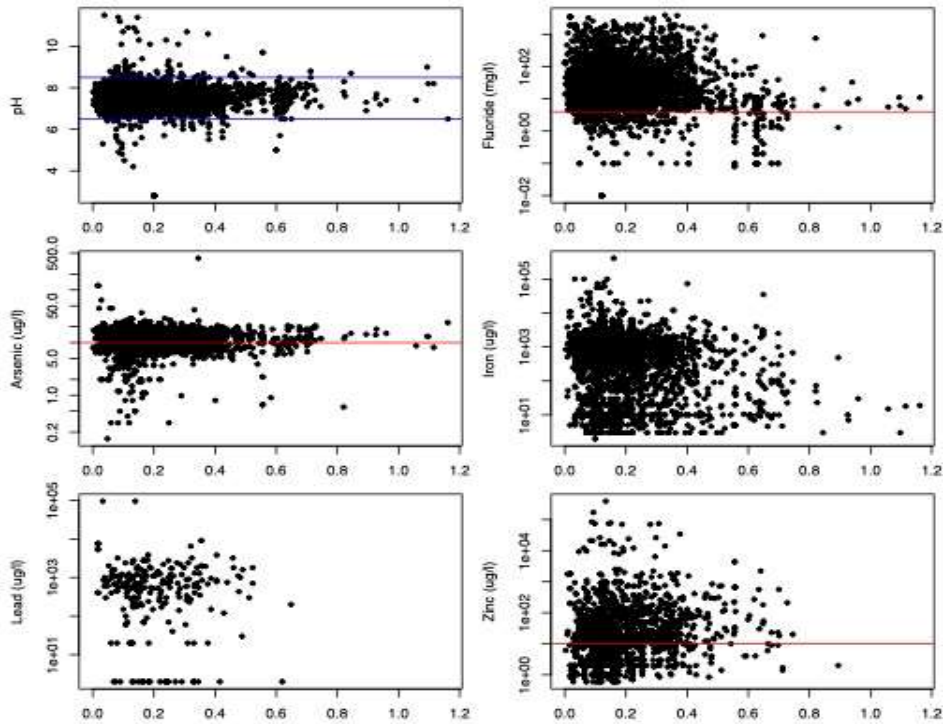
Figure 9: Distance from landfill (in miles) compared to containment rate. EPA drinking water standard represented by color lines.
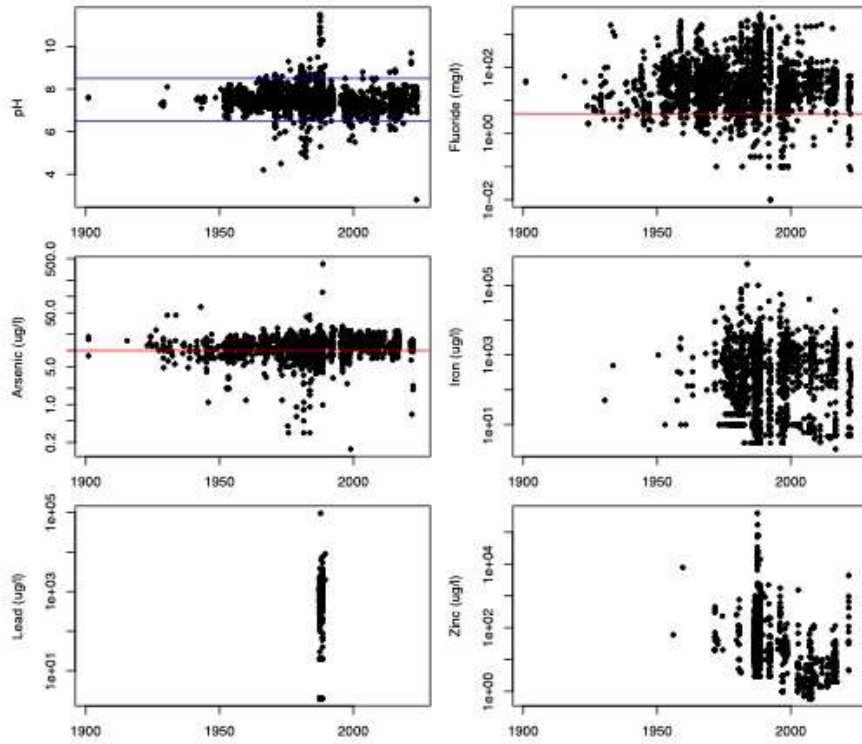
Figure 10: Sample date for USGS well compared to containment rate. EPA drinking water standard represented by colored line.
