Health, Environmental, and Regulatory Concerns of Water Treatment

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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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STS Research Paper

Introduction

Where does drinking water come from? Water is an essential resource for the quality of life. All living organism, including humans, animals, plants, and microorganisms such as bacteria and cells, must have water to keep living. However, people are not aware of the process that occurs to produce the drinkable water. Water, as a resource, is typically available everywhere, either as tap water flowing through pipes into homes and buildings or as bottled water sold in stores. Both forms have a monetary cost associated with them, but they are relatively cheap for the public as it is a necessity. The price is posed on water because behind the scenes are enormous treatment plants that utilize long, complex processes to treat different water sources into drinking water. According to the Center for Diseases and Prevention (CDC), some examples of water sources include groundwater, surface water, and recycled water (CDC, 2022). Billions of gallons of water are produced daily to supply the whole population with drinkable water. Unfortunately, the water sources are proven unclean when initially used, as they contain different harmful contaminants such as viruses, bacteria, salts, and sediments, according to the research conducted by the Unites States Environmental Protection Agency (EPA), along with chemicals that may cause long-term issues if the quantity exceeds standard limits (EPA, n.d). Hence, treatment plants utilize processes that ensure the cleanliness of the water product supplied to the population.

Contaminants in drinking water pose an immense threat to the population as many tend to cause diseases and harm the environment. Depending on the concentrations, the harm may be severe or minor. Luckily, there exist standards on the limits of these concentrations that can affect the population before the final product is supplied to consumers. However, contaminant

issues should not be taken lightly due to the significance of the harm it poses. Diseases from bacteria and viruses, such as salmonella and norovirus, exist in water sources as they are water-soluble. According to tests and surveys done by the World Health Organization (WHO), microbiologically contaminated water can transmit diseases and cause approximately 505,000 diarrheal deaths yearly (WHO, 2023). Similarly, industrial waste, such as brine disposal, pollutes the water and causes numerous environmental issues, such as global warming and the extinction of marine life. Many different treatment plants dispose brine instead of forming other beneficial products such as fertilizers or table salt. According to a science writer that works for the MIT News Office, "Currently, the world produces more than 100 billion liters (about 27 billion gallons) a day of water from desalination, which leaves a similar volume of concentrated brine. Much of that is pumped back out to sea, and current regulations require costly outfall systems to ensure adequate dilution of the salts." (Chandler, 2019). This research paper covers the health concerns exerted by salmonella and norovirus through highlighting the mechanism and the symptoms that occur, environmental concerns by brine waste compared to processing into different useful products, and regulatory concerns on water treatment, specifically desalination.

Methods

Keywords: Water Treatment, Desalination, Diseases, Brine, Regulations

This research paper conducts a thorough and comprehensive analysis of the health implications associated with salmonella and norovirus, the environmental impact of brine waste, and regulatory challenges within the water treatment sector. The research utilizes a variety of scholarly sources, including extensive exploration of online research databases, in-depth discussions with well-known university faculty specializing in safety regulations for chemical processes (including water treatment), and critical evaluation of peer-reviewed literature from various esteemed academic institutions and research centers.

Background Information

Salmonella is the bacterium responsible for the salmonellosis disease that causes multiple different symptoms when contracted. Ralph Giannella, the author of the book *Medical Microbiology*, explained in scientific terms what a salmonella bacterium is. "Salmonellae are Gram-negative, flagellated, facultatively anaerobic bacilli possessing three major antigens: H or flagellar antigen; O or somatic antigen; and Vi antigen (possessed by only a few serovars). H antigen may occur in either or both of two forms, called phase 1 and phase 2. The organisms tend to change from one phase to the other. O antigens occur on the surface of the outer membrane and are determined by specific sugar sequences on the cell surface. Vi antigen is a superficial antigen overlying the O antigen; it is present in a few serovars, the most important being *S typhi*." (Giannella, 1996). In other words, it is a rod-shaped bacterium that causes foodborne illness and is typically found in humans and animals, but stomach acid and other intestinal bacteria protect the intestinal tract before it causes problems. However, when contacted externally, it holds a higher concentration than the ones inside the stomach. When it reaches the stomach, it can pass by the stomach acid barrier and reach the mucosa, a mucus layer covering certain organs in the digestive system, to produce toxins. As a result, an inflammation reaction is alerted, which, in return, causes the body to experience diarrhea in the hopes of flushing the bacteria away (Giannella, 1996). That is only one symptom of many others that can potentially occur.

