AID VIA ACTION GLOBAL HEALTH JOURNAL

Review

Aid Via Action Global Health Journal 1(1); 2023:16-21 [www.aidviaaction.org]

# Water Contamination and its Impact on Global Health

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## Abstract

"Water, water, everywhere, and not a drop to drink"

- Samuel Taylor Coleridge, "The Rime of the Ancient Mariner"

Water, comprising 75% of the Earth, is vital for our survival, constituting over half of our bodies. Yet, despite its importance, water remains an underappreciated aspect of human health. Insufficient water intake and contaminated water sources pose significant health challenges. From historical incidents of waterborne diseases like cholera in London to modern cases of water pollution, the consequences of inadequate water access are profound. To understand and address the global water crisis, it is crucial to explore the historical significance of water and medicine, as well as its present-day implications.

*AvaGHJ* 1(1); 2023: 16-21 https://doi.org/10.59016/avaghj.18315

Keywords:
1. Water Contamination
2. Public Health
3. WaSH System
4. Preventable Diseases

About this article:
Received July 26, 2023
Accepted Aug 12, 2023
Published Aug 22, 2023

Peer Reviewers:
B. Yi
M. Diaz
C. Huchim

## Introduction

Earth is about three-quarters water, and less than a hundredth of that is potable. The human body is more than half water. Through evolution, we have effectively transitioned from salty sea creatures to land dwellers carrying the sea within our blood. Water is fundamental to our basic structure and function, yet it somehow remains an underappreciated piece of the human health puzzle. The National Academy of Medicine recommends a daily water intake of 15.5 cups for men and 11.5 cups for women. The average daily intake in America is 3.9 cups[1]. The question of quantity, however, is only scratching the surface of our water problem in healthcare. The more important question is: what is *in* those 3.9 cups? When major compromises of the water supply occur in places like Flint, Michigan, or East Palestine, Ohio, how do we respond and what do we observe in the resulting health status of these cities? When vast swaths of countries, such as Haiti and Rwanda, lack basic water services, what impact does that have on development, both of the community and the individual? How does access to clean water determine a population's health, and what can we do to decrease the millions of preventable deaths from dehydration? In order to consider these questions and anticipate solutions for the future, we must first look to the history of water and medicine.

## Results

### *History of Water Contamination*

In the 1800s, a mysterious illness plagued the Soho neighborhood in London. With no apparent source, individuals were falling ill with intense bouts of diarrhea, emesis, and severe symptoms of dehydration. The miasmatic theory proposed that bad air from rotting organic matter caused the illness. Although this theory is easy to criticize in hindsight, it was not that far off in the basic principle. Something shared, a substance that every person requires daily, was the root of the illness. In 1854, John Snow discovered that the origin of the mystery plague was water, famously localizing the source of many deaths to a contaminated pump on Broad Street (Figure 1).

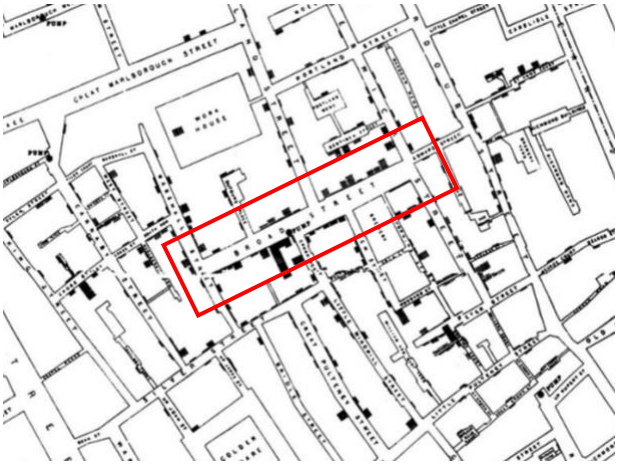

**Figure 1.** John Snow's original map of cholera deaths in the Soho neighborhood, 1854. Each black bar represents one death. A red rectangle has been added to highlight the location of the Broad Street Pump and the significant incidence of death in the immediate vicinity.

Lacking proper sanitary services, officials decided to drain the cesspools beneath Soho in the River Thames, a source of drinking water. Over 600 individuals died of cholera in Soho, a preventable and avoidable tragedy[2].