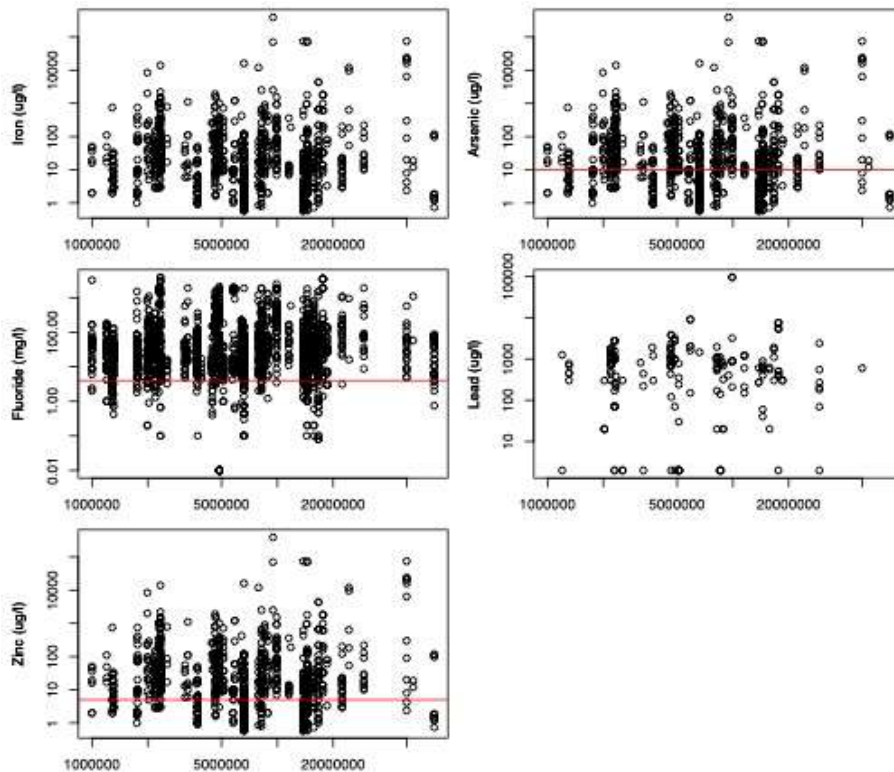
Lastly, the total population and median income compared to landfill placement as shown by Figure 12. This found that most of the states' landfills are placed in high-population counties, as shown in the darker purple squares. There are also more landfills in the $55,000 to $73,000 median-income counties, as shown by the lighter green squares. The median income counties with the largest amount of landfill are also found in the counties with larger population size. The lowest median-income communities coincide with the lowest total population by county. If landfill placement is based on which county needs it more because more people are generating trash in those places, would we find the exact landfill placement in the county's impoverished area? With more research, landfill placement by neighborhood can be considered to understand better the relationship between landfills and poorer minority communities.