Norovirus is a virus also common to affect the gastrointestinal area of the human body. "The human norovirus genome is composed of a linear, positive-sense RNA that is ~7.6 kb in length. The genome is covalently linked to the viral protein genome (VPg) at the 5′ end and polyadenylated at the 3′ end. There are three open reading frames (ORFs), designated ORF-1,

ORF-2, and ORF-3, encoding eight viral proteins. ORF-2 and ORF-3 encode the structural components of the virion, viral protein 1 (VP1) and VP2, respectively" (Robilotti et al., 2015), according to a group of professors at Stanford University that have performed extensive research on infectious diseases especially norovirus. There are three open reading frames (ORFs), designated ORF-1, ORF-2, and ORF-3, encoding 8 viral proteins. ORF-1 encodes the 6 nonstructural (NS) proteins that are proteolytically processed by the virally encoded cysteine proteinase (Pro). ORF-2 and ORF-3 encode the structural components of the virion, viral protein 1 (VP1), and VP2, respectively (Robilotti et al., 2015). In simpler terms, it is an RNA virus and a human enteric pathogen that causes significant health issues affecting the digestive system. A few symptoms include vomiting and diarrhea, similar to the symptoms of salmonella. However, this virus does not yet have a vaccine to combat it. Research is still ongoing to create an antidote for this terrifying and dangerous infection that harms the body in numerous ways.

Brine waste is a by-product of the desalination process, which aims to separate water from contaminants to produce drinkable water. Contaminants in brine waste include toxic metals, salts, bacteria, and viruses. Many plants tend to dispose of brine waste by throwing it back into the ocean, either untreated or without proper disposal measures. These actions have harmful effects on the water and its environment, impacting marine life. A group of professors with extensive experience in brine treatment from desalination plants at Qatar University has highlighted some effects on the ocean and its environment, such as increased salinity, temperature, and the presence of chemicals (Omerspahic et al., 2022). Although the US implements regulations regarding brine waste based on contaminant concentrations, this problem persists due to a lack of strictness and implementation in these plants.

Water treatment plants are vital facilities that produce an essential product like drinking water on a large scale, requiring specific regulations to maintain a clean process and product while minimizing safety issues and environmental damage. All plants must comply with federal regulations, although state regulations vary depending on the state. Federal regulations are typically established by the EPA and the Occupational Safety and Health Administration (OSHA). Additionally, there are codes and standards in place, although they are often recommended rather than mandatory. According to chemical engineer Waseem Saeed, these codes and standards are typically sourced from organizations such as the American Petroleum Institute (API), the American National Standards Institute (ANSI), the National Fire Protection Association (NFPA), and many others (Saeed, 2013). These institutes and agencies provide data for safety, health, and environmental standards, ensuring legal and safe operations.

STS Framework

Some people tend to assume that water is naturally clean and pure and do not expect diseases and harmful chemicals to be present, however, as much as water treatment plants are doing a great job at providing clean, potable water, many different aspects of it could go wrong which could lead to national outbreaks and mass extinctions. A research paper that talks about the burden of diseases that arises from desalination plants highlighted that “the median burden of GI attributable to drinking water was approximately 2720 cases per 100,000 population (range = 37–18,250 per 100,000) across studies that estimated total GI burden or that could be adjusted to estimate this burden” (Debbie et al., 2023). Gastrointestinal diseases from drinking water are increasing exponentially, which is the responsibility of the water treatment plant. Another research paper agrees that the threat of bottled water consumption supplied by desalination plants is high, especially in countries that rely heavily on desalinated water. "Bottled water consumption is an important route of trace element exposure as the continued intake of heavy metals in drinking water, even at low concentrations, has been associated with various cancers, neurotoxic effects, central nervous system disorders, cardiovascular system impairments and reproductive and genetic effects” (Rowell et al., 2015).

