The Negative Impacts of Wastewater Treatment Plant Operation on the Health and Quality of Life of Neighboring Communities

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Background

In 2017, 1.6 million people died due to diarrheal diseases, among the leading causes of death worldwide (Dadonaite, Ritchie, & Roser, 2019). Unsafe drinking water, inadequate availability of water for hygiene, and lack of access to sanitation were attributed to around 88% of these deaths (Centers for Disease Control and Prevention, 2018). 1.2 million people in Dakar, Senegal alone had no flushing toilets and were not connected to a sewer line in 2015 (Cashman, 2020). Instead, they used tiny pit latrines in the middle of their streets, increasing the possibility of exposure to pathogens and other contaminants leaching into the surrounding environment (Cashman, 2020). More than 2.4 billion people (one-third of the world) face living in such unsanitary conditions because they do not have access to improved sanitation (Ritchie & Roser, 2019). The combination of inadequate sanitation, hygiene, and clean drinking water is a major cause of poor living standards, vulnerability to disease, and poverty (World Health Organization, 2019).

These ubiquitous concerns over sanitation and health could be attributed to ineptitude in safely dealing with sewage produced on a daily basis. In 2019, nearly 4.5 billion people (60% of the world) did not have access to sanitation facilities that safely manage their excreta and wastewater (Ritchie & Roser, 2019). Wastewater is water that has been used by homes, businesses, and industries but also includes storm runoff (United States Geological Survey, 2020). It contains an amalgamation of undesirable substances: human waste, food scarps, oils, soaps, chemicals, excessive nutrients, bacteria, viruses, and disease-causing pathogens (United States Geological Survey, 2020). When wastewater is left untreated or inadequately treated to specific standards set by governments, this can have tangible, deleterious impacts on ecosystems and human health. Harmful pollutants and organic material can seep into groundwater, polluting drinking water sources, such as wells. They can also enter surface water, such as lakes and rivers, posing a threat for human exposure to waterborne illnesses, such as hepatitis-A, typhoid, polio, cholera, and dysentery (Taylor, Yahner, Jones, & Dunn, 1997). Wastewater treatment (WWT) is intended to prevent such effects through the creation of wastewater treatment facilities (WWTFs), or wastewater treatment plants (WWTPs). WWTPs intake wastewater and significantly reduce the amount of pollutants to a level that nature or humans can handle (Cressler, 2018). In the United States alone, there are more than 16,000 functional wastewater treatment plants (American Society of Civil Engineers, 2021). However, WWTPs have been identified as a significant source of emerging organic contaminants, pathogenic airborne microorganisms, and released harmful gases, called aerosols (Navarro et al., 2018; Vantarakis et al., 2016). All of these constitute significant health risks to plant workers and surrounding inhabitants of WWTFs (Vantarakis et al., 2016). In addition, people who live within a closer proximity to treatment plants can experience a lower overall satisfaction of life compared to communities located farther from them (Vantarakis et al., 2016).

WWTPs convert the world’s waste into water that is acceptable for humans and the environment. Their intent is to, in turn, better the living conditions for city populations by increasing access to sanitation, hygiene, and potable water. Despite this benevolent intent, WWTP operation can counterproductively marginalize and harm certain communities, namely those living closest to it. This paper explores how WWTP operation negatively impacts the health and quality of life of surrounding communities.