Figure 12: Total Population and Median Income compared to Landfill location

Appendix for Results Section

Appendix A- Code to Graphs

```
1  ###########################################################
2  ## Code to accompany Master's Thesis for Taylor Mitchell
3  ## Completed between 2023 and 2024
4  ## Last updated 15 April 2024 with comments from Drew Gronewold
5  ###########################################################
6
7  ## Install packages
8  library(dplyr)  #; install.packages("dplyr")
9  library(ggplot2)#; install.packages("ggplot2")
10
11 ## Main Code- Distance/Contaminate Graphs
12 # Set working directory (change as needed)
13 # setwd("/Users/taylormitchell/Desktop/Thesis/R software")
14 setwd("C:/Users/drewgron/Desktop/taylor_thesis")
15
16 ## Read in water quality data from USGS monitoring wells
17 ## Data sheet modified to include only data for key parameters, including:
18 ## -- iron    (p01047)  (iron II; ug/l)
19 ## -- arsenic  (p01000)  (dissolved; ug/l [micrograms per liter])
20 ## -- zinc    (p01092)  (aquous; ug/l)
21 ## -- fluoride (p00950)  (mg/l)
22 ## -- pH     (p00400)  (standard pH units)
23 ## -- lead    (p01049)  (dissolved; ug/l)
24 ## (details on codes can be found at: https://help.waterdata.usgs.gov/parameter_cd?group_cd=%)
25
26 ##
27
28 #usgs.wq    <- read_xls('USGSwaterquality.xlsx')    # Set unique object name
29 usgs.wq   <- read.csv('USGSwaterquality_B.csv')   # Formerly called USGS
30 dist.dat  <- read.csv('USGSwellsExcel_B.csv')   # Formerly called 'Distance'
31
32 ## Quick look at data
33 head(usgs.wq);  summary(usgs.wq)
34 head(dist.dat);  summary(dist.dat)
35 new.sample.date = as.Date(usgs.wq[,2],format = "%m/%d/%Y")
```

```
#format = "%m/%d/%Y")
## Basic plot of time series of all data from all wells
## Plot most y axes on log scale (removes some zero values; ok

pdf(file = "time_summary.pdf", height = 6, width = 7, paper = "special")
par(mfrow = c(3,2))
par(mar = c(2.5, 4.5, 0.5, 0.5))

  # pH
  plot(new.sample.date, usgs.wq[,3], pch = 20,
    xlab = "", ylab = "pH")
  abline(h = c(6.5, 8.5), col = "blue")    # NSDWR standards for pH

  # fluoride
  plot(new.sample.date, usgs.wq[,4], pch = 20, log = "y",
    xlab = "", ylab = "Fluoride (mg/l)")
  abline(h = 4, col = "red")          # EPA flouride limit of 4.0 mg/l (check!)

  # arsenic
  plot(new.sample.date, usgs.wq[,5], pch = 20, log = "y",
    xlab = "", ylab = "Arsenic (ug/l)")
  abline(h = 10, col = "red")          # WHO standard 10.0 ug/l (check!)

  # iron
  plot(new.sample.date, usgs.wq[,6], pch = 20, log = "y",
    xlab = "", ylab = "Iron (ug/l)")
  abline(h = 0.30, col = "red")        ## Find iron standard

  # lead
  plot(new.sample.date, usgs.wq[,7], pch = 20, log = "y",
    xlab = "", ylab = "Lead (ug/l)")
  abline(h = 0, col = "red")         ## Find lead standard
```

```
69     # zinc
70     plot(new.sample.date, usgs.wq[,8], pch = 20, log = "y",
71       xlab = "", ylab = "Zinc (mg/l)")
72     abline(h = 5, col = "red")        ## Find zinc standard
73
74   dev.off()
75   # View the PDF file in RStudio
76 - if (interactive()) {
77     # Open the PDF file using the system's default PDF viewer
78     rstudioapi::viewer("time_summary.pdf")
79 - } else {
80     # For non-interactive sessions, print a message with the file location
81     cat("PDF file saved as 'time_summary.pdf'. Please open it using a PDF viewer.\n")
82 - }
83
84
85   ## Merge with associated landfill data and create new master data set
86
87   master.dat=left_join(usgs.wq, dist.dat, by = c( "site_no"="SITENO"))
88
89
90   pdf(file = "distance_summary.pdf", height = 6, width = 7, paper = "special")
91   par(mfrow = c(3,2))
92   par(mar = c(2.5, 4.5, 0.5, 0.5))
93
94     # pH
95     plot(master.dat[,10], master.dat[,3], pch = 20,
96       xlab = "Distance (miles)", ylab = "pH")
97     abline(h = c(6.5, 8.5), col = "blue")   # NSDWR standards for pH
98
99     # fluoride
100    plot(master.dat[,10], master.dat[,4], pch = 20, log = "y",
101      xlab = "", ylab = "Fluoride (mg/l)")
102    abline(h = 4, col = "red")          ## EPA flouride limit of 4.0 mg/l (check!)
