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REVIEW 

# Severity of waterborne diseases in developing countries and the effectiveness of ceramic filters for improving water quality

Godfrey Michael Shayo[1*], Elianaso Elimbinzi[1], Godlisten N. Shao[1] and Christina Fabian[1]

## Abstract

**Background** It is anticipated that three (3) billion people will experience water stress by 2025 due to limited access to clean water. Water-related diseases and fatalities affect both industrialized and developing countries. Waterborne diseases are challenging worldwide, especially in developing countries. This article evaluates strategies used by various countries, particularly developing countries, to combat waterborne diseases. These strategies have been largely successful in reducing the prevalence of water-related diseases in developing countries.

**Main body of the abstract** The effectiveness of these strategies is evaluated in terms of their ability to remove water contaminants such as bacteria, viruses, and chemicals. Different strategies can be used, including traditional water treatment techniques such as boiling, chlorination, flocculation, solar disinfection and ceramic-based water filtration systems. These methods can help improve water quality and safety. The choice of strategy depends on the specific contaminants in the water and the desired outcome. Proper implementation of these strategies is key to ensuring safe drinking water.

**Short conclusion** It was revealed that in developing countries, multiple water treatment techniques are used. This has led to the reduction in waterborne diseases from 50 to 90%. Ceramic-based water purification systems are reportedly the modern and least expensive technique, since they are highly efficient and can be made locally. Thus, ceramic water filtration systems are widely used due to their affordability and easy maintenance.

**Keywords** Waterborne diseases, Developing countries, Drinking water, Water contaminants, Water-filtration strategies, Water quality

## Background

Waterborne diseases are conditions caused by pathogenic microorganisms such as bacteria, protozoa, and viruses transmitted through water. When measures are delayed, these pathogens may cause adverse effects on human health, such as disability, illness, disorders, or death (Landrigan et al. 2020). Transmission of these pathogens occurs while using infected water for drinking, food preparation, and washing clothes (WHO 2022). However, most waterborne infections are spread by the fecal–oral pathway, which happens when human feces are consumed by drinking contaminated water or eating infected food, which is mostly caused by inadequate sewage management and sanitation. Waterborne pathogens, which accelerate waterborne diseases, significantly affect people's health by causing mortality and morbidity (Ferreira et al. 2021; Gall et al. 2015a, b; Shailemo et al. 2016). Waterborne diseases can cost people their lives and their socioeconomic status. Several research reports, government and non-government resources demonstrate this quietly. Access to clean water and sanitation facilities is

*Correspondence:
Godfrey Michael Shayo
godfreyshayo14@gmail.com
[1] Department of Chemistry, Mkwawa University College of Education, University of Dar es Salaam, P.O. Box 2513, Iringa, Tanzania

essential for the prevention of waterborne diseases and the protection of public health. Proper management of water resources is critical for the prevention and control of waterborne diseases. Water quality monitoring and surveillance is necessary to protect public health.

Globally, 2.1 billion people lack access to clean and safe drinking water, resulting in 2.2 million deaths from waterborne diseases each year (UN 2019). Domestic water supplies must be free of disease-carrying microbes and other chemical contaminants to be safe for human consumption. It was once anticipated that until 2021, only 44% of the world's population would have access to safe sources of water. This left a larger population, i.e., 56% of the world's population, with access to unsafe and contaminated water from sewage, septic tanks, latrines, agricultural activities, and other human activities (World Health Organization 2020). Contamination of surface and groundwater ensures that waterborne diseases persist, particularly in developing countries. Currently, the global picture of water and health has a strong local dimension, with 1.1 billion people still lacking access to improved drinking water sources and 2.4 billion to adequate sanitation. There is extensive evidence that water-related, sanitation, and hygiene-related diseases account for 2.2 million deaths annually and an annual loss of 8.2 million disability-adjusted life (Anyango 2019; Kätzl 2019). The severity is much higher in developing countries than developed countries.

Waterborne diseases are one of society's most persistent and economically disastrous biological threats. Four-fifths of all illnesses in developing countries are caused by waterborne diseases, with diarrhea being the leading cause of childhood deaths (Luby et al. 2018). Generally, 1.8 million people die every year from waterborne diseases including cholera, typhoid, urinary tract infections, schistosomiasis and other diarrheal diseases. Nevertheless, waterborne diarrhea remains a prominent cause of mortality and sickness among children in developing nations, with 90% of diarrhea fatalities occurring in children under five. Rural residents in developing countries use discharge near or around neighboring shrubs and jungles for defecation, which results in fecal pollution of water in rural African and other developing-country locations. (Manetu and Karanja 2021). Common waterborne diseases include bacteria-caused diseases such as cholera, typhoid, and diarrhea, protozoa such as amoebiasis, and viral diseases such as retrovirals, hepatitis A, hepatitis E, and polio infections.

In contrast to many other outbreaks of diseases with incurable diagnoses or expensive preventions and treatments (Paliwal 2021), waterborne infections can be combated with local, affordable resources, minimal lifestyle changes, culturally relevant solutions, and clear and affordable awareness campaigns. Due to their ambiguity and variable applicability to different societies, environments, and durations, these sorts of solutions are called acceptable strategies. This paper reviews several strategies on their efficacy in combating waterborne diseases, particularly in rural regions of developing countries. Researchers have reported on several different strategies previously. A number of suggestions are provided, especially for developing countries that still suffer the brunt of waterborne disease. Finally, it suggests cost-effective and easy strategies when employed.

## Main text

### Severity of waterborne diseases in the world, developing countries and rural areas

Waterborne infections are transmitted through infected drinking water and food sources. The major causes of contamination are poor hygiene and sanitation. According to the World Bank, 2.6 billion people worldwide lack access to basic sanitation, which is defined as a clean and safe toilet or latrine (Gall et al. 2015a, b; Weststrate et al. 2019). As a result, more than a quarter of the world's population must defecate behind buildings, in fields, or near communal water supplies. Disease transmission is significant when fecal matter is not properly disposed of. Infection and sickness can result from unintentional contact with excrement by people or other living things like pets or flies. In addition, using untreated human waste as fertilizer in agricultural techniques results in many infectious diseases. Additionally, due to a lack of control over the movement and habitat of most animals, pollution of nearby water sources by the feces of both domesticated and wild animals is a significant issue that is frequently more challenging to manage (Diedrich et al. 2023).

