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Microbiological Contaminants in Drinking Water: Current Status and Challenges

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Abstract Water is a vital resource to every living thing on the earth. Once the water is contaminated (physically, chemically, biologically, or radiologically), it brought negative impacts to the living thing. This paper provides a brief review of the characterization of biological pollutants in drinking water and their effects on human health. Some biological contamination was detected in water resources such as pathogenic bacteria (*Escherichia coli*, *Vibrio cholerae*, *Salmonella*, etc.), viruses (hepatitis A virus, hepatitis E virus, rotavirus, etc.), parasites (*Giardia*, *Entamoeba*, *Cyclospora*, etc.), and parasitic worm (*Ascaris lumbricoides*, *Ancylostoma duodenale*, *Strongyloides stercoralis*, etc.). The diseases were significantly prevalent in developing countries due to limited access to clean water and poor sanitation. Most of the diseases had common symptoms such as diarrhea, fever, and body and muscle aches that were transmitted to humans through the fecal–oral route. About 1.7 billion children were affected by diarrhea each year and about 525,000 of the children died each year. Besides, nearly 1 million adults were killed by diarrhea every year. Some treatment was implemented to remove the biological contamination in drinking water, such as oxidation treatment, ultraviolet radiation, distillation, biologically active carbon filtration, electrochemical, and nanotechnology.

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1 Introduction

Water is a vital resource for almost every living thing on earth. Most living things, including humans, need water to survive. Once the water is contaminated, it has destructive consequences for living things (Cidu et al., 2011; Frichot et al., 2021; Maharjan et al., 2021; Ng and Elshikh, 2021). Polycyclic aromatic hydrocarbons, pesticide, synthetic dyes, microplastics, and heavy metals have been produced in large quantities as a result of the rapid development of industry and agricultural activities (Al Farraj et al., 2019; Hadibarata et al., 2011; Hii, 2021; Ishak et al., 2021; Rubiyatno et al., 2022; Tang, 2021). Biological contaminants are usually referred to as pathogenic microorganisms, which include pathogenic bacteria, viruses, parasites, and protistans (Behnam et al., 2013). Disinfection is the process that kills, removes, or deactivates pathogenic microorganisms. However, the process of disinfection can be divided into several stages, and only the high level of disinfection can eliminate all microorganisms (Rutala & Weber, 2004). There have been many disinfection methods with respective benefits and limitations. Some of them were cheap and easy to use but less effective against microorganisms. Therefore, biological contamination can still occur despite the water has already gone through the disinfection process (Sharma & Bhattacharya, 2017). In Bangladesh, due to water pollution, the inhabitants who lived near the Turag River suffered from various kinds of health problems, such as respiratory illness, diarrhea, anemia, and more (Halder & Islam, 2015). Besides, in Punjab, Pakistan, about 76% of residents faced health problems, such as nail and skin problems due to water pollution (Ashraf et al., 2010). Nowadays, most people use tap water for their daily water consumption. The water supply is usually from rivers, lakes, or undergrounds, depending on the existing water resources of the respective locations. In most countries, water (from water resources) has been diverted to water treatment plants before being delivered to humans (households, businesses, public buildings, etc.) through distribution systems. In the sewage treatment plants, the water usually went through several major processes, which include coagulation, sedimentation, filtration, and disinfection to ensure that the water does not contain any physical, chemical, biological, and radiological substances that can cause human health problems. Figure 1 shows the most important water treatment processes. Besides, biological contaminants could also enter the distribution system due to reasons such as broken pipelines. Biologically contaminated water could have serious consequences. Children under the age of five in the countries, especially in Asian and African countries, were most affected by the waterborne diseases from the contaminated water (Seas et al., 2000). The health effects of biological contamination in drinking water are shown in Fig. 2.

2 Types of Biological Pollutants in Tap Water

2.1 Pathogenic Bacteria

Pathogenic bacteria contained the ability to cause infections or diseases to humans through ways such as releasing toxic substances which could damage human tissues, act as parasites inside human cells, or form colonies in the human body that could disrupt normal human functions. Many types of pathogenic bacteria could be found in water, including *Vibrio cholerae*, *Escherichia coli*, *Salmonella typhi*, etc., which could cause various kinds of waterborne diseases, such as diarrhea, cholera, typhoid, etc. (Al-Abdan et al., 2021; Ali et al., 2014, 2020, 2021; Cabral, 2010). Table 1 shows pathogenic bacteria occurrence in water sources in various countries. *Escherichia* was a gram-negative bacterium, which was shaped like a rod with a small tail under the microscope and was widely distributed in nature. Gram-negative bacteria were inherently resistant to antibiotics (Rossolini et al., 2017). Therefore, diseases