103
```

```
103
104     # arsenic
105     plot(master.dat[,10], master.dat[,5], pch = 20, log = "y",
106       xlab = "", ylab = "Arsenic (ug/l)")
107     abline(h = 10, col = "red")          ## WHO standard 10.0 ug/l (check!)
108
109     # iron
110     plot(master.dat[,10], master.dat[,6], pch = 20, log = "y",
111       xlab = "", ylab = "Iron (ug/l)")
112      abline(h = 0.30, col = "red")        ## Find iron standard
113
114     # lead
115     plot(master.dat[,10], master.dat[,7], pch = 20, log = "y",
116       xlab = "", ylab = "Lead (ug/l)")
117     abline(h = 0.3, col = "red")          ## Find lead standard
118
119     # zinc
120     plot(master.dat[,10], master.dat[,8], pch = 20, log = "y",
121       xlab = "", ylab = "Zinc (ug/l)")
122     abline(h = 10, col = "red")          ## Find zinc standard
123
124   dev.off()
125   # View the PDF file in RStudio
126 ▾ if (interactive()) {
127     # Open the PDF file using the system's default PDF viewer
128     rstudioapi::viewer("distance_summary.pdf")
129 ▾ } else {
130     # For non-interactive sessions, print a message with the file location
131     cat("PDF file saved as 'distance_summary.pdf'. Please open it using a PDF viewer.\n")
132 ▴ }
133
134
135     ## Explore contamination by county (try in log scale as well)
136
137     plot(master.dat[,3] ~ as.factor(master.dat$County), las = 2, cex.axis = 0.65, xlab = "")
```

```
137   plot(master.dat[,3] ~ as.factor(master.dat$County), las = 2, cex.axis = 0.65, xlab = "")
138   plot(master.dat[,4] ~ as.factor(master.dat$County), las = 2, cex.axis = 0.65, xlab = "")
139   plot(master.dat[,5] ~ as.factor(master.dat$County), las = 2, cex.axis = 0.65, xlab = "")
140   plot(master.dat[,6] ~ as.factor(master.dat$County), las = 2, cex.axis = 0.65, xlab = "")
141   plot(master.dat[,7] ~ as.factor(master.dat$County), las = 2, cex.axis = 0.65, xlab = "")
142   plot(master.dat[,8] ~ as.factor(master.dat$County), las = 2, cex.axis = 0.65, xlab = "")
143
144   ## Explore contamination by ownerhip type (try in log scale as well)
145
146   plot(master.dat[,5] ~ as.factor(master.dat$Ownership), las = 2, cex.axis = 0.65, xlab = "")
147
148
149 ▾ ###########################################################################
150 ▾ ###########################################################################
151
152   ## Plot open and close dates of all landfills
153
154   landfill.time = distinct(master.dat, master.dat$LandfillID, .keep_all = TRUE)
155
156   plot(x = c(1900,2200), y = c(1,112), type = "n", ylab = "", xlab = "", axes = F); box()
157     abline(v = 2024, col = "red")
158     segments( x0 = landfill.time$open_year,
159         x1 = landfill.time$close_year,
160         y0 = seq(1:112))
161     axis(1)
162
163   ## Try a different plot, ordered by start year (to "clean" it up)
164   pdf(file = "landfill_duration.pdf", height = 7.5, width = 6.5, paper = "special")
165   par(mar = c(2.5, 0.5, 0.5, 0.2))
166     plot.order = order(landfill.time$open_year)
167     plot(x = c(1900,2200), y = c(1,112), type = "n", ylab = "", xlab = "", axes = F); box()
168       abline(v = 2024, col = "red")
169       segments( x0 = landfill.time$open_year[plot.order],
```

```r
163    ## Try a different plot, ordered by start year (to "clean" it up)
164    pdf(file = "landfill_duration.pdf", height = 7.5, width = 6.5, paper = "special")
165    par(mar = c(2.5, 0.5, 0.5, 0.2))
166      plot.order = order(landfill.time$open_year)
167      plot(x = c(1900,2200), y = c(1,112), type = "n", ylab = "", xlab = "", axes = F); box()
168        abline(v = 2024, col = "red")
169        segments( x0 = landfill.time$open_year[plot.order],
170              x1 = landfill.time$close_year[plot.order],
171              y0 = seq(1:112))
172        axis(1)
173    dev.off()