Around 15% of the world's population lives in water-stressed areas (Javed and Kabeer 2018). Rural areas in developing nations lack access to reliable clean water supply points. Thus, they are vulnerable to waterborne diseases (Gwenzi and Sanganyado 2019). On the other hand, around 2.5 billion people lack access to proper sanitation, and 2–2.5 million people die from diarrhea each year (Javed and Kabeer 2018). Therefore, most people in these places drink untreated water from readily available contaminated sources, putting them at risk of contracting waterborne diseases. Generally, contaminated water is commonly used as a medium for disease transmission (Shailemo et al. 2016 Ali and Ahmad 2020).

The prevalence of waterborne intestinal pathogens such as bacteria, viruses and protozoa in domestic water sources poses a serious health risk to humans (Wen et al. 2020). The majority of outbreaks, though infrequent, are usually associated with sewage-contaminated or inadequately treated water. Figure 1 illustrates the

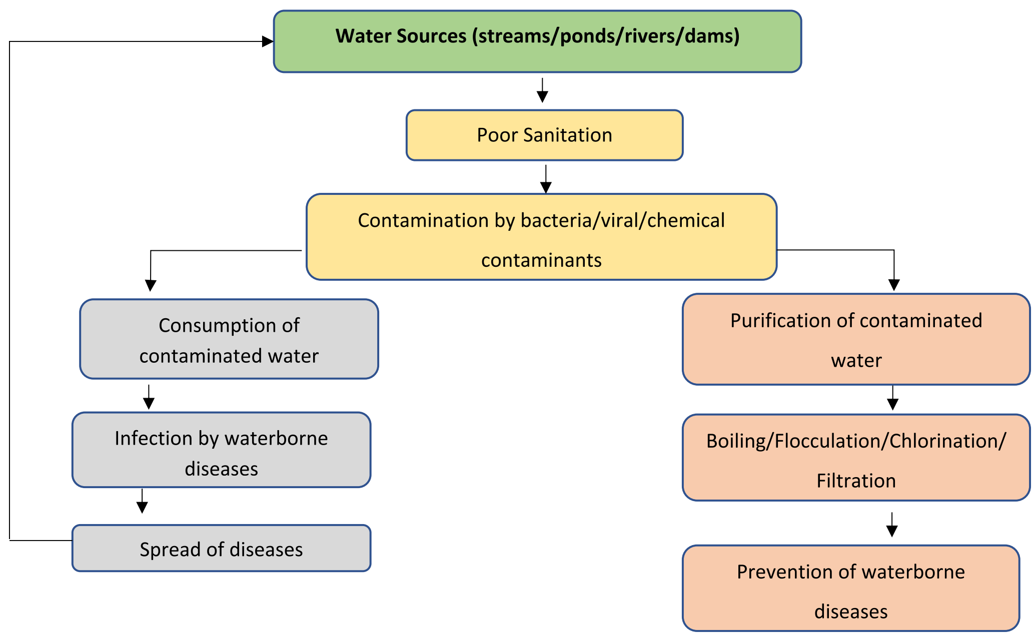


**Fig. 1** Schematic presentation of waterborne diseases transmission in human being

transmission of waterborne diseases in the human population. Contaminated water sources serve as the primary reservoir for various contaminants, including bacteria, viruses and chemicals. These contaminants can enter the human body through ingestion, inhalation, or contact with contaminated water. Inadequate sanitation and poor hygiene practices further facilitate the spread of waterborne diseases. Once inside the body, these pathogens can cause a range of illnesses, such as gastroenteritis, cholera, hepatitis, and parasitic infections. Effective prevention and control measures, such as access to clean drinking water, proper sanitation systems, education on hygiene practices and the employment of water treatment techniques such as filtration, are crucial for reducing the incidence and impact of waterborne diseases. By addressing these factors, we can safeguard public health and promote a safer and healthier environment. Furthermore, sewage system failure and overpopulation raise the danger of infectious disease transmission, either via the virtual presence of a large number of bacteria in the environment or through contaminated drinking water (Mwambete and Tairo 2018).

Although access to clean water is somehow managed in urban areas of developing countries, the situation is still poor or non-existent in rural parts of these countries (Murei et al. 2022). Approximately, 49% of unimproved sources, such as dug wells, natural springs, and other surface water sources are observed in rural areas. Diarrhea occurs worldwide and causes 4% of all deaths and 5% of disability loss. For example, in Bangladesh, 35 million people are daily exposed to elevated arsenic levels in their drinking water. This will ultimately threaten their health and shorten their life expectancy (World Health Organization 2020). Infection is common in low-income and middle-income countries with poor sanitary conditions and hygiene practices, where most children almost 90%, have been infected with the hepatitis A virus before 10 years, most often without symptoms (WHO 2022). Infection rates are low in high-income countries with proper sanitary and hygiene conditions.

## Strategies in combating waterborne diseases

There are ways for disadvantaged people all over the world, especially those living in rural regions, to get access to clean water for drinking and other household needs. These may be referred to point-of-use (POU). Several domestic treatment methods, including boiling, sun disinfection, filtration, chemical disinfection like chlorination and flocculation, and/or sedimentation, have been implemented by several developing nations as part of their adaptation to treatment tactics (Branz et al. 2017; Lantagne and Yates 2018). The main treatment methods are shown in Table 1 along with each method's characteristics. People use these methods to prevent waterborne illnesses. Results for addressing various water pollutants, such as color, total solids, turbidity, and odor, are highly encouraging. However, in some cases, they cannot remove other water contaminants such as virus, chemicals that is, chlorine, heavy metals and other organic contaminants and bacteria contaminants. This leaves