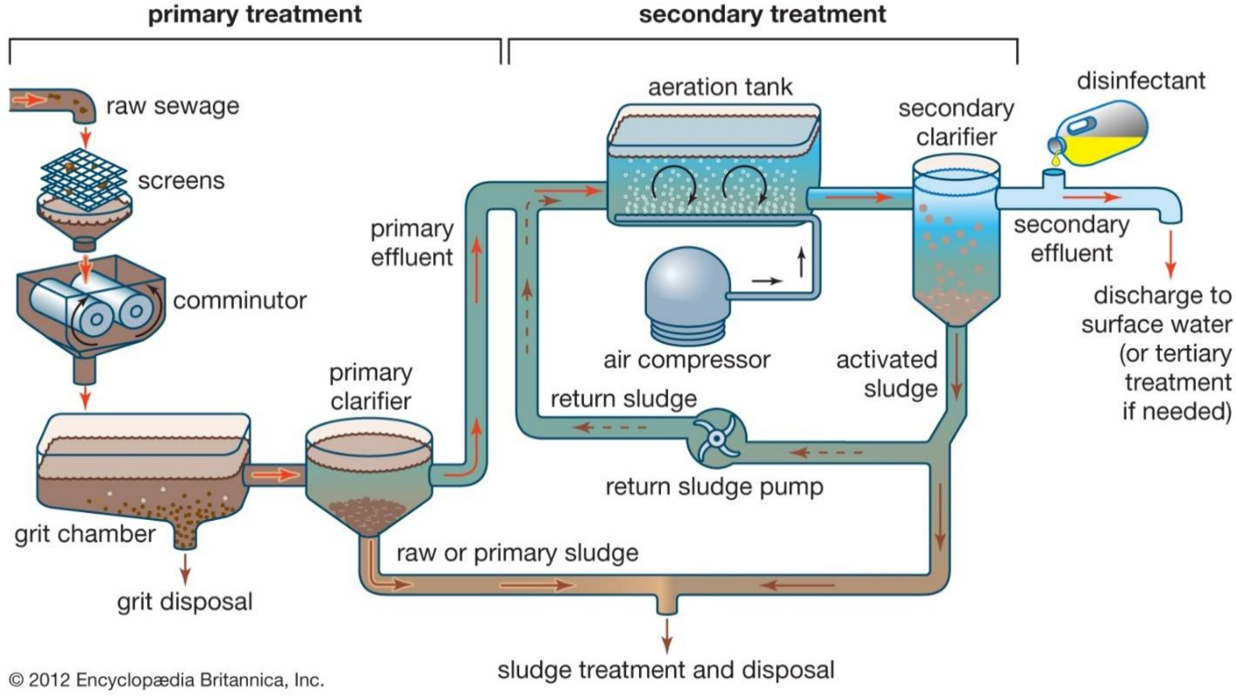

Figure 1. Flow Diagram of a Wastewater Treatment Process (Britannica, 2021).

Conventional Wastewater Treatment Process

Wastewater purification entails a variety of sequential steps to convert highly contaminated water into an effluent that can be returned to the water cycle with a minimized impact on the environment and humans (Wikimedia Foundation, 2020b). The process typically entails three stages: primary treatment, secondary treatment, and disinfection. The general overall WWT process is shown in Figure 1 above. During primary treatment, raw sewage must first pass through screening equipment to remove objects that could potentially damage other equipment in the treatment process. This can include cans, rags, wood fragments, plastics, and hair (AES Arabia, 2020; City of Oconomowoc, WI, 2021). Materials that are held back by the screen will skip the treatment process to be washed and safely disposed of in a landfill. Other materials in the wastewater will enter a comminutor. This is a sewage grinder used to reduce the particle size of wastewater solids (Jamrock, 2020). The wastewater will then enter a grit chamber to remove heavy but finer material, such as silt, sand, and gravel (Britannica, 2021; City of Oconomowoc, WI, 2021). In grit chambers, water velocity is maintained sufficiently high to prevent the settling of most organic solids (Food and Agriculture Organization, 2021). These “grit” materials are removed from the bottom of the chamber and separately disposed of. The first three aforementioned steps of primary treatment (screening, comminution, and grit removal) are typically referred to as “preliminary treatment” (United States Environmental Protection Agency, 1987). The velocity of wastewater is significantly slowed upon entrance into the primary clarifier, or a sedimentation tank. This piece of equipment removes material in the water that will readily settle out by gravity (Britannica, 2021). The wastewater spends approximately two hours in this tank to allow settleable solids to sink (Britannica, 2021). These primary solids, called raw or primary sludge, are pumped from the bottom of the sedimentation tank and subjected to sludge treatment and disposal processes (ibid.). The water that exits the primary clarifier, called the primary effluent, can then proceed to secondary treatment.

Secondary treatment involves several steps to remove the soluble organic matter that escapes primary treatment (Britannica, 2021). Primary effluent will enter an aeration tank, where the introduction of microbes and oxygen causes biological degradation to take place. Microbes are continually fed oxygen by an air compressor, which induces rapid mixing within the tank (ibid.). Mixing allows microorganisms to consume thousands of organic impurities in wastewater and convert them into carbon dioxide, water, and energy needed for their own growth and reproduction (ibid.). This induced biological activity is reminiscent of what naturally occurs at the bottom of lakes and rivers over several years (City of Oconomowoc, WI, 2021). Microorganisms that thrive in oxygenated wastewater conditions form an active, healthy suspension of biological solids known as activated sludge (Britannica, 2021). After an aeration period of approximately six hours, the dissolved organics in the wastewater have been consumed and transformed into activated sludge (ibid.). The wastewater then enters a secondary clarifier, where activated sludge can be separated from water and removed from the bottom of the tank. Approximately 30% of this activated sludge is still valuable because these microbes are well acclimated to the sewage environment and can readily metabolize more organic material (Britannica, 2021). Therefore, a portion of the activated sludge will be combined with primary effluent and reintroduced into the aeration tank to undergo biological degradation again. However, the remaining 70% of this secondary sludge will be combined with the raw or primary sludge to undergo final sludge treatment and landfill disposal (ibid.). At the conclusion of secondary treatment, approximately 85-90% of organic matter and other contaminants in sewage have been successfully removed (Safe Drinking Water Foundation, 2021).

The final step in customary WWT is disinfection, also known as advanced or “tertiary” treatment. This stage ensures that wastewater effluent is free of bacteria that may still remain (City of Oconomowoc, WI, 2021). Methods can include chlorination, ultraviolet (UV) radiation, and ozone treatment. The final effluent of WWTPs must be tested for pathogenic bacteria, which could have adverse effects on humans and ecosystems. These bacteria levels must be within specified discharge permit levels (City of Oconomowoc, WI, 2021). Further water analysis and testing for proper pH levels, ammonia, nitrates, phosphates, dissolved oxygen, and residual chlorine levels may be performed so WWTPs can conform to national pollutant discharge elimination system (NPDES) permits (Cole-Parmer, 2020). Once a WWTP has met their permit-specific standard, wastewater has officially become safe enough to discharge into environmental waters and the WWT process is complete.

After the treated water has been safely discharged into a natural environment, it can be sent to a municipal water treatment plant (MWTP) where the water will be treated to a standard acceptable for human consumption. Because WWTPs expel effluent to natural waters and MWTPs receive influent from these natural waters, the environment is considered a “buffer” between the two processes. The purpose of this is to lessen the “yuck factor”, or the typical negative public perception of drinking water that was once contaminated with waste.