174    # View the PDF file in RStudio
175 -  if (interactive()) {
176      # Open the PDF file using the system's default PDF viewer
177      rstudioapi::viewer("landfill_duration.pdf")
178 -  } else {
179      # For non-interactive sessions, print a message with the file location
180      cat("PDF file saved as 'landfill_duration.pdf'. Please open it using a PDF viewer.\n")
181 ^  }
182
183    #Ph couty
184    pdf("ph_county.pdf", width = 8.5, height = 4, paper = "special") +
185      plot(master.dat[,3] ~ as.factor(master.dat$County), las = 2, cex.axis = 0.65, xlab = "", ylab = "pH")
186      dev.off()
187      # View the PDF file in RStudio
188 -    if (interactive()) {
189        # Open the PDF file using the system's default PDF viewer
190        rstudioapi::viewer("ph_county.pdf")
191 -    } else {
192        # For non-interactive sessions, print a message with the file location
193        cat("PDF file saved as 'ph_county.pdf'. Please open it using a PDF viewer.\n")
194 ^    }
195

196    #WasteinPlace
197      pdf(file = "WasteinPlace_summary.pdf", height = 6, width = 7, paper = "special")
198      par(mfrow = c(3,2))
199      par(mar = c(2.5, 4.5, 0.5, 0.5))
200      options(scipen = 999)
201
202      #Iron
203    waste.lm <- lm(master.dat$p01092 ~ master.dat$waste_tons)
204      plot(master.dat$waste_tons, master.dat$p01092, log ='xy',
205          xlab = "Waste Tons", ylab = "Iron (ug/l)")
206      abline(h = 0.30, col = "red")
207      title(ylab = "Iron (ug/l)")
208    #  abline(waste.lm, col = "blue")
209
210      #Arsenic
211      waste.lm <- lm(master.dat$p01092 ~ master.dat$waste_tons)
212      plot(master.dat$waste_tons, master.dat$p01092, log ='xy',
213          xlab = "Waste Tons", ylab = "Arsenic (ug/l)")
214      abline(h = 10, col = "red")
215      title(ylab ="Arsenic (ug/l)")
216
217
218      # fluoride
219      waste.lm <- lm(master.dat$p00950 ~ master.dat$waste_tons)
220      plot(master.dat$waste_tons, master.dat$p00950, log ='xy',
221          xlab = "Waste Tons", ylab =  "Fluoride (mg/l)")
222      abline(h = 4, col = "red")
223      title(ylab = "Fluoride (mg/l)")
224
225      # lead
226      waste.lm <- lm(master.dat$p01049 ~ master.dat$waste_tons)
227      plot(master.dat$waste_tons, master.dat$p01049, log ='xy',
228          xlab = "Waste Tons", ylab =  "Lead (ug/l)")
229      abline(h = 0.3, col = "red")
230      title(ylab =  "Lead (ug/l)")
```
:57:1   ☐ (Untitled) ‡   R Script ‡

```
224
225     # lead
226     waste.lm <- lm(master.dat$p01049 ~ master.dat$waste_tons)
227     plot(master.dat$waste_tons, master.dat$p01049, log ='xy',
228           xlab = "Waste Tons", ylab =  "Lead (ug/l)")
229     abline(h = 0.3, col = "red")
230     title(ylab =  "Lead (ug/l)")
231
232
233     # zinc
234     waste.lm <- lm(master.dat$p01092 ~ master.dat$waste_tons)
235     plot(master.dat$waste_tons, master.dat$p01092, log ='xy',
236           xlab = "Waste Tons", ylab =  "Zinc (ug/l)")
237     abline(h = 5, col = "red")
238     title (ylab =  "Zinc (ug/l)")
239
240
241
242
243   dev.off()
244   # View the PDF file in RStudio
245 - if (interactive()) {
246     # Open the PDF file using the system's default PDF viewer
247     rstudioapi::viewer("WasteinPlace_summary.pdf")
248 - } else {
249     # For non-interactive sessions, print a message with the file location
250     cat("PDF file saved as 'WasteinPlace_summary.pdf' Please open it using a PDF viewer.\n")
251 - }
252 - #########################################################################
253 - #########################################################################
254 - #########################################################################
255 - #########################################################################
256
257   |
258
```

Appendix B- USGS Metadata