Environmental concerns are prevalent in water treatment processes. Marine life and ecosystems are most affected by these processes, primarily due to brine discharge. A research paper discusses the impact of brine discharge on the environment and explains how organisms are harmed. According to Yoland et al. elevated salinity of the receiving water body is able to harm organisms due to changes in osmotic pressure, damaging their cells. Additionally, brine may contain toxic components such as heavy metals that harm aquatic organisms (Yolanda et al.,

2019). Brine disposal has been a major concern for water treatment plants due to its immense harm to the environment and its contents.

Regulations in the US are debatable because there are two opposing sides that can agree and disagree on the sufficiency of them. Improvements in this section are always needed regardless of the incident or issue arising since extremes occur abruptly with no prior notice and no indication of severity. Regulations are changing yearly through updates on existing ones or implementing a new one from scratch. Nonetheless, a portion of the public is unsatisfied with the regulations written, as they think water treatment plants, such as desalination plants, are not sustainable. They consume a large amount of energy and harm the environment. However, current regulations address concerns related to salinity levels caused by brine disposal, urban development, and particular wildlife affected by the process (Ocasio, 2015). Since these regulations affect society heavily and gets manipulated by the public/government, there is a discrepancy between who is satisfied and who is not.

Results and Discussions

Mechanism and Symptoms of Salmonella

Salmonella is a water-soluble bacterium that infiltrates treated water supplied by water treatment plants and interacts with the human body to cause damage internally. Salmonella is responsible for salmonellosis disease, which is a symptomatic infection that affects the gastrointestinal tract and carries different symptoms that can harm the human body. According to a research paper that investigates the presence and persistence of Salmonella in water sources, "it is estimated that Salmonella species causes 93.8 million cases of gastroenteritis worldwide annually with 155,000 deaths (5−95th percentile, 39,000–303,000)" (Liu et al., 2018). Salmonella outbreaks are still increasing nowadays as it harnesses dangerous risks against the human body. The main source of salmonellosis is from animal products that people consume on a daily basis. In recent years, different sources have emerged as salmonella carriers, and it includes fresh vegetables, fruits, and nuts. These sources go through nourishment for a long period of time which is mainly governed by water. The type of water used makes a difference in the way these plants grow and nourish.

Water sources are susceptible to numerous factors that contribute to salmonellosis. Irrigation water is an example that depends on the water source it came from. Water sources such as wastewater, desalinated water, surface water, and ground water are affected by the environment surrounding which include animals, sewage, and weather. Salmonella, normally, resides in animals and can also stay in the human body asymptomatically. Animal feces that are used in fertilizers or produced directly into water sources transmit salmonella. As it goes through treatment processes, there is a possibility that the bacteria can still survive. The research group mentioned earlier confirms this finding. "However, studies have indicated that *Salmonella* in

manure can survive as long as 231 days and may eventually contaminate produce by rain water splashing and/or by surface irrigation water (Liu et al., 2018). Contamination occurs when processes are not effective enough, like chlorination or filtration, or the concentrations of the bacteria is too high. Once the "treatment" is accomplished, people receive it through their taps and consume the contaminated water, which results in salmonellosis disease.

People are able to contaminate water sources as well. The human body can harbor salmonella bacteria without experiencing symptoms from the disease. The same research study has investigated the concentrations of salmonella that human feces can contribute to sewage effluents. "The average concentration of *Salmonella* can reach as high as 2.7×10^2 CFU/100 ml, which could become a major source of contamination if discharged directly or with inadequate treatment" (Liu et al., 2018). A lack of effective treatment processes or caution by treatment plants could result in the bacteria passing through the treatment processes and reaching the public's tap water supply, resulting in a potential salmonellosis outbreak. Millions of people can experience excruciating and fatal symptoms that are difficult to treat as they last for about two to seven days. Fever, diarrhea, abdominal cramps, chills, headache, and vomiting are examples of such symptoms (Johns Hopkins Medicine, n.d.). Ultimately, underestimating the lack of stringency in water treatments is not advisable.