**Table 1** General properties of some of household water treatment technologies, strengths, drawbacks and percentage of applicability

| Treatment technique (s) | Treatment process | Strengths | Drawbacks | Percentage of applicability |
|---|---|---|---|---|
| Boiling (until first big bubble appears), i.e., 100 °C | Heating/boiling water to approximately 100 °C | Effective in removing most of pathogens (bacteria and protozoa)<br>Easy, simple and widely accepted method | It can be costly due to high fuel consumption<br>Doesn't remove chemicals, turbidity, taste, smell and color | Over 98.5% efficiency in *E. coli* removal (Burleson et al. 2019; Sobsey and Brown 2012) |
| Chlorination | Chemical Treatment | Effective at deactivating most bacteria and viruses that cause diarrheal disease<br>Ease-of-use and acceptability<br>Scalability and low cost | Not effective at inactivating some protozoa, such as *Cryptosporidium*<br>Ineffectiveness in turbidity, but also potential taste and odor objections<br>Potential long-term effects of chlorination by-products | The Safe Water System has been implemented in over 35 countries. (Ghernaout, 2014, 2017; Li et al. 2022) |
| Solar disinfection | Heating by Sunlight radiations | Proven reduction of viruses, bacteria and protozoa in water<br>Simplicity of use and acceptability<br>No cost if using recycled plastic bottles<br>Recontamination is low because water is served and stored in the small narrow necked bottles | Need to pretreat water of higher turbidity with flocculation and/or filtration<br>Limited volume of water that can be treated all at once<br>Uncertainty in the Length of time required to treat water | Over 2 million people in 28 developing countries (Bitew et al. 2018; Jeon et al. 2022) |
| Ceramic Filtration | Filtration of contaminants | Proven reduction of bacteria and protozoa in water<br>Simplicity of use and acceptability<br>Long life if the filter remains unbroken<br>A low one-time cost | Not as effective against viruses<br>No chlorine residual protection—can lead to recontamination<br>A low flow rate of 1–3 L per hour for non-turbid waters<br>Filters and receptacles must be cleaned regularly, especially after filtering turbid water | Ceramic filters have been implemented in over 20 countries (Bulta and Micheal 2019; Kallman et al. 2011; Lantagne et al. 2010) |
| Slow Sand Filtration (Bio-Sand Filter) | Filtration of contaminants | Proven reduction of protozoa and most bacteria<br>High flow rate of up to 0.6 L per minute<br>Simplicity of use and acceptability<br>Visual improvement of the water<br>Local production (if clean, appropriate sand is available)<br>One-time installation with low maintenance requirements<br>Long span (estimated > 10 years) with no recurrent expenses | Not as effective against viruses<br>No chlorine residual protection<br>Can lead to recontamination<br>Routine cleaning can harm the bio-layer and decrease effectiveness<br>Difficult to transport due to weight—high initial cost | Bio-Sand Filter projects are established in 24 developing countries (El-Taweel and Ali 2000; Mulugeta et al. 2020; Verma et al. 2017) |
| Flocculant-disinfectant Powder | Chemical treatment and filtration | Proven reduction of bacteria, viruses and protozoa in water<br>Removal of heavy metals and chemicals<br>Increased free chlorine protection against contamination<br>Easy to transport and long shelf life of sachets | Multiple steps are necessary (require training or demonstration)<br>Requires a lot of equipment (2 buckets, cloth and a stirrer)<br>The higher relative cost per liter of water treated | Efficiency in the removal of Arsenic from water for over 88% (Okoh et al. 2020; Norton et al. 2009) |

it up to researchers to investigate the efficacy of creating a ceramic filtration system with multiple capabilities for water purification. This includes the incorporation of nanomaterials like silver, copper, and gold to remove bacterial and pathogenic microorganisms. However, the incorporation of hydroxyapatite helps to remove heavy metal chemical contaminants and improve pores structure for correction of color, pH, turbidity, total dissolved solids and biological oxygen demagnetization.

Water quality and resource protection are still funded by international and non-governmental groups. Several cases of aquatic infectious diseases have been documented (Annan et al. 2018). Incorporating nanoparticles of noble metals into filtration technology seems to be a viable option. Some studies have reported the removal of viral and chemical contaminants through doping conventional ceramic water filters with metal oxide. Conventional ceramic water filters have been advantageous in the filtration of some water contaminants, such as bacteria, protozoa and other contaminants with ≥ 2 μm diameter size (Nigay et al. 2019). Recently, some studies have reported the removal of viruses through doping of standard ceramic water filters with metal oxides, such as aluminum oxide, magnesium oxide, iron oxide and titanium oxide (Mutuma et al. 2015; Nigay et al. 2019; Shao et al. 2014, 2015) and chemical contaminants through hydroxyapatite (HA) doping (Haider et al. 2019; Nigay et al. 2019; Farrow et al. 2018). For a decade, the filtration of water contaminants such as physical, chemical and biological contaminants has been in practice in several countries. This is to address the problem of lack of safe and clean drinking water.

## Viral waterborne diseases in developing countries

Viruses are the tiniest microorganisms of all parasites, with an approximate size ranging from 0.03 to 0.1 μm. Viruses are present in drinking water sources but their impact on human health is less widely understood and acknowledged. However, swallowing them can have major health consequences (Gall et al. 2015a, b; Adelodun et al. 2021). More than 100 different human and animal enteric viruses have been identified as water transmissible. Rotavirus, enterovirus, norovirus and hepatitis A and E are all viral infections spread through water. Researchers have had limited success in deactivating or eliminating viruses from drinking water (Annan et al. 2018). Surface water contamination with enteric viruses due to human waste disposal is a public health hazard. This is especially true if these surface waterways are used for recreational, irrigation or drinking water production (Gall et al. 2015a, b; McKee and Cruz 2021). Polluted water transfers viruses, including drinking and recreational water. Outbreaks involving huge numbers of diseased people are typical because numerous people may ingest a batch of water or come into contact with contaminated materials (McKee and Cruz 2021). Viral gastroenteritis outbreaks are mostly caused by norovirus, whereas viral hepatitis outbreaks are mostly caused by Hepatitis A Virus and rarely by Hepatitis E Virus (Bosch et al. 2011; McKee and Cruz 2021).