Actor Network Theory and Wastewater Treatment Processes

Clearly, the WWT process is an extremely complex, technologically-reliant process that also involves many people and organizations to ensure that wastewater is treated to specific standards. Due to this complexity, Latour’s (1992) Actor Network Theory (ANT) will be utilized to define and describe the actors involved and emphasize their importance across the board. More specifically, the concepts of program of action (POA), delegation, and discrimination will provide the foundation for investigating how WWT operation can have negative impacts on surrounding communities’ health and quality of life.

The social and natural worlds exist in incessantly shifting networks of relationships (Wikimedia Foundation, 2020a). These networks are the sum of material and semiotic “actors” that interact to form relationships. An actor is defined as the source of an action regardless of its status as human or nonhuman (Cresswell, Worth, & Sheikh, 2010). Actors within a network comprise three separate categories: human, tangible nonhuman, and nontangible nonhuman. While human actors denote a living user or producer of technology, nonhuman actors are inanimate entities that take over the selective attitudes of those who engineered them (Latour, 1992). However, nonhumans can be both palpable and abstract. Tangible nonhuman actors involve pieces of technology themselves that can replace the designated role of a human actor. Nontangible nonhuman actors include ideas, perceptions, and customs that contribute to the environment and manner in which a network operates. Multitudinous humans, organizations, technologies, materials, ideas, and customs all equally work together to uphold the system. Each actor's defined role within the heterogenous network makes the WWT network functional.

ANT acknowledges that relationships are developed through negotiations between people, institutions, and organizations (Latour, 1992). However, Latour emphasizes that material artifacts are an integral part of these negotiations as well. All of these entities in a network should be described in the same terms, allowing human and nonhuman actors to be treated equally (Wikimedia Foundation, 2020a). Therefore, each stakeholder, both human and nonhuman, are studied symmetrically in ANT (Latour, 1992). Latour opines that technological artifacts can be deliberately designed to both replace human action and constrain and shape the actions of other humans in the network. In this sense, networks are constantly evolving as social reality is both complex and fluid (Cresswell et al., 2010; Law, 1999).

Program of action

Program of action (POA) denotes goal-directed behavior of both human actors and technological artifacts (Schulz-Schaeffer, 2006). For a human actor, POA consists of a human strategy for goal attainment (Schulz-Schaeffer, 2006). For a nonhuman actor, this includes an algorithm determining the behavior of a piece of technology (ibid). Latour (1992) denotes POA as an actor's set of goal-oriented written instructions. While each individual actor has a uniquely-prescribed POA, they are all innately interrelated by the overarching POA of a network. This broad POA is considered the answer to the undesired outcomes, or antiprogram, against which the mechanism braces itself (Latour, 1992). Every actor is only one portion of the overarching POA and of the fight necessary to win against many antiprograms (Latour, 1992). When one actor fails to uphold their individual POA, other POAs in the network are compromised and the overarching POA is nullified. For every living person in the network, the POA is to understand and effectively execute the tasks for which there is not a technological replacement. For each piece of technology and equipment in a network, the POA is to function by its particular affordance and its scripted use or purpose (Foley, 2017).

Delegation and discrimination

Some actors perform tasks delegated to them in an innately more deliberate and effective way than the actants who would otherwise perform the task (Schulz-Schaeffer, 2006). Therefore, to preserve the functionality of a network, parts of a POA may be delegated to a human or nonhuman actor (Latour, 1992). Latour (1992) describes this as the transformation of a major effort by one actor into a minor effort by another. When actors in a network have been prescribed a certain goal-oriented task or behavior that becomes too burdensome or unrealistic to maintain, they can displace, translate, delegate, or shift the work to better uphold the POA. In the WWT network, this is most often seen in shifting the POA from a human actor to specific inanimate inventions or technologies. This translation of POA means that humans place extreme faith in technologies to function exactly as they were intended to. When these technologies fail to do this, discrimination can occur.

While the process of delegation may be intended to ensure that a specific POA is effectively upheld, certain actors may be discriminated against as a result. So even when individual delegated and prescribed goals are met by each actor, other actors and relationships can experience undesired effects. In this sense, networks can establish structures of discrimination because of a natural distribution of competences between humans and nonhumans (Latour, 1992). Inventors of technology act as a moderator between humans and nonhumans, having a profound influence on both types of actors. They can “act at a distance” through the design of their technologies and the technology can appear to compel certain actions from the user (ibid.). To avoid discrimination, inventors of technology must reinvent by imagining a nonhuman character that will not prescribe certain goals and actions to its human users (ibid.). However, certain values and structures of discrimination are inevitably achieved through the development and incorporation of technologies in the world (ibid.).

ANT is a framework used to identify and describe the many actors involved in an operational network as well as the relational ties between them (Nyakuengama, 2014). Latour’s ideas of POA, delegation, and discrimination illuminate how a single actor (and their delegation of responsibility to another) has the ability to contribute to the dismemberment of the original fabric of WWT. One actor (whether nonhuman or human) has the capability to make the entire process of WWT not only counterproductive to its original intent, but hypocritical. Understanding the POAs and delegated roles of each actor within wastewater industry can highlight how and why WWT operation allows for discrimination to occur against neighboring communities.