```
# File created on 2023-11-30 12:50:18 EST
#
# U.S. Geological Survey
#
# This file contains selected water-quality data for stations in the National Water Information
# System water-quality database.  Explanation of codes found in this file are followed by
# the retrieved data.
#
# The data you have secured from the USGS NWISWeb database may include data that have
# not received Director's approval and as such are provisional and subject to revision.
# The data are released on the condition that neither the USGS nor the United States
# Government may be held liable for any damages resulting from its authorized or
# unauthorized use.
#
# To view additional data-quality attributes, output the results using these options:
# one result per row, expanded attributes.  Additional precautions are at:
# https://help.waterdata.usgs.gov/tutorials/water-quality-data/help-using-the-water-quality-data-retrieval-system#Data_retrievals_precautions
#
# agency_cd                 - Agency Code
# site_no                   - Station number
# sample_dt                 - Begin date
# sample_tm                 - Begin time
# sample_end_dt             - End date
# sample_end_tm             - End time
# sample_start_time_datum_cd - Time datum
# tm_datum_rlbty_cd         - Time datum reliability code
# coll_ent_cd               - Agency Collecting Sample Code
# medium_cd                 - Medium code
# tu_id                     - Taxonomic unit code
# body_part_id              - Body part code
# P00003                    - Sampling depth, feet
# P00010                    - Temperature, water, degrees Celsius
# P00020                    - Temperature, air, degrees Celsius
# P00021                    - Temperature, air, degrees Fahrenheit
# P00025                    - Barometric pressure, millimeters of mercury
# P00028                    - Agency analyzing sample, code
# P00029                    - Project number
# P00041                    - Weather, World Meteorological Organization (WMO) code
# P00045                    - Precipitation, total, inches
# P00056                    - Flow rate of well, gallons per day
# P00058                    - Flow rate of well, gallons per minute
# P00059                    - Flow rate, instantaneous, gallons per minute
# P00063                    - Number of sampling points, count
# P00070                    - Turbidity, water, unfiltered, Jackson Turbidity Units
# P00076                    - Turbidity, water, unfiltered, nephelometric turbidity units
# P00080                    - Color, water, filtered, platinum cobalt units
# P00090                    - Oxidation reduction potential, reference electrode not specified, millivolts
# P00095                    - Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
# P00098                    - Sampling depth, meters
# P00100                    - Time of travel, hours
# P00191                    - Hydrogen ion, water, unfiltered, calculated, milligrams per liter
# P00300                    - Dissolved oxygen, water, unfiltered, milligrams per liter
# P00301                    - Dissolved oxygen, water, unfiltered, percent of saturation
# P00310                    - Biochemical oxygen demand, water, unfiltered, 5 days at 20 degrees Celsius, milligrams per liter
# P00340                    - Chemical oxygen demand, high level, water, unfiltered, milligrams per liter
# P00400                    - pH, water, unfiltered, field, standard units
# P00403                    - pH, water, unfiltered, laboratory, standard units
```

Appendix C- Excel File for "USGSwells"

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	SITENO	NEAR_DIST	LandfillID	LandfillName	City	County	Zip	Ownership	open_year	close_year	status	waste_tons	waste_year
2	4.60134E+14	0.3660368	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
3	4.60254E+14	0.35450126	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
4	4.60653E+14	0.26498735	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
5	4.60928E+14	0.22004643	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
6	4.61037E+14	0.20214061	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
7	4.611E+14	0.40489752	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
8	4.61144E+14	0.41551709	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
9	4.61309E+14	0.16106326	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
10	4.6133E+14	0.36426941	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
11	4.61332E+14	0.15209789	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
12	4.61346E+14	0.14724342	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