Viral infections, particularly those caused by rotavirus, are the most common causes of acute diarrheal diseases. Over half a million people worldwide die each year from the rotavirus, which is so pervasive that it infects almost every child by the age of five (Charoenwat et al. 2022). Typically, viral hepatitis affects the liver. It can be acute (fresh infection, fast onset) or chronic (long onset) (Aggarwal 2011; Kim et al. 2021). Infection with one of the five known hepatotropic viruses (hepatitis A, B, C, D and E viruses) causes viral hepatitis. Viral-based waterborne diseases can also be transmitted through inhalation or contact with skin and eyes which can both spread viruses, resulting in respiratory and ocular diseases. For healthy people, viral infections are typically self-limiting, but in children under five, the elderly, immune-compromised adults and pregnant women, they are at higher risk (Gall et al. 2015a, b). Waterborne virus-based infections may be more common in developing countries, where hunger is common, and there are huge populations of HIV-positive (Gall et al. 2015a, b; WHO 2022).

For this paper, only waterborne hepatitis viruses A and E will be discussed. In populations with unsafe water and inadequate sanitation, viral hepatitis A and E are food and waterborne diseases that can cause acute epidemics. They do not cause chronic infection or liver damage, and there is no treatment for them. Improvements in sanitation, food safety, and immunization are all effective prevention methods (Aggarwal 2011; Kim et al. 2021). The most typical clinical outcome of hepatitis A or E virus infection is a sickness typified by an abrupt onset of fever and systemic symptoms, followed by jaundice a few days later.

### *Hepatitis A and E viral waterborne diseases*

Hepatitis A is a self-limiting liver illness caused by Hepatitis A virus infection. Hepatitis A viral infection spreads by the fecal–oral route, which can be transmitted directly from person to person or indirectly through the intake of feces-contaminated food or water (Foster et al. 2019). Because the hepatitis A virus is abundantly discharged in feces and may live in the environment for extended periods of time, it is usually a food-waterborne illness (Foster et al. 2019; Gullón et al. 2017). In regions where sanitation is inadequate and living conditions are dense, infections arise early in life. Infections are delayed due to increased sanitation and hygiene, and the number of people vulnerable to the disease rises (Gullón et al. 2017). In these circumstances, fecal contamination from a single source might result in explosive epidemics. Adults are increasingly contracting hepatitis A virus infections in most developed countries, where hepatitis A is no longer considered a childhood illness (Foster et al. 2019; Gullón et al. 2017).

Hepatitis E is an acute hepatitis caused by the Hepatitis E Virus infection. The virus spreads predominantly by the fecal–oral route, and it is extremely prevalent in certain underdeveloped nations where drinking water might be contaminated (Aggarwal 2011; Magana-Arachchi and Wanigatunge 2020). It manifests itself as outbreaks and occasional instances of acute hepatitis in these highly endemic locations. The illness is usually self-limiting and resembles other hepatotropic viruses. However, in some cases, the condition progresses to severe liver failure (Magana-Arachchi and Wanigatunge 2020). The Indian subcontinent, China, Southeast and Central Asia, the Middle East and northern and western Africa are all highly endemic to hepatitis E (Yekta et al. 2021). Hepatitis E outbreaks of various magnitudes have been documented in these regions. Furthermore, hepatitis E virus infection is responsible for a substantial number of sporadic acute hepatitis cases in these locations. The most prevalent mode of illness transmission in these places is water (Yekta et al. 2021). The hepatitis E virus has been linked to a 25% mortality rate in pregnant women (World Health Organization 2022). Several strategies have been discussed to combat hepatitis A and E viral waterborne infections including physical elimination, chemical treatment and UV light disinfection.

#### *Strategies for combating viral waterborne diseases in developing countries*

In the elimination of viral water contaminants from drinking water, several strategies have been used. However, there are two common and effective strategies used in the world and particularly in developed countries, which are physical elimination of pathogens by conventional treatment and the inactivation of viral pathogens using ultraviolet irradiation or chemical oxidants such as chlorine, chloramines, ozone and chlorine dioxide (Gall et al. 2015a, b). Because viruses are so small, conventional treatment methods, such as filtration, are unsuccessful in physically eliminating them (Gall et al. 2015a, b; Nigay et al. 2019). Disinfectants are heavily dependent on water chemistry and local restrictions. A common disinfection technique in recent years has been chlorination, where free chlorine is derived from hypochlorous acid and hypochlorite ions that are dissolved in water and hydrolyzed. This strategy has been used to disinfect water since the early 1900s (Branz et al. 2017; Gall et al. 2015a, b; Lantagne and Yates 2018). This powerful oxidant renders most viruses dormant. However, free chlorine treatment may release harmful disinfection by-products and fails to control Cryptosporidium, a protozoan that causes diarrhea and spreads through water (Khan et al. 2019; Gall et al. 2015a, b). To control the formation of regulated toxic disinfection by-products, some drinking water utilities are switching to monochloramine which is formed by mixing chlorine and ammonia with the latter in slightly excess; and/or either monochromatic (254 nm) or polychromatic (200–300 nm) ultraviolet (UV) light to control both disinfection by-products formation and Cryptosporidium contamination. In spite of these modifications to the disinfection method, the UV light technique comes with a very high cost for virus control compared to other conventional methods (Gall et al. 2015a, b; Ibrahim et al. 2021).

In order to deal with the viral-based waterborne situation, total abstinence from all water sources such as streams, ponds, rivers and lakes is necessary, as well as other water sources that may be contaminated by waterborne pathogens and other chemicals. With a variety of methods, some developed countries, such as the United States, Canada, the Netherlands, and Western Australia, have shown efficiency in wastewater treatment. This is due to differences in socioeconomic factors (Ferreira et al. 2021). Most waterborne illnesses are not prevalent in developed countries because of sophisticated water systems that filter and chlorinate water to eradicate all disease-carrying organisms. In developing countries, however, waterborne diseases such as Hepatitis A and E, remain prevalent. The strategies employed in developed countries may not be feasible, particularly in rural areas where proper sanitation and infrastructure for water management are difficult to attain (Levy et al. 2018). As a result, this review recommends using point-of-use water treatment technology as a replacement, particularly for ceramic water filters that can be produced at a price affordable for rural residents when doped with metal oxides like alumina, titania, iron oxide, zinc oxide, or magnesium oxide (Mutuma et al. 2015; Nigay et al. 2019).