Research Question and Methods

The research question unites communities negatively impacted by WWTF operation around the world by highlighting one single commonality: proximity to a WWTF. The thesis will investigate how communities adjacent to WWTF operation have been marginalized by the operation of facilities designed to abate the harm that wastewater poses to humans. More specifically, how does the operation of WWTFs impact the health and quality of life of communities that live near them?

Data of negative impacts will be gathered and dissected into two categories: human health and quality of life. Evidence of WWTP health impacts will be gathered from published chemistry, environmental science, and technology journals (Gobelius et al., 2018; Hu et al., 2016; Stoiber, Evans, & Naidenko, 2020; Vantarakis et al., 2016). Evidence of health effects include research on WWTP release of harmful emerging contaminants, namely polyfluoroalkyl substances (PFASs), and airborne biological aerosols. Symptoms and diseases associated with their release from WWTPs will be presented to link WWTP operation to tangible human consequences. Quality of life will be studied using a case control study of 235 inhabitants living within a 500-meter radius of a WWTF (Vantarakis et al., 2016). More specifically, frequency of negative emotions (bad mood, angry, tired, sick, etc.) and unpleasant odors were considered the negative quality-of-life impacts of interest. This study also performed an evaluation of air microbiological quality surrounding the WWTP and nearby community, which will be presented as both a quality-of-life and human health impact.

The method of data analysis is a consequential analysis of specific risks to humans that are associated with living near WWTP operation. The abovementioned case study and scientific research articles will be utilized to collect concrete evidence of this. Data will be interpreted using Latour’s ANT to classify which actors within the WWT network are accountable for neglecting neighboring communities. This overall network will be analyzed using ANT’s themes of POA, delegation, and discrimination.

The Negative Impacts of the WWT Network

WWTPs worldwide has been shown to compromise the health of communities living adjacent to their operation (Stoiber et al., 2020; Vantarakis et al., 2016). Health-impairing contaminants contained in wastewater have returned to humans by way of surface or groundwater migration (Galke & SCS Engineers, 1979). WWTPs have been linked to releasing carcinogenic contaminants that are particularly persistent in a variety of environmental compartments, namely polyfluoroalkyl substances (PFASs) (Stoiber et al., 2020). PFASs can have serious consequences on human health, especially to those living closest to the water, air, and soil that these contaminants are incorporated into. A few include elevated cholesterol levels, high blood pressure, changes in liver enzymes, and increased risk of kidney and testicular cancer (Agency for Toxic Substances and Disease Registry, 2020). Additionally, WWTFs release biological aerosols, or bioaerosols, that contain harmful bacteria and pathogens (Galke & SCS Engineers, 1979; Stoiber et al., 2020). The release of aerosols into surrounding air, when inhaled by WWTP workers and communities nearby, are capable of producing skin, digestive system, respiratory, and nervous system diseases as well as human allergies (Kruczalak & Olańczuk-Neyman, 2004; Vantarakis et al., 2016). Adjacent communities to WWT operation also experience negative impacts on their life satisfaction, or “quality of life” (Vantarakis et al., 2016). Those in closest proximity to WWTP operation were found to have higher incidences of bad mood, anger, sickness, neural symptoms, and mental disorders (Vantarakis et al., 2016). The air quality surrounding the WWTP, closest to this community, was shown to have the highest exposure to culturable bacteria (Vantarakis et al., 2016).