While this story is perhaps the most commonly discussed example of water contamination and its impact on public health, it is by no means unique. The past two centuries have witnessed seven cholera pandemics across the globe; in fact, the seventh is still occurring today. How can a disease with a known pathogen, a known source, and known prevention still persist? The answer lies in the accessibility of clean water sources, free of human feces and properly sanitized. Long before Louis Pasteur's germ theory, communities recognized the value of clean water. Sanskrit medical lore and Egyptian inscriptions highlight ancient awareness of water treatment. As far back as the 15th century BC, various purification methods (e.g. boiling, wick siphons, filtration) were known and utilized. Hippocrates himself recognized the importance of clean water in maintaining proper health, using "Hippocrates' sleeve", a cloth bag, to strain boiled rainwater (Figure 2)[3]. Given this base of knowledge and the subsequent discoveries, it would seem surprising that water could be overlooked as a major determinant of an individual's health. If there were a pill that all of humanity required multiple times a day, and a significant number of people developed severe morbidities from a contaminated batch, we would not just shrug our shoulders and continue taking the pill. The challenge is not simply recognizing that the pill is contaminated, however. We must then take steps to clean up our medication.

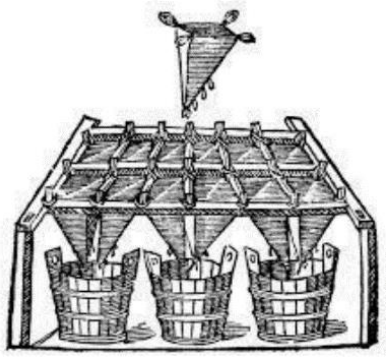

**Figure 2.** Illustration of Hippocrates' Sleeve for water filtration.

In 1892, Dr. Robert Koch provided evidence that proper water filtration protected against disease. He studied Hamburg and Altona, two contiguous cities in Germany that both received drinking water from the Elbe River. The key difference was that Altona filtered their water, while Hamburg did not. Controlling for climate, soil, and other confounding variables, Koch found that Altona had a significantly lower incidence of cholera than Hamburg[4]. It was concluded that filtration removed the offending bacteria from the drinking water. In the following decades, chlorination would be introduced in the United States to further decontaminate water supplies. Epidemiological studies provided clear evidence that a dual system of filtration and chlorination reduced instances of typhoid fever, among other water-borne illnesses. Interestingly, in an accidental 'challenge-dechallenge-rechallenge' experiment, chlorination was discontinued for three weeks in Wheeling, West Virginia[4]. The original "challenge" of introducing chlorination reduced the incidence of typhoid fever from 155-200 per 100,000 to 7 *total* cases. During the three weeks of the "dechallenge" period, the incidence was 21 cases, a 300% increase. Finally, in the "rechallenge" phase, the incidence dropped back down to 11 cases. Examples of the benefits of water purification abound, yet there is still a struggle to see water for the vital medication that it truly is. Over the course of the industrialized era, particularly in the 21st century, water contamination has become an increasingly complex public health issue. With the rapid development of synthetic chemicals, novel energy production methods, and an increasingly polluted biosphere, the effort to keep water clean becomes a Sisyphean task. To fully appreciate the scope of this health crisis, one must look beyond the borders of America and explore the status of water abroad.

### *Globally*

Over the past century, the world's population has quadrupled, from 2 billion in the 1920's to just under 8 billion today. All 8 billion of those individuals need water and providing them all with clean water grows increasingly difficult. The United Nations (UN) estimates that 25% of the global population lacks safely managed drinking systems, with 1.2 billion lacking even a basic level of service[5]. The majority of those in the latter category live in rural areas, primarily in least developed countries (LDCs). In areas that do have sanitation services and growing populations, water filtration systems are burdened with novel chemicals, heightened fecal load, and lack of maintenance.