### Bacterial waterborne diseases

Bacteria are single-celled or non-cellular, spherical, spiral or rod-shaped microorganisms that reproduce by fission and are key pathogens and biochemical characteristics. Bacteria are well-known diarrhea-causing diseases transmitted through contaminated drinking water. Depending on the bacteria kind and number present, these bacteria may or may not be detrimental, but the cumulative effect might be devastating. Bacteria are generally between 0.5 and 2 μm long (Annan et al. 2018). *Vibrio cholerae*, *Salmonella* sp., *Campylobacter* sp., *Shigella* sp., and

*Staphylococcus aureus* are all bacteria spread through water. Coliform bacteria are a group of microorganisms found in the environment and mammals' intestines. They are usually harmless, but their presence indicates that drinking water's microbiological quality is of concern (Mwambete and Tairo 2018; World Health Organization 2006). Some coliforms bacteria include *Escherichia, Serratia, Enterobacter, Proteus, Klebsiella, Citrobacter, Yersinia* and *Hafnia species*. However, *E. coli* is the only member found in the intestines of mammals including humans; thus, its presence indicates recent fecal contamination and the possible presence of other waterborne pathogens.

Drinking water is a significant vehicle for bacterial waterborne infections such as cholera, diarrhea and typhoid fever (Gwenzi and Sanganyado 2019; Mwambete and Tairo 2018; World Health Organization 2006). Cholera is caused by the bacteria *Vibrio cholerae*, which causes severe diarrhea, vomiting, dehydration and death. It can be severe if not treated properly, up to 50% of the time. However, medication can reduce the severity to as little as 1% of the time. Cholera causes 100,000 deaths worldwide (Lee et al. 2017). *Salmonella typhi* bacteria are the source of the potentially fatal bacterial infection known as typhoid fever. There are still roughly 21 million cases of typhoid fever each year in developing nations. Only people carry *Salmonella typhi*. Typhoid fever patients have bacteria in their blood and intestines. Few people, called carriers, recover from typhoid fever but still carry the germ. Sick persons and carriers excrete *S. typhi* in their stools. Consuming or drinking food or beverages that have been touched by someone shedding *S. typhi* bacteria or drinking or washing food with sewage contaminated with *S. typhi* bacteria can result in typhoid fever (Brockett et al. 2020).

In developing countries, *E. coli* is the most common cause of diarrheal disease infections and human gastrointestinal tract infections caused by ingesting contaminated water (Gwenzi and Sanganyado 2019). In Africa, for instance, a severe cholera epidemic broke out in Zimbabwe in 2008 and quickly spread to neighboring nations (Zambia, Botswana, Mozambique and South Africa). Due to poor sanitation and waste management practices and a limited supply of clean piped water, the scarcity of safe drinking water in Zimbabwe's urban areas had a significant role in the development and spread of the disease. Poor water sanitation and hygiene are linked to a higher proportion of intestinal parasitic infections, with the majority being fecal–oral (Gwenzi and Sanganyado 2019; Gwimbi et al. 2019). In rural regions of most developing nations, where water supplies are communally shared and exposed to many fecal–oral transmission paths within their neighborhood boundaries, bacterial contamination of drinking water is a major contributor to waterborne illnesses (Reece et al. 2017; Iwu and Okoh 2019). *E. coli* infections linked to polluted water continue to be a serious public health problem, as their presence indicates the prevalence of deadly disorders such as diarrhea (Iwu and Okoh 2019). Despite the fact that the endemicity and intensity of bacterial waterborne illnesses have decreased in developing countries, the case fatality rates in cholera cases remain significantly higher in Africa (about 60%) than in Asia (29%) (Montufar-Salcedo, 2018). However, the World Health Organization (WHO) reports that 1.3 million suspected cases of typhoid fever have been recorded in Africa since 2021, with 502 deaths (2%) out of 30,934 confirmed cases in DRC. These are the most common bacterial-associated waterborne diseases in most developing countries (Gwimbi et al. 2019).

### *Strategies for combating bacterial waterborne diseases*

Recently, bacterial-based water contaminants have been solved thanks to the availability of common point-of-use water treatment technologies. In most developing countries, the technologies include boiling, chlorination of contaminated water, solar disinfection and filtration techniques such as bone char, bio-sand, slow sand, membrane purifiers and ceramic filters (Farrow et al. 2018). Although all of them work effectively in bacterial removal, ceramic filters are perceived by most users and developers due to their easy and affordable cost of fabrication, as they require the availability of regional materials such as clay, soil, sawdust, starch, wheat flour, and milled rice husk which hence makes their dissemination to people cost-effective and economically sound. The incorporation of noble metals into ceramic water filters ensures the efficient functioning or performance of the filters, this is to say, by increasing bacterial disinfection or by increasing bio-film disinfection ability. Metal oxide nanoparticles' antibacterial capabilities, manufacturing techniques and microorganisms removed during water treatment are summarized in Table 2.

From Table 2, based on the different Lewis-dot structures, metal oxides display diverse physicochemical and functional properties, including magnetic, optical, mechanical, and electrical properties/features (Raghunath and Perumal 2017). They have shown the ability to interact with bacteria through electrostatic interactions through prokaryotic cell walls and enzyme or DNA alteration through reactive oxygen species (ROS) production (Gold et al. 2018). Under light exposure (He et al. 2016), magnesium oxide nanoparticles act as antibacterial agents and produce ROS. The ROS then enters the bacterial cell membrane while reducing both oxidative stresses on the cell organelles and lipid peroxidation, thereby preventing oxidative degradation of lipids (Gold et al. 2018).

Since titania is a strong photocatalytic material with high oxidizing power and long-term stability, it can generate ROS with a wavelength of around 320–385 nm, hence its ability as an antimicrobial agent (Kumaravel et al. 2021). The action of metal oxide antimicrobial agents involves several working mechanisms, including cell membrane damage due to electrostatic interaction, disruption in metal/metal ion homeostasis, production of ROS and oxidative stress, protein and enzyme dysfunction, genotoxicity, signal transduction inhibition, and photoremoval (Raghunath and Perumal 2017).