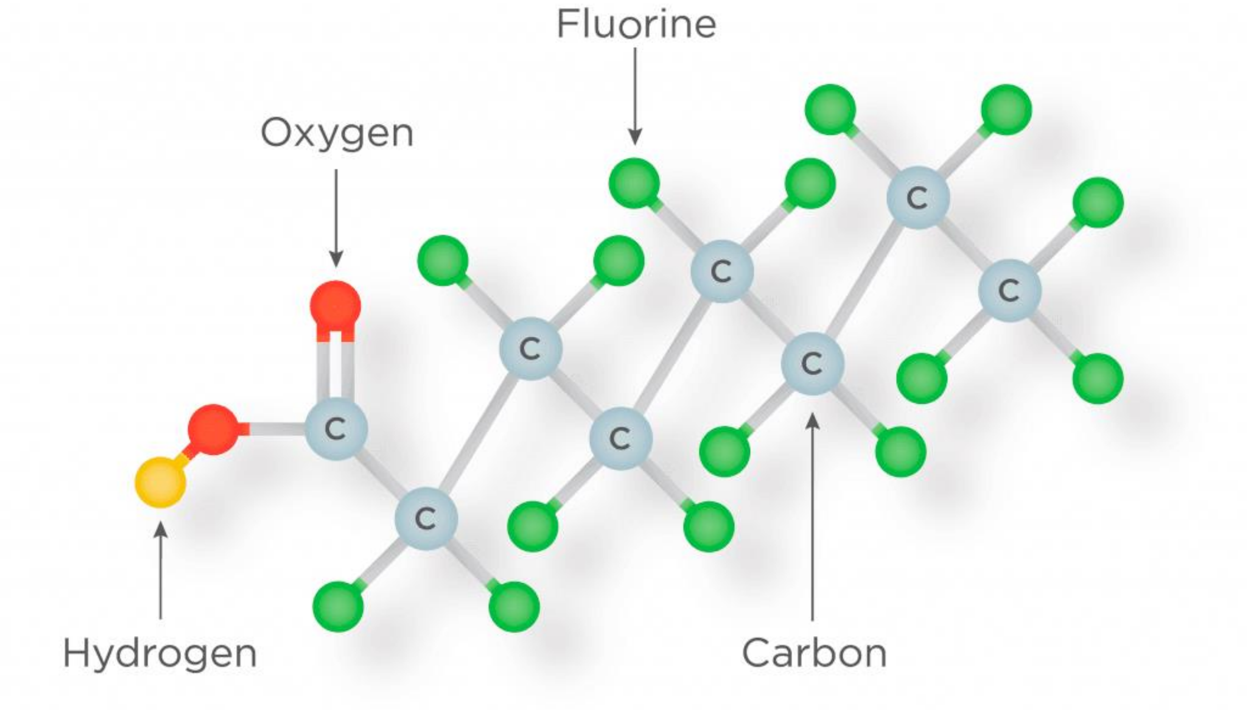

Figure 2. Chemical Structure of a Polyfluoroalkyl Substance (PFAS) (Mansfield Massachusetts Public Health Department, 2021).

Impacts on human health

WWTPs have been identified as a prominent source of compounds linked to deleterious effects on human health, exposing those closest to their release to more serious risk than the general public. These are per- and polyfluoroalkyl substances, or PFAS (Stoiber et al., 2020). This class of manmade chemicals have been used to make products that can resist heat, oil, stains, grease, and water since the 1940s (Centers for Disease Control and Prevention, 2019; United States Environmental Protection Agency, 2016). PFASs, see Figure 2 above, are highly stable chemicals that are persistent in both the environment and human body (United States Environmental Protection Agency, 2016). Human PFAS exposure has been linked to numerous negative health effects, including deleterious effects on thyroid function, immune response, pregnancies and (Hu et al., 2016; Stoiber et al., 2020). Exposure to PFAS can come from dietary sources, household dust, air, and drinking water (Hu et al., 2016).

WWTPs receive liquid PFAS-laden waste from municipal wastewater, landfills, and industrial wastes (Stoiber et al., 2020). Despite its effectiveness in treating suspended organic, inorganic, and biological material, conventional WWT processes do not remove PFAS (Stoiber et al., 2020; United States Geological Survey, 2020). In fact, effluent from WWTPs can have higher levels of detectable PFAS compared to the influent, which suggests that, in the course of WWT, PFAS are transformed into smaller, more mobile species (Stoiber et al., 2020). This poses great risks to the health of neighboring communities who live closest to the surface waters where the effluent is discharged and whose drinking water sources are nearest the WWTP itself.

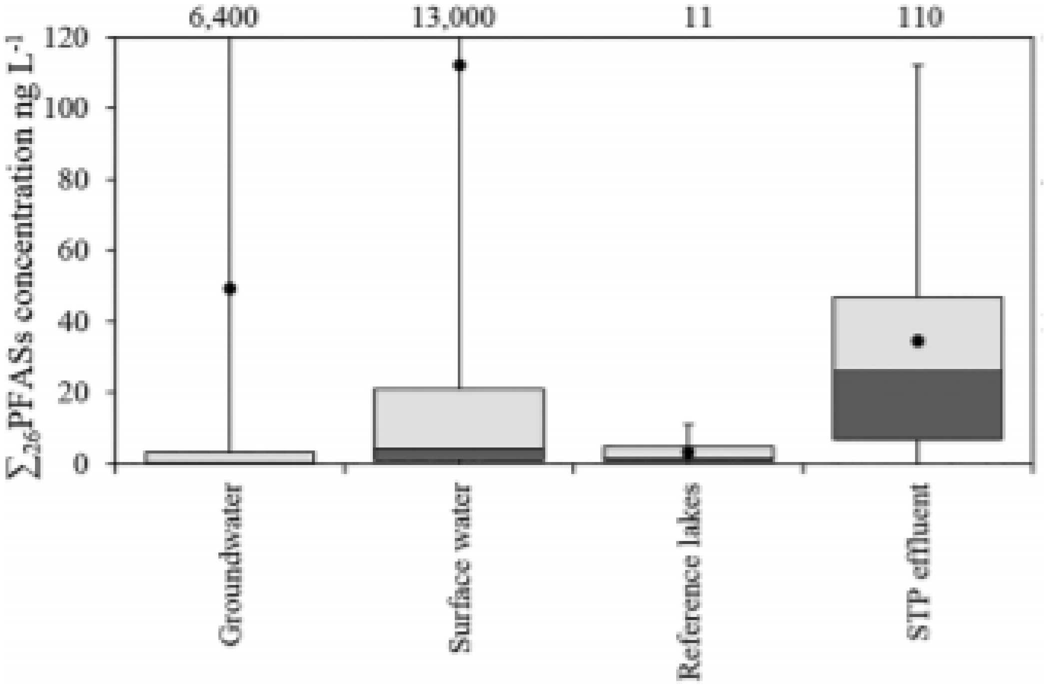

Figure 3. Boxplot Diagram with Whiskers Showing the $\sum_{26}$PFAS Concentrations [ng L^{-1}] in Groundwater (N = 161), Surface Water (N = 289), Reference Lakes (N = 10), and STP Effluent (N = 13). The Maximum Concentrations are Given at the Top (Gobelius et al., 2018).