13	4.61404E+14	0.14471598	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
14	4.61605E+14	0.11261966	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
15	4.62304E+14	0.02920045	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
16	4.62343E+14	0.2432982	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
17	4.624E+14	0.07025366	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
18	4.62446E+14	0.06844356	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
19	4.62613E+14	0.0609359	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
20	4.62651E+14	0.24400172	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
21	4.62708E+14	0.07663586	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
22	4.6271E+14	0.07684429	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
23	4.62923E+14	0.12379874	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
24	4.62926E+14	0.12932891	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
25	4.62938E+14	0.1256213	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
26	4.63327E+14	0.31685217	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
27	4.6333E+14	0.2952003	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
28	4.63508E+14	0.42360359	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
29	4.63802E+14	0.54302508	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
30	4.63833E+14	0.46778243	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
31	4.63833E+14	0.46778243	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
32	4.63956E+14	0.5168028	21146	Wood Island	Wetmore	Alger	49895	Private	1992	2044	Open	1760609	2021
33	4.4254E+14	0.64825319	393642	HOLCIM (US)	Alpena	Alpena	49707	Private	1970	2025	Open	398,000	2022
34	4.42621E+14	0.63246444	393642	HOLCIM (US)	Alpena	Alpena	49707	Private	1970	2025	Open	398,000	2022
35	4.42629E+14	0.63193711	393642	HOLCIM (US)	Alpena	Alpena	49707	Private	1970	2025	Open	398,000	2022
36	4.4263E+14	0.63002972	393642	HOLCIM (US)	Alpena	Alpena	49707	Private	1970	2025	Open	398,000	2022
37	4.42631E+14	0.62990582	393642	HOLCIM (US)	Alpena	Alpena	49707	Private	1970	2025	Open	398,000	2022

USGSwellsExcel_B

Conclusion

As shown by the results, USGS wells near a landfill were found to have an exceeding amount of heavy metals pollution. While the point-source of pollution can vary based on other sources of pollution that may also be around the landfill. We can suggest by the results found that residents using private wells near a landfill should routinely check their water quality. In addition, those communities should have priority in government funding for water quality testing to ensure equitable and accessible assurance to clean water. While no evidence was found on the placement of landfills based in minority and impoverished communities within this research, more research is needed to understand the city, neighborhood, and diversity index of exact locations of landfills. More people are populating the earth, which means more trash is being generated, and our relationship with waste management has not yet represented sustainability. Water interconnects us all and the trash we produce is polluting our water in more ways than one. The issue of leachate pollution from landfills poses a persistent threat to groundwater wells in Michigan. The existing EPA regulations do not adequately address the long-term consequences of leachate contamination and the potential harm it can cause to public health. Addressing this issue requires effective regulation, ongoing monitoring, and a commitment to safeguarding groundwater. "The cost of monitoring, removing, and cleaning leachates from our groundwater supply, as well as the need to abandon contaminated wells, underscores the urgency of the problem and the need for proactive solutions to protect our environment and public health" (Steinman et al. 2022). In addition, with the EPA not requiring private well water sampling we lack information and the accessibility of knowing how safe the groundwater supplying private wells are. With this study, we as a community can acknowledge our relationship to waste and how we can create this circular economy mindset in our own lives; while also advocating for safe drinking water in every community, under every circumstance. Federal and state policy should be responsible for ensuring no corporation is abusing this shared resource with laws that require consistent water quality testing and extraction limits. Let's provide our groundwater with the same care and protection as we do our surface waters in the Great Lakes Basin as it is all one water.

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