Some countries, such as Haiti, primarily rely on clean water delivery rather than sanitation. When natural disaster or internal violence erupts, these water delivery routes are disrupted, leaving chunks of the population vulnerable to water poverty. In fact, this exact situation occurred after the 2010 Haitian earthquake, resulting in 820,000 cases of cholera. Nearly 10,000 human beings died as a result of contaminated water. Regarding water sanitation infrastructure, Haiti is recognized as the most underserved country in the Americas. As long ago as 1900, dysentery outbreaks were reported as a result of "impure water". Gelting et al reports that in 2013, only "69% of the population ha[d] access to an improved water source, and 17% had access to improved sanitation facilities in 2010"[6]. Due to national and global efforts to improve water sanitation in Haiti, the Cholera epidemic ended in February 2019. This is no longer a story of some by-gone era; this is the last decade.

Not all water contamination deaths are due to the actual ingestion of water, however. Some arise from an attempt to avoid contaminated water. Rwanda is a densely populated country which has been plagued by war, genocide, and a refugee crisis. To make matters worse, AIDS has steadily risen as a leading cause of young adult death in the country. While the cities and towns of Rwanda have access to antiretroviral therapies (ART), the rural regions do not. Less than 5% of those needing ART in rural areas receive it. This crisis is heightened by a concurrent lack of clean water. Mothers, hoping to prevent water-borne diarrheal mortality, practice universal breast-feeding. This results in high mother-to-child transmission of HIV in rural Rwanda. Even when ART is offered, mothers defer to breast-feeding - choosing the longer-term risk of HIV over the more certain and painful death of dehydration[7]. For those living with HIV/AIDS, it is especially important to maintain proper hygiene as well. 20-liter cans of clean water are available for purchase in urban centers for the equivalent of 5-7 American pennies, but many rural dwellers do not have access to this resource. Even if they did, most lack the funds to purchase clean water and instead walk to natural sources that are often hours away. Piped-in water is also necessary to boil, and many cannot afford the fuel to do so. The UN International Children's Emergency Fund (UNICEF) reports that overall, "just 5% of households in Rwanda have a place… to wash hands with soap"[8]. Thus, individuals at higher risk of skin infections, such as those with HIV, must bathe themselves with unsanitary water.

These examples illustrate countries with poor sanitation services, and the public health crises that arise as a result. However, some of the more wealthy and industrialized countries suffer from contaminated water as well - precisely because of their industrialization. In 2020, the annual turnover for pharmaceutical goods in the United Kingdom was 54.6 billion British pounds. With a rapidly growing pharmacopeia, it may seem easier to focus on the immediate effect of these pills rather than the long-term impact on public health. Scientists and healthcare providers consider what the drug is doing inside the body and turn a blind eye to what happens when it exits. There are a variety of ways that drugs can be metabolized, but ultimately, they must be excreted. £54.6 billion worth of metabolites flow into England's sewage system, spreading into rivers and ultimately refiltering through purification technology. Because of the country's geography and population density, the natural river flow available for dilution of sewage is one of the lowest in Europe. This situation prompted Dr. Andrew Johnson, a British scientist, to investigate models of water purity at home and abroad. He found that although the predicted worst-case scenario results in residual drug at a concentration far below its therapeutic dose, the effect on developing fetuses could still be substantial[9]. Since the filtered water contains a "cocktail" of minute drugs, it is difficult to assess what the exact risk would be. Pomati et al. (2006) studied the effect of 13 drugs, merged to mimic association and concentration profiles found in drinking water, on human embryonic cells. They found that at typical environmental exposure levels, the drug mix inhibited growth, with a 30% decrease in cell proliferation compared to controls[10]. Other developed countries have found similar drug cocktails in their water supply. In Italy, various chemical and medicinal products were discovered in drinking water from Lake Maggiore[9]. In an assessment of Berlin's tap water, it was found to contain drugs in multiple samples. A 2008 investigation into America's water supply discovered "a vast array of pharmaceuticals - including antibiotics, anticonvulsants, mood stabilizers and sex hormones… in the drinking water supplies of at least 41 million Americans"[9]. The presence, even at trace levels, of these novel chemicals should be a major public health concern.

### *Nationally*

The Yale Performance Index ranks the United States as 26th in water quality, just above Brunei in 27th[11]. However, the US has a GDP that is orders of magnitude greater than that of Brunei. How can a country with so much wealth rank so poorly in water quality? As in the case of England, one factor may be America's vast and rapid industrial landscape. Another major contributor is lack of proper maintenance in sanitation and delivery systems. The recent cases of East Palestine, Ohio and Flint, Michigan demonstrate these significant short-comings.