Gobelius and others (2018) measured the concentrations of 26 PFAS compounds in a variety of Swedish aquatic environments surrounding a WWTP. 161 groundwater sources, 289 surface water sources, and 13 WWTP effluents were sampled and compared with 10 references lakes. The combined concentrations of the 26 combined PFAS compounds are shown in Figure 3 above, where the maximum concentrations are given at the top. It was found that WWTP effluents had a $\sum_{26}$PFASs mean concentration of 35 nanograms per liter (ng L^{-1}), with a maximum concentration of 110 ng L^{-1}. In the variety of surface waters (lakes and rivers), the mean and maximum concentrations were significantly higher: 110 ng L^{-1} and 13,000 ng L^{-1}. Groundwater samples resulted in mean and maximum concentrations of 50 ng L^{-1} and 6,400 ng L^{-1}. According to Swedish drinking water guidelines, a combined concentration for 11 PFAS compounds should not breach a threshold value of 90 ng L^{-1}. Compared to both the concentrations found in 10 reference lakes and promulgated by the Swedish Environmental Protection Agency (EPA), this data is suggestive of PFASs exiting WWTPs at relatively lower concentrations. However, PFAS infiltrates into surrounding communities' groundwater supplies and surface waters at substantially larger concentrations, beyond that of governmental recommendation. PFASs are known to be released from WWTPs in pathways besides the water effluent itself. This includes volatilization during the treatment process and subsequent sludge application as agricultural fertilizer (Alder & van der Voet, 2015; Gobelius et al., 2018).

This study links WWTFs to the releasing PFAS into surrounding communities, where these compounds spread and amplify into a variety of water sources. Adverse health effects can include those of carcinogens, such as immunosuppressive effects and changes to hormone balance and thyroid function (Stoiber et al., 2020). These concerns not only become a massive concern for all people living in the area studied in Sweden, but especially for those located close to this WWTP itself. This study proves how neighboring communities of plant operation are disenfranchised as their water and air has the possibility of containing significantly higher amounts of PFAS than what governments have promulgated. Adjacent communities blindly subject themselves to the risks that PFASs pose to their health simply by living near a WWTP. The general public, while not immune to the health effects of PFAS from WWTPs, possesses an inherent reduced risk based on their farther proximity to WWTP operation.

Air quality and its pollution significantly influences the health and good living of humans, animals, and plants inhabiting it (Blanchard & Syzdek, 1970; Vantarakis et al., 2016). WWTPs are considered a major source of biological aerosols, or bioaerosols, that contain different types of microorganisms such as viruses, pathogenic bacteria, and fungi, capable of

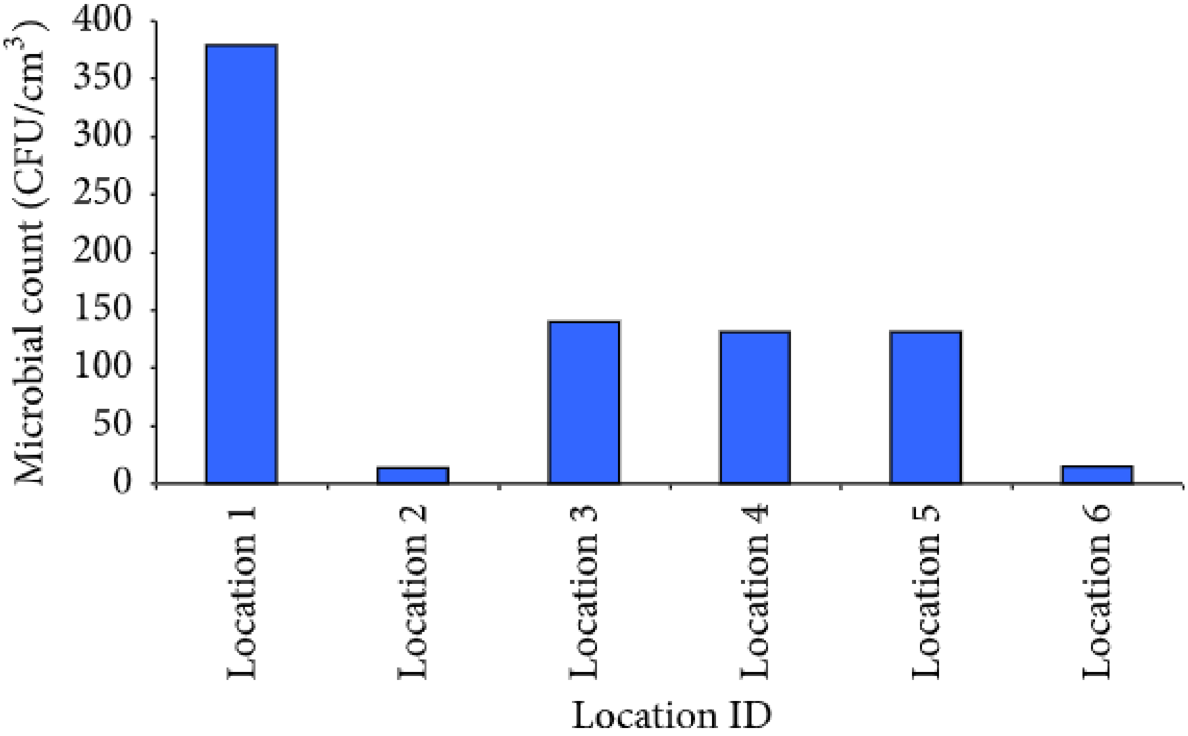

Figure 4. Average Microbial Count Per Sampling Location (CFU/m^3) (Vantarakis et al., 2016).