However, from Table 2, it is anticipated that a higher concentration of MgO inhibits bacteria's growth against *E. coli* which is higher than *Bacillus sp*. On the other hand, CuO provides more room to be used as a biocidal agent, such as against *B. subtilis.* This is due to its cost-effectiveness and better biocidal ability than other noble metal oxides (Hoseinnejad et al. 2018). In many studies, ZnO is proposed to have higher antibacterial ability than other metal oxides since they can pose a threat to both gram-positive and gram-negative bacteria. Furthermore, $Al_2O_3$ at high concentrations has mild deactivation properties owing to the free radical scavenging capability of nanoparticles that prevent cell wall disintegration (Makvandi et al. 2020). Nevertheless, $Al_2O_3$ has also been suggested to trap viral contaminants due to its positively charged surface (Nigay et al. 2019).

#### Chemical contamination of water

Water is a carrier of infectious microorganisms such as bacteria, parasites and viruses that spread via the fecal–oral route in water-based diseases. Similarly, chemicals are sometimes thought to be a source of infectious agents (Javed and Kabeer 2018). Water-stressed areas are home to about 15% of the world's population. Waterborne diseases are caused by chemical toxins, mostly found in industrial, municipal, and agricultural wastes (Javed and Kabeer 2018). For instance, heavy metals such as chromium, cadmium, nickel, lead, mercury and arsenic; cations, such as sodium, potassium, and calcium; anions, such as carbonates, bicarbonates, and nitrates; and pesticides, such as dichlorodiphenyltrichloroethane and benzene hexachloride enter water bodies from point and non-point sources and cause several health complications among people in many developing countries (Syafrudin et al. 2021).

Pesticide use has a number of advantages, including better food quality and quantity and reduced insect-borne diseases, but it has also prompted concerns about potential negative impacts on the environment, especially water sources (Syafrudin et al. 2021). Pesticides end up in bodies of water due to runoff from agricultural fields and industrial waste. Soluble pesticides are taken away by water molecules, which percolate lower into the soil layers and eventually reach surface waters and groundwater (Syafrudin et al. 2021). As a result, water quality deteriorates and drinkable water quantity decreases. Drinking water contaminated with heavy metals, pesticides, cations, and anions causes life-threatening complications in the gastrointestinal, renal, cardiovascular, pulmonary, and reproductive systems (Syafrudin et al. 2021). Furthermore, chemicals carried by polluted water can cause urinary tract burning and calculi, leukomelanosis, hyperkeratosis, black foot disease, neuropathy and cancer (Javed and Kabeer 2018; Syafrudin et al. 2021).

Chemicals in drinking water that exceed allowable levels may harm human health. This could be caused by human activities or natural occurrences. Chemical pollutants in drinking water have also been linked to a wide range of negative health impacts, including cancer, cardiovascular illness, neurological disease, and miscarriages. Leaching, spills, runoff, and air deposition are ways through which chemicals enter water systems (Annan et al. 2018). Heavy metals are found naturally in the earth's crust and are long-lasting environmental pollutants since they cannot be degraded or removed. They enter the human system in tiny amounts from food, air, and water, and bioaccumulate over time (Ali et al. 2017; Annan et al. 2018). Table 3 shows WHO and USEPA maximum permissible heavy metals in drinking water values.

With an acceptable concentration of 0.002 mg/L poisonous level, thallium and mercury are the most poisonous metals (Table 3). This puts human health at high risk compared to all other metals mentioned in the table. While nitrate, with a WHO rating of 11.3 mg/L and a USEPA rating of 10.0 mg/L, represents the highest allowable chemical concentration in the human body. Chemical contaminants in drinking water can pose a threat to human health sometimes, but the human body needs several heavy metal elements in their divalent cation forms, such as $Zn^{2+}$, $Fe^{2+}$ and $Cu^{2+}$. For instance, these metal divalents are required by the human body in the regulation of numerous physiological functions. These functions include protein and nucleic acid synthesis, antioxidant defense, and membrane stabilization. However, these metal divalents are required by the human body at very low concentration (Ali et al. 2017; Rehman et al. 2021). If their concentration exceeds the body's requirement level, metal divalent leads to health effects (Ali et al. 2017). Other heavy metals are poisonous to humans, such as $Cd^{2+}$, $Pb^{2+}$, $Co^{2+}$, $Pt^{2+}$ and $Ni^{2+}$. When the human body is contaminated with these metals, the