Harmful Effects of Norovirus from Water Treatment

Norovirus is a common viral pathogen known for causing gastroenteritis outbreaks worldwide. While the primary transmission route is through direct person-to-person contact or contaminated food, waterborne transmission via water treatment plants is also a concern. Norovirus has been detected in various stages of water treatment processes, including raw water sources, treatment units, and finished water samples. According to a research study that

investigated water samples from norovirus outbreaks in Finland, “the most prominent viruses that caused waterborne outbreaks were noroviruses (18 outbreaks).” The number of norovirus outbreaks found is high considering the source it was found from. Fatalities can occur as norovirus does not have a vaccine developed yet. The study mentions the consequences of these outbreaks and says, “in every year except 2001, several norovirus outbreaks occurred in Finland. During the study period, 6 large norovirus epidemics with >200 cases were encountered. In the largest epidemics, >10,000 persons were exposed, and 2,000–5,500 cases occurred; in addition, 7 medium-sized (40–100 cases) and 5 small outbreaks (<20 cases) were caused by noroviruses” (Maunula et al., 2005). These findings underscore the significant impact of norovirus outbreaks on public health and highlight the challenges faced in controlling waterborne transmission. Norovirus is notorious for its ability to cause large-scale epidemics, leading to substantial numbers of cases and exposures within the population. The absence of a vaccine against norovirus further complicates the situation, as prevention primarily relies on stringent hygiene measures and effective sanitation practices.

Moreover, the detection of norovirus in various stages of water treatment processes, including raw water sources and finished water samples, raises concerns about the efficacy of current water treatment methods in eliminating viral contaminants. The persistence of norovirus throughout the treatment process suggests potential gaps or limitations in disinfection and filtration techniques, necessitating continuous improvements and innovations in water treatment technologies.

Harmful Effects of Brine Waste Disposal on the Environment

Desalination plants operate mainly on water sources that are saline, which include seawater and brackish water. Desalination is the process of removing salts and other minerals

from water, making it suitable for human consumption, irrigation, or industrial uses (US Department of Energy, n.d.). Once the salts and minerals are separated, it forms a brine that is considered waste for the purposes of desalination. Typically, many plants decide to dispose brine waste back into the ocean or wherever the water source is from instead of processing it. The brine waste now is made up of concentrated salts, hazardous chemicals, and other solids. Disposing it into the ocean will harm the environment including marine life and ecosystem surrounding it.

According to a recent research paper that investigates the threats of brine discharge from desalination plants on the environment, "globally, two billion people suffer from constant water stress, and about four billion people live in areas that undergo severe water scarcity for at least one month each year" (Sirota et al., 2024). The impact of brine discharge from desalination plants on marine ecosystems is significant and multifaceted. One of the primary concerns is the elevated salinity levels in the discharged brine, which can create localized areas of hypersalinity near the discharge point. An increase in salinity has detrimental effects on marine life, particularly on sensitive species such as corals, seagrasses, and certain fish and invertebrates.

Furthermore, the brine waste often contains elevated levels of chemicals used in the desalination process, such as anti-scaling agents and cleaning chemicals. Some of these chemicals are toxic to marine organisms and can bioaccumulate in the food chain, posing risks to higher trophic levels, including humans who consume seafood from affected areas. The same research paper showcases these chemicals in a table that highlights the concentrations of different chemicals in brine.

U.S. Regulatory Concerns of Water Treatment

Desalination is gaining traction in the United States as a potential solution to water scarcity issues. However, compared to other industries, the regulations governing desalination plants in the U.S. are not as stringent. While there are guidelines in place to ensure environmental protection, resource sustainability, and public health, the overall regulatory framework is relatively lenient. These regulations cover areas such as water quality standards, energy efficiency, discharge management, and permitting procedures but often provide leeway for industry players.