causing skin, digestive system, respiratory, and nervous system diseases and human allergies (Kruczalak & Olańczuk-Neyman, 2004). Vantarakis et al (2016) conducted a microbiological analysis of the surrounding air at various distances from a WWTF in Patras, Greece. This microbial investigation was carried out during ordinary workdays when biological treatment was normally running (Vantarakis et al., 2016). Culturable airborne bacteria was collected in air samples at six different sampling stations (1-6 in Figure 4 above), each increasing in distance from above the center of the WWTF. The calculated concentrations at each station are shown in Figure 4. The closest sampling location (Location 1) has the highest concentration of airborne microorganisms, with 340.89 colony forming units per cubed meter (CFU/m^3). Biological concentrations generally decreased with distance from the plant, showing how it is adjacent communities, in particular, whose air quality suffers based on their living situation. Along with this poorer air quality comes the perils of breathing and living in it, particularly with the aforementioned health symptoms and diseases that can arise thorough the inhalation of microorganisms present in air. In a standardized questionnaire administered to individuals living within 500 meters of the WWTF, Vantarakis and others (2016) found that 43.4% of individuals living adjacent to the facility reported having neural symptoms and/or diseases, compared to 18.6% of individuals living further away. This microbial study signifies the tangible health effects that specific communities face as a result of WWTP operation due to water laden with PFAS and air occupied with harmful bacteria.

Impacts on quality of life

Vantarakis and others (2016) investigated the "quality of life" impact on people living in close proximity to a municipal WWTP in Patras, Greece through a case control study. This study included 235 inhabitants living permanently within a 500-meter radius of the plant for more than eight hours per day (cases) (Vantarakis et al., 2016). The results were compared against 97 inhabitants living permanently in an area located more than 5 kilometers from the plant (controls) (Vantarakis et al., 2016). A standardized questionnaire about general health perception and overall life satisfaction was administered and self-completed by the majority of all participants. Frequency of negative feelings experienced by the two groups during the study period is shown in Table 1 below.

Table 1. Frequency of Negative Feelings Experienced by the Cases and Controls

Sample Characteristics	# Cases (%)	# Controls (%)	P Value
Mood	126 (53.6%)	60 (63.8%)	0.058
Frequency of bad mood (>2/week)	54 (42.9%)	17 (28.4%)	**< 0.05**
Angry	135 (57.4%)	52 (58.4%)	0.873
Frequency of being angry (>2/week)	64 (47.4%)	19 (36.6%)	**0.05**
Sick	36 (15.3%)	19 (21.1%)	0.213
Frequency of being sick (>2/week)	24 (68.6%)	4 (22.3%)	**0.001**

The total percentage of people reporting experiencing bad mood, anger, and sickness during the study period was similar between the cases and controls. However, frequencies of experiencing these negative feelings more than two days per week were statistically different ($p < 0.05$) between the cases and controls. More specifically, 42.9% of cases reporting having a bad mood experienced it more than two days per week, compared to nearly 28.4% of controls (Table 1). 47.4% of cases reporting anger experienced it more than two days per week, compared to 36.6% of controls. The most statistically-significant result was found in the frequency of sickness: 68.6% of cases reporting feeling sick experienced it more than two days per week, compared to merely 22.3% of controls. This elevation in experiencing bad mood, anger, and sickness for individuals living within 500 meters of a WWTP is indicative of treatment operation disenfranchising neighboring communities over others in terms of their quality of life.

The questionnaire results also found a statistically-significant fact about the difference in health symptoms associated with living distance from a WWTP. Individuals living closer to the WWTF had a noticeably higher rate reporting neural disorders compared to controls: 43.4% compared to 18.6%. An undisclosed but increased rate of mental disorders was also reported by the population living near the WWTP. Higher rates of neural and mental disorders and diseases are suggestive of a trend of lower overall health and, therefore, quality of life for communities living nearby WWT operation.

Other aspects were analyzed in the questionnaire concerning undesirable qualities of living near a WWTP. 79.6% of cases reported unpleasant odors coming from the facility at some point in a normal day, 61.7% of which reported this more than three days per month. Additionally, the perceptions about WWTPs by fence-line communities was noticeably positive: 72.8% of residents found the presence of the WWTP "indispensable", while only 17.4% believed that it was dangerous to their health. Nearly three quarters of the cases positively described the WWTF as providing an essential service, yet less than one quarter thought of it negatively in terms of impacting human health. The study conducted by Vantarakis and others proves that despite this general positive perception of WWTP operation by close communities, the majority of people actually reported similar negative effects on their quality of life. Clearly, this is a reality that marginalized people are unaware of and, for many, unable to escape.

Absence of a program of action by governments is discrimination

The WWT network is made up of technologies, researchers, WWTP employees, government agencies and regulators, and even the general public perception of WWTPs. All of these interacting actors (with individual delegated roles) allow the WWT process to function.

However, WWTPs have no regulatory obligation of examining how close communities' lives are impacted by their operation. This is because government agencies and regulators do not prioritize emerging contaminants which, in turn, allows WWTPs to continually release them regardless of their potential harm. Therefore, people in bordering regions of WWTP operation are blatantly marginalized and negligently discriminated against because of the inattention and refusal by governments and WWTFs to establish a POA for protecting these communities.