**Table 2** Antibacterial properties of metal oxide nanoparticles in water treatment of impactful study works from 2010

| References | Metal oxide | Preparation method (Synthesis) | Antimicrobial Efficiency | Contaminants REMOVAL |
|---|---|---|---|---|
| Wang et al. (2010) | CuO<br>$Fe_2O_3$<br>ZnO<br>$TiO_2$<br>NiO<br>$Co_3O_4$ | Top-down methods (i.e., Diffusion, Irradiation and thermal decomposition)<br>Bottom-up (i.e., Chemical polyol fabrication method, Electrochemical synthesis and Chemical reduction) | Excellent ZnO (71%), CuO (77%) and NiO (85%)<br>Low $Fe_2O_3$, $Co_3O_4$, Ti2O | *E. coli* |
| Vargas-Reus et al. (2012) | CuO<br>$Cu_2O$<br>ZnO<br>Ag-CuO | Sonochemical<br>photo reduction<br>Sol gel combustion | 100% bacterial removal by the oxides | *P. intermedia*<br>*P. gingivalis*<br>*F. nuclatum*<br>*A. actionmycetemeomitans* |
| Azam et al. (2012) | ZnO<br>CuO<br>$Fe_2O_3$ | Sonochemical<br>photo reduction<br>Sol gel combustion | Excellent ZnO, i.e., 72–88%<br>Moderate CuO, i.e., 50–72%<br>Low $Fe_2O_3$, i.e., 27–50% | Gram-positive (*S. aureus* and *B. subtilis*)<br>Gram-negative (*E. coli and P. aeruginosa*) |
| Tsao et al. (2015) | $Fe_2O_3$ | Top-down methods (i.e., Diffusion, Irradiation and thermal decomposition)<br>Bottom-up (i.e., Chemical polyol fabrication method, Electrochemical synthesis and Chemical reduction) | Bacterial removal, i.e., *E. coli* 99.9%<br>Viral, i.e., bacteriophage 98.83% | *E. coli*<br>Viral, i.e., bacteriophage |
| Hoseinnejad et al. (2018) | ZnO<br>$TiO_2$<br>MgO*<br>CuO**<br>$Al_2O_3$ | Top-down methods (i.e., Diffusion, irradiation and thermal decomposition)<br>Bottom-up (i.e., Chemical polyol fabrication, Electrochemical synthesis) | Bacterial removal, i.e., *E. coli* 99.9%<br>Viral, i.e., bacteriophage 98.83% | *S. aureus and B. subtilis*<br>*E. coli and P. aeruginosa*<br>*P. mirabilis* |
| Raghunath and Perumal (2017) | ZnO<br>$TiO_2$<br>MgO<br>CuO<br>$Al_2O_3$<br>$Fe_2O_3$<br>CaO | Chemical methods<br>Biosynthesis (i.e., (CuO, $Fe_3O_4$ and ZnO)<br>Co-precipitation (i.e., $Fe_3O_4$ and ZnO)<br>Electrochemical (i.e., $Cr_2O_3$ and CuO)<br>Wet chemical (i.e., CuO, $Fe_3O_4$ and ZnO)<br>Hydrothermal (i.e., MgO and ZnO)<br>Sonochemical i.e., CuO<br>Sol gel (i.e., ZnO and $TiO_2$) | NS | Gram-positive *(S. aureus and B. subtilis)*<br>Gram-negative *(E. coli and P. aeruginosa)*<br>Viral contaminants |
| Gold et al. (2018) | ZnO<br>$TiO_2$<br>MgO | Colloidal method<br>Atomic layer deposition<br>Sol gel nanofabrication | High for small size (30–50 nm) fabricated NPs<br>Low for larger size (70–130 nm) fabricated NPs | Gram-positive (*S. aureus* and *B. subtilis*)<br>Gram-negative (*E. coli* and *P. aeruginosa*) |
| Nigay et al. (2019) | MgO<br>$Al_2O_3$ | Wet chemical<br>Hydrothermal<br>Sonochemical<br>Sol gel | Bacterial removal, i.e., *E. coli* 99.98%<br>Viral removal 99.45% | *E. coli*<br>Viral (not specified) |
| Vega-Jiménez et al. (2019) | MgO<br>$Mn_3O_4$<br>$Fe_2O_3$<br>ZnO | Top-down methods (i.e., Diffusion, Irradiation and thermal decomposition)<br>Bottom-up (i.e., Chemical polyol fabrication method, Electrochemical synthesis and Chemical reduction) | Excellent ZnO, MgO<br>Low $Fe_2O_3$, $Mn_3O_4$ | *S. aureus and B. subtilis*<br>*E. coli and P. aeruginosa*<br>*S. mutans*<br>*S. epidermis*<br>*V. cholerae and*<br>*Shingella* sp. (i.e., $Mn_3O_4$) |
| Makvandi et al. (2020) | MgO<br>$Ag_2O$<br>$Fe_2O_3$<br>ZnO<br>$TiO_2$<br>$Al_2O_3$ | Excellent ZnO, MgO<br>Low $Fe_2O_3$, $Mn_3O_4$ | Viral (i.e., HIV-1) 98% ($Ag_2O$)<br>99.99% for Ag-$TiO_2$) HIV-1 | Gram-positive (*S. aureus* and *B. subtilis*)<br>Gram-negative (*E. coli* and *P. aeruginosa*) |

*define that; Higher concentrations of MgO inhibit bacteria's growth against *E. coli* being higher than *Bacillus sp.*

** define that CuO provides more room to be used as a biocidal agent i.e. against *B. subtilis* even at low concentration

**Table 3** Standards for chemical contaminants in drinking water according to World Health Organization (WHO) and United States Environmental Protection Agency (USEPA)

| Heavy metal and other metals | WHO/USEPA maximum acceptable concentration (mg/L) | The health implications of ingesting some of these chemicals (if they exceed the maximum acceptable limit) |
|---|---|---|
| Mercury (Hg) | USEPA/WHO 0.002 | Headache, abdominal pain and diarrhea, paralysis, and gum inflammation<br>Kidney damage |
| Silver (Ag) | USEPA/WHO 0.1 | Skin discoloration |
| Arsenic (As) | USEPA/WHO 0.01 | Serious skin problems, endocrine disruptor<br>Causes cancer—skin, bladder, lung, kidney, liver, prostate<br>Harms cardiovascular and nervous systems |
| Cadmium (Cd) | USEPA 0.005 and WHO 0.003 | Kidney Damage<br>Carcinogenic, causes lung fibrosis, dyspnea |
| Zinc (Zn) | USEPA/WHO 5 | Stomach cramps,<br>skin irritations, vomiting and nausea,<br>Respiratory disorders, anemia and mental fever |
| Lead (Pb) | USEPA 0.015 and WHO 0.01 | Infants and children may experience delays in physical or mental development, as well as minor attention span and learning deficiencies<br>Kidney disorders and high blood pressure in adults |
| Uranium (U) | USEPA/WHO 0.03 | Kidney toxicity<br>Increased risk of cancer |
| Antimony (Sb) | USEPA/WHO 0.006 | Increase in blood cholesterol<br>Decrease in blood sugar |
| Chromium (Cr) | USEPA 0.1 and WHO 0.05 | Nausea, gastrointestinal distress, stomach ulcers, skin ulcers, allergic dermatitis<br>Kidney and liver damage<br>Reproductive problems<br>Lung and nasal cancer |
| Copper (Cu) | USEPA 0.1 and WHO 0.05 | Acute copper poisoning can cause symptoms of nausea, vomiting, diarrhea, gastrointestinal illness, abdominal and muscle pain<br>Severe cases of copper poisoning have led to anemia, liver poisoning, and kidney failure |
| Cyanide ($CN^-$) | USEPA/WHO 0.2 | Nerve damage<br>Thyroid problems |
| Thallium (Tl) | USEPA/WHO 0.002 | Hair loss<br>Changes in blood<br>Kidney, intestine, or liver problems |
| Fluoride ($F^-$) | USEPA 4.0 and WHO 1.5 | Skeletal fluorosis, from long-term consumption > 4 mg/L (a serious bone disorder resembling osteoporosis and characterized by extreme density and hardness and abnormal fragility of the bones)<br>Children may get mottled teeth (i.e., Mottling (discoloration) of teeth in children under 9 years of age (from long-term consumption at > 2 mg/L) |
| Nitrate ($NO_3^{-1}$) and Nitrate ($NO_2^{-1}$) | $NO_3^{-1}$ USEPA 10.0 and WHO 11.3<br>$NO_2^{-1}$ USEPA 1.0 and WHO 1.0 | Methemoglobinemia (blue baby syndrome)<br>Most potential health effects are seen in infants under the age of 6 months |
| Barium | USEPA 2.0 and WHO 0.7 | Difficulties in breathing<br>Increased blood pressure and changes in heart rhythm<br>Stomach irritation, brain swelling, muscle weakness<br>Damage to the liver, kidney, heart, and spleen |