Regulations in the U.S. differ based on the state the desalination plant is operating in, but, generally, there are basic regulations, federally, that align with every state. These regulations come from a federal act implemented and enacted in 1972, called the Clean Water Act (CWA). The Clean Water Act (CWA) is one of the most significant pieces of environmental legislation in the U.S., aimed at regulating and protecting the country's water resources. It includes a notable provision that encompasses its core objective. Section 101(a) of the CWA states, "The objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (United States Congress, 1972). This quote emphasizes the Act's passionate goal of preserving water quality and ecosystem health throughout the United States. Desalinated water falls under the category highlighted in the act. One of the primary goals of the Clean Water Act is to eliminate the discharge of pollutants into waters of the United States, unless authorized by a permit. The Act establishes the National Pollutant Discharge Elimination System (NPDES), which requires industries, municipalities, and other entities to obtain permits for discharging pollutants into water bodies. These permits set specific limits on the types and amounts of

pollutants that are allowed to be discharged, as well as monitoring and reporting requirements to ensure compliance.

While the CWA has a wide coverage over multiple different aspects regarding water treatment, there are a few aspects that were not covered even after several amendments were imposed. Firstly, new emerging contaminants have threatened water quality in recent years. The rapid evolution of pharmaceutical and microplastic industries have created new contaminants such as antibiotics, hormones, additives, and microplastic particles that affect both aquatic organisms and public health. Secondly, the CWA does not provide clear guidelines about brine disposal regarding desalination processes. The Act's lack of stringent guidelines on the best practices for brine disposal or effective management of such by-product exacerbates environmental damage associated with desalination activities. Finally, desalination plants use a large amount of energy to operate their facilities. The CWA does not emphasize on more efficient ways to consume energy or rather conserve energy. The energy consumption could reach up to 11 kWh/gal when producing 10 million gallons of water per day in the U.S. "In the United States alone, this accounts for about $45 million per year in electricity consumption using the 2015 market size and approximately $70 million using the 2020 projections" (U.S. Department of Energy, 2019). If the value is that big only in the U.S., how would that look like worldwide? According to Brian Bienkowski, a Michigan-based science and environmental journalist, "Desalination plants around the world consume more than 200 million kilowatt-hours each day, with energy costs an estimated 55 percent of plants' total operation and maintenance costs" (Bienkowski, 2015). High energy consumption's consequences are not intuitive at first, as it is an abstract concept. However, the consequences that the environment can face are massive in the long-term, which in recent years has been noticed. According to Just Energy, a retail

energy provider operating in the U.S. and Canada, “On the energy consumption side, there’s a significant impact on climate change too. As we consume more electricity, power plants must increase power generation to make up for it. An increase in power generation ultimately leads to an excessive burning of fossil fuels, creating more GHG emissions, and contributing even more to climate change” (Just Energy, 2023). On top of that, air pollution and thermal pollution tend to emerge along with climate change, which worsens the conditions for desalination plants. Ultimately, even though desalination plants are essential to providing a source of water for people, the consequences it carries are lethal to the public and the environment and can only be mitigated when the government interferes and creates more trustworthy, stringent regulations the people can depend on.

Future Work and Recommendations

Although this research paper highlights important concerns regarding water treatment, there are other concerns that were not touched upon. Other potential diseases, harms of brine waste, and regulations written by different government entities are some examples that would further enrich this topic. Additionally, data from local lab tests is an excellent resource to use to provide a better understanding of the issue and a scientific perception for the public. Exploring these additional aspects would offer a comprehensive view of the challenges faced by water treatment facilities and their impact on public health and the environment.

Conclusion

In conclusion, this study has focused on the vital role of water treatment processes and the challenges they confront. Through an examination of issues such as contaminant impacts, environmental repercussions of brine waste, regulatory frameworks, and the importance of public awareness, valuable insights were gained. While progress has been made in technology and regulatory standards, ongoing efforts are needed. Collaborative initiatives among governments, industries, and communities are essential for ensuring sustainable water management practices. Emphasizing innovation, cooperation, and public education emerge as critical tactics for building a healthier, cleaner, and more resilient water supply system for current and future generations.

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