The only true responsibility of WWTPs that governments can hold them accountable for is to conform to the facility-specific national pollutant discharge elimination system (NPDES) permits and emissions standards. These require WWTPs to treat a plethora of chemicals and compounds in air and water to certain standards before releasing and are legally enforced by national governments (United States Environmental Protection Agency, 2015). However, contaminants of concern (CECs) or emerging contaminants, such as PFAS, are not included as a primary standard, or even considered secondary for that matter. There is typically less public knowledge about the risks and consequences associated with human exposure to CECs than compounds treated as primary standards. CECs continue to undergo research, testing, and evaluation to understand their point sources and impacts to a greater depth. Because WWT is a ceaseless process throughout the world, WWTPs continue to release CECs, without complete knowledge of their effects on humans and the environment. This being said, there is no POA for WWTPs to treat PFAS because of its recognition as a CEC. And therefore, conventional technologies within WWTFs are not designed to remove them. Unlike the contaminants acknowledged under primary drinking water standards, CECs are ignored by current technologies as their delegated roles and POAs revolve around treating government-deemed "primary" contaminates to a specified level. Even when all actors within the WWTPs technically fulfill their delegated POAs, discrimination against adjacent communities to WWT operation can occur because there is an absence of a functional POA to address emerging toxins. Just because WWTPs may be addressing their contaminants of primary concern, this does not absolve them of participating in the discrimination of adjacent communities. More than 16,000 communities in the United States and thousands of others worldwide still bare the damaging consequences of PFAS-laden water and elevated bacteria in their air.

Limitations and future work

There were a variety of limitations found during the investigation of how fence-line communities are affected by WWTP operation. While data on WWTP operation impacting the general public is more accessible and abundant, data pinpointing the health and quality-of-life impacts on fence-line communities was much more elusive. This limited the amount of data that was available for the investigation. Additionally, the subjective nature of "quality of life" meant each case study and research article studied it differently. This being said, the impacts on a person's quality of life and life satisfaction are difficult to quantify and standardize for adjacent communities around the world. Therefore, the limited data collected from Vantarakis et al (2016) and Gobelius et al (2018) was utilized as representative of the all adjacent communities to WWTP operation. Because the health effects of emerging contaminants are still being traced and identified, there was less consistent data detailing the specific health effects of PFAS specifically released from WWTPs. Additionally, when air quality data was collected by Vantarakis et al (2016), it was noted that the results of the air microbiological analysis only represent a "picture" of the sampling time. Physiochemical properties of the air as well as the degree of contamination at a given point can significantly change within a few minutes (Maier, Pepper, & Gerba, 2000;

Vantarakis et al., 2016). The data of health and quality of life effects on adjacent communities cannot realistically be extrapolative, both in terms of time and location, even though it was assumed to be for the purpose of this investigation.

In the future, it would have been beneficial to collect data on how many countries in the world actually have government-set standards for emerging contaminants, such as PFAS, and what their PFAS effluent standards for WWTPs are. Such data could have been presented to highlight the lack of governmental protections for nearby communities throughout the world. It could have also served as a more extrapolative form of evidence for the blatant disregard by governments to establish a POA for protecting fence-line communities' health and quality of life. Future investigation could involve incorporating primary sources, such as surveys administered to the community surrounding a Charlottesville WWTP. This, combined with the previous case studies and research articles, could have substantiated the link between living location of a WWTP and tangible impacts on health and quality of life.

My engineering practice has been advanced through increasing my awareness to the importance of not only acknowledging the unanticipated, negative outcomes during the development stage of technology but actively striving to eliminate them. Additionally, analyzing from the perspective of ANT illuminated the multitudinous actors involved in a functional network of relationships. Understanding the specific POAs of prominent actors within the WWT network allowed me to understand *how* specific groups of people are discriminated against and essentially treated as if they were never a significant part of the network. As a future engineer, I will make decisions that weigh both anticipated and unanticipated effects and, even if they seem trivial, consider *all* actors involved.

Conclusion

Every living person on Earth breathes air, drinks water, and creates sewage in one form or another. However, the operation of WWTPs allows some communities to do these daily activities more safely simply based on where they live. Regardless of their original intent to improve the lives of humans, WWTFs significantly contribute to diminishing human health and quality of life for neighboring communities. Human trust in technology has the ability to better the lives of millions of people. However, this trust can also counterproductively create unanticipated consequences on specific communities when no POA exists to protect them. Fence-line communities are not only subjected to the highest risks during operation of WWTFs, but they are entirely detached from understanding those risks. These facilities and, more importantly, governments and regulators have a moral obligation to ensure that their adjacent communities are not compromised or disregarded during the WWT process.

In the future, government agencies and regulators should treat emerging contaminants, like PFAS, with equal urgency to other contaminants. Sampling of these compounds in WWTP effluents, home wells, and surface waters should be completed *while* the effects of them are being assessed. Additionally, WWTPs should be obligated to hold meetings or send newsletters to surrounding communities, notifying them of the possible consequences of living near WWTP operation. Surrounding communities can also increase their voice within the network through political participation, such as voting for new political officials, writing and petitioning to legislators, and rallying at town hall meetings. Forming these coalitions could increase communication, foster a more inclusive atmosphere, and advance opportunities for further discussion between different actors in the WWT network. It also has the ability to remind WWTPs of their responsibilities and hold government officials accountable to their constituents.

All of these recommendations offer more promising and effective steps to address the omnipresent issue of fence-line community marginalization.

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