kidneys, for instance, suffer the most. Hence, several effects are observed, including a decrease in essential elements entry due to heavy metal competition (Ali et al. 2017; Rehman et al. 2021).

#### *Strategies for combating chemical contamination of water*

Several studies have reported some positive progress advances in the discovery of therapeutic tools, such as cell protectors and metal chelators. These tools can be administered when an individual has taken the chemicals in any way, particularly through contaminated drinking water. But treatment must be a last option if, at all costs, the situation can be prevented from happening. Studies have reported developing point-of-use water treatment technologies, such as ceramic water filters, among many others as speculated in Table 1, being more feasible for many people due to their low cost and ease of fabrication (Gupta et al. 2018; Farrow et al. 2018). Ceramic filters can be boosted in their efficiency in the removal of heavy metals, pesticides, and organic chemical contaminants when doped with hydroxyapatite chemicals, and the chemical materials made from bones (Haider et al. 2019; Nigay et al. 2019; Farrow et al. 2018). Nigay et al. (2019) reported that through a substitution mechanism, HA chemicals can interchange their chemical contents, that is, calcium ions, hydroxyl groups, and phosphate groups, with the heavy metal chemicals present in the contaminated water (Nigay et al. 2019).

## Future prospect

Ceramic water filters, as used in many developed countries such as the USA, Netherlands, Canada, and Western Australia, can be used in developing countries with some modifications. This will improve performance and efficiency at the point-of-use. Conventional ceramic water filters can improve water quality in several parameters but fail in others. For instance, most bacterial contaminants can be physically filtered through conventional ceramic water filters. However, after some time of filter use, bacteria and mold grow on the surface of the system. Incorporating ceramic water filters with noble metals such as silver, copper, or gold in their nanoparticle form removes bacteria and prevents the system from becoming infected with protozoa (Loza et al. 2020; Praveena and Aris 2015). However, for several years, viral-based contaminants have been linked to hepatitis A and E diseases, which may cause liver cancer if chronic. Removal of viruses is quite challenging due to their small size, so they cannot be removed through physical strains. However, doping ceramic water filters with metal oxides including titania, alumina, magnesium oxide, or iron oxide facilitates the adsorption of viruses from water (Haider et al. 2019; Mutuma et al. 2015; Shao et al. 2015). This is due to the fact that viruses have negative surface charges and hence can be attracted to metal oxides, which are positively charged. Additionally, chemicals can be removed from water by hydroxyapatite chemicals (Haider et al. 2019; Nigay et al. 2019; Farrow et al. 2018). Doping ceramic water filters with hydroxyapatite is feasible and increases chemical removal efficiency. Therefore, the feasibility of having one system that simultaneously removes bacterial, viral, and chemical contaminants is quite possible. This is when a ceramic water filter is incorporated with noble metal nanoparticles and doped with metal oxides and hydroxyapatite.

## Conclusions

Regardless of the disinfection method employed by a drinking water utility, cross-contamination can happen throughout the water distribution infrastructure. This is due to cavitation and unintended depressurization when treated water moves from the treatment facility to the point-of-use. However, because municipal water services are typically not available in poor nations, residents must acquire water from other nearby sources. Most of these sources are tainted with pollutants and bacteria that cause waterborne illness. The World Health Organization estimated in 2017 that environmental changes including expanding access to clean drinking water and raising sanitation and hygiene standards may prevent 94% of cases of waterborne diarrhea diseases. However, the increasing water availability, sanitation, hand washing, and domestic water treatment and safe storage can reduce diarrhea episodes by 25%, 32%, 45% and 39%, respectively. Although, these distribution systems need additional disinfectants. This review also offers recommendations for how developing nations can lower waterborne illnesses prevalence. These include raising the quantity and quality of drinking water, ensuring safe sewage disposal, and offering accessible, affordable sanitation solutions. For example, the adoption of point-of-use water treatment technologies. These technologies are simple, low-cost, and have the potential to reduce waterborne illnesses significantly. Furthermore, these solutions should be combined with educational campaigns to ensure that people are aware of how to use and maintain the technologies.

### Abbreviations

| | |
|---|---|
| ROS | Reactive oxygen species |
| *E. coli* | *Escherichia coli* |
| USEPA | United State Environmental Protection Agency |
| WHO | World Health Organization |
| POU | Point of use |
| CWF's | Ceramic water filters |
| HIV | Human immunodeficiency virus |
| HA | Hydroxyapatite |
| UV light | Ultraviolet light |
| HAV | Hepatitis A viruses |
| HEV | Hepatitis E viruses |
| UN | United Nation |

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### Author contributions

GMS participated in designing, writing, and submitting the manuscript. GNS originated the water purification system idea and conducted research relating to chemical contaminants in water and final approval of the version to be submitted. CFP involved in organization of the manuscript, editing of the manuscript, and revision of the manuscript critically for important intellectual content. EE was a major contributor to the manuscript's writing and interpretation of the relevant literature. All authors have read and approved the manuscript.

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