On February 3rd, 2023, a train derailed near East Palestine, Ohio. Nobody in the small town of 5,000 was immediately injured, but the long-term peril of this situation is under study. Eleven of the cars that derailed were carrying hazardous material, such as carcinogenic vinyl chloride. Other chemicals on board included ethylene glycol, monobutyl ether, ethylhexyl acrylate, isobutylene, and butyl acrylate. The rail company, Norfolk Southern, contracted out water testing companies that deemed the water safe to drink. They reported low levels of the leaked chemicals, yet the quality of these reports remains in question. The Ohio Department of Natural Resources estimated that 3,500 fish died in the Ohio River as a direct result of the derailment (Figure 3). Residents of the town were surveyed by the Ohio Department of Health; 74% reported headaches, 61% coughing, 58% fatigue/tiredness and 52% irritation/pain/burning of skin[12]. While some of these symptoms may be air-borne, the possibility that they are a result of water-borne ingestion of dangerous chemicals exists. This incident highlights a public health threat that could become increasingly common if updated filtration technology, based on purifying novel chemicals, is not pursued.

**Figure 3.** Dead fish on a shoreline of the Ohio River, following the Norfolk Southern train derailment in East Palestine, Ohio.

Flint, Michigan also faced a water contamination issue, one rooted in both structural deficiency and government negligence. In April 2014, Flint's water source was changed from Lake Huron to the Flint River in the hopes of saving money. However, proper erosion control was not enacted to ensure the quality of the water delivery system. An estimated 140,000 individuals were exposed to drinking water contaminated with lead and other chemicals as a result[13]. Lead poisoning can cause microcytic anemia, and children often suffer from neurological delays. In Flint, residents began noticing skin rashes, hair loss, and itchy skin. In 2015, a water study team from Virginia Tech reported that 40% of Flint homes had elevated levels of lead[14]. A 2016 morbidity and mortality report from the CDC found that of nearly 10,000 blood lead level tests received from children, 3% showed elevated levels of lead[14]. While the percentage may seem small, the unnecessary harm of even a single child is unacceptable. The mistakes that resulted in Flint's contaminated water may have repercussions for years to come, and there are likely other unknown towns suffering from similar issues. Thankfully, the national attention that gathered around Flint resulted in massive efforts to remedy the filtration and delivery systems in place. These examples make it clear that water is essential to community health and development across the globe. To solve the massive public health crises posed by unclean water, we must recognize water as a human birthright. There are several effective technologies and systems that can create this reality, but creative solutions towards implementing them are necessary.

### *Solutions and Future Directions*

The United Nations recognizes water and sanitation as human rights, yet billions live without access to clean water. While the UN's stance is a good place to begin, actionable steps must be taken to make this right into a reality for all. There are several models in place to address this goal, as well as novel technologies. The benefit to public health is apparent in places where these efforts have been made.

WaSH (Water, Sanitation, and Hygiene) is a framework used by many organizations to improve public health where these three factors are lacking. The United Nations' Sustainable Development Goal 6 seeks to ensure access to WaSH globally. After the 2010 earthquake in Haiti, the CDC implemented WaSH-based responses, working with the Haitian Ministry of Public Health and Population to stop the cholera outbreak. Epidemiological studies assessed household water treatment, local water/sanitation technicians were trained to support 133 communes, and an oral cholera vaccine campaign addressed disease prophylaxis. As a result of these efforts, access to improved drinking water sources increased from 43% in 2012 to 59% in 2016. Concurrently, cholera transmission declined from 352,000 cases in 2011 to 720 in 2019. In February 2019, the cholera epidemic ended, yet WaSH efforts remained in place. In 2021, toilets were installed in 500 households, laboratory systems were reinforced to prepare for future water-borne epidemics, and water quality was monitored to assess maintenance[15]. WaSH programs have also been implemented in Rwanda, with UNICEF providing water supply to over 600,000 people in rural areas. Additional efforts focus on providing hygienic latrines to households and monitoring sanitation coverage. The work in Rwanda reflects a combination of federal and private investment, yet there is still a significant gap in coverage. In 2017, Huttinger et al. (2017) found that although drinking water treatment was reported at 15 of 17 sites, only 60% of water access points were functional, 44% of sanitary facilities were in hygienic condition, and no healthcare facility had on-site capacity for performing repairs. Although the healthcare facilities met national policy standards for water access, they failed to meet the World Health Organization guidelines for water quality[16]. These two examples illustrate that the WaSH model, properly implemented, can provide public health advantages. However, the efforts must be coordinated, locally supported, and maintained for true long-term benefit. The WaSH model is applied primarily in LDCs, although its goals are universal. A revaluation of water infrastructure in more developed countries may provide public health benefits there as well.

There are a few emerging water purification technologies that can help provide access to even the most remote parts of the world. Nanotechnology-based purification utilizes nanoparticles, particularly carbon nanotubes, to remove various contaminants from water. The large surface area to volume ratio provides a unique capacity for purification (Figure 4). Savage et al. (2005) describes nanomaterials as an opportunity to provide "more efficient and cost effective… water purification"[17].

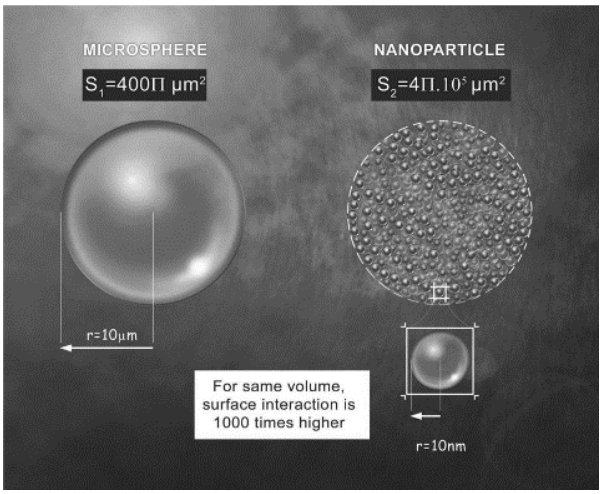


**Figure 4.** Increased surface area of a nanoparticle relative to a microparticle of the same volume. Illustration from Am J Physiol Gastrointest Liver Physiol 300: G371–G383, 2011.

Photocatalytic water purification technology is also highly efficacious in purifying water supplies. A photocatalyst, using ultraviolet radiation, separates substances and breaks down both organic and inorganic material. Point-of-use disinfection technologies are considered key for successful water purification in rural areas, and solar-driven processes are one of the most effective means of implementation[18]. Another creative innovation harnesses the natural design of aquaporin channels to selectively filter water from contaminated sources. NASA has invested heavily in this technology, as the benefits for space travel could be immense[19]. Here on Earth, however, bio-mimetic technology could provide a cheap method of forward-osmosis to purify filthy drinking water. There are many other methods of water sanitation being developed, yet all face the same problem. The large-scale implementation of any new technology will require community support. To be accepted, the public needs to recognize that water is a medication that everyone must take. That medication has grown increasingly tainted over the last century, and it will require immense effort to clean it. Large-scale capital investments today will pay off in healthcare cost savings for years to come.

## Conclusions

Water binds all of humanity, yet many take it for granted as a plentiful resource. Water itself may be bountiful, but without clean and accessible sources, there will not be a drop to drink. Efforts to purify water for public health have existed for thousands of years, from ancient Hindu scriptures to the writings of Hippocrates. Water-borne illnesses plague countries all over the world, from those lacking basic filtration systems to those with heightened industrial contamination. Recent chemical contamination events in American cities have shown that the problem of clean water is not limited to LDCs. When thousands of children die each day from preventable diseases of dehydration, such as diarrhea, it is time to invest in clean water[20]. The recognition of water as a human right is a first step towards ameliorating this public health crisis. Investment in novel sanitation technologies and maintenance of existing infrastructure, coupled with an appreciation of the WaSH system will pave the way to a brighter future. Water is constantly present around and within the human body. Clean, accessible water is the most valuable medication available, and a global prescription is long overdue.

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