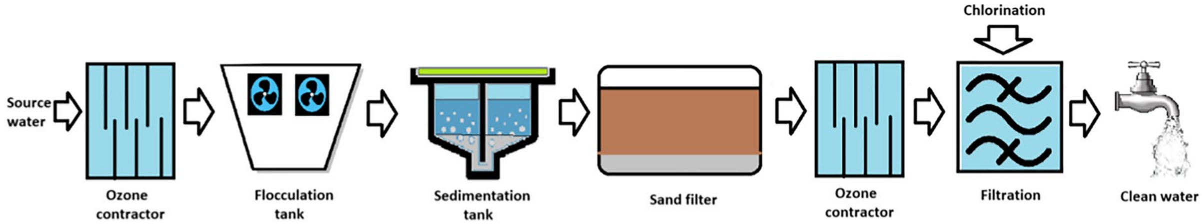

Fig. 1 The most important water treatment processes [icon from Flaticon Basic License CC3.0 (Creative Commons)]

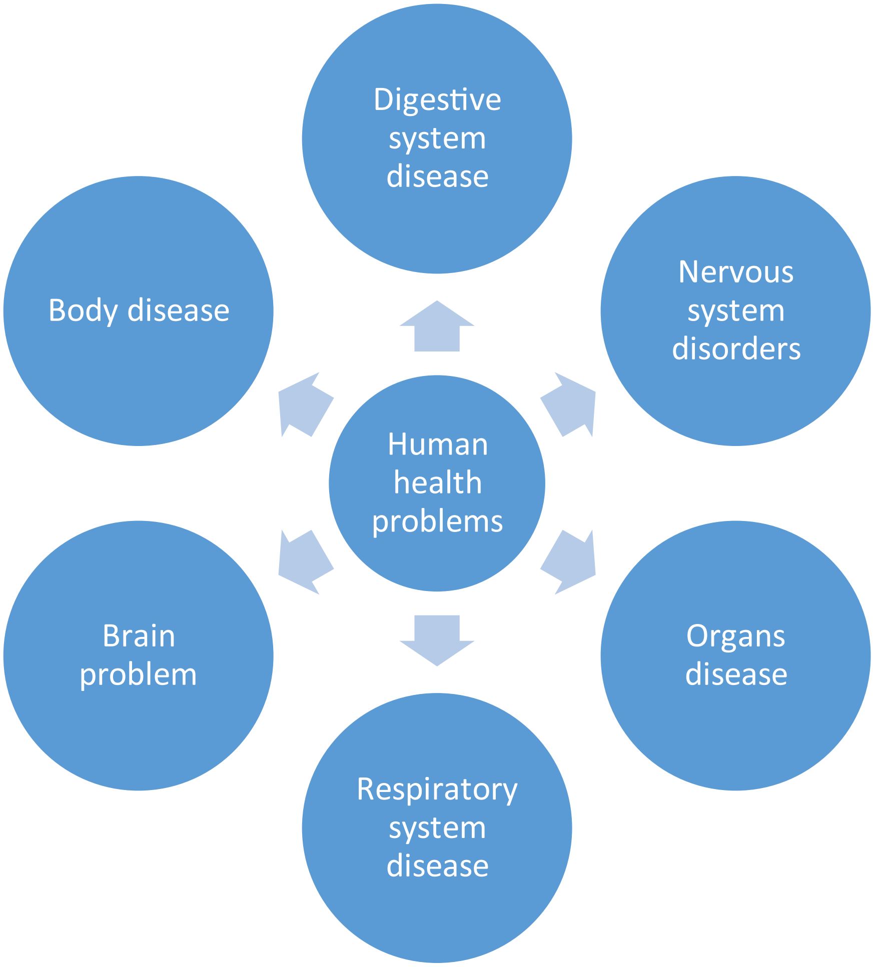

Fig. 2 Health impact of biological contamination in drinking water

caused by *Escherichia*, such as diarrhea and gastroenteritis, were harder to be treated with antibiotics. The species of *Escherichia* include *Escherichia coli*, *Escherichia albertii*, *Escherichia fergusonii*, *Escherichia hermannii*, etc. Among the species, *Escherichia coli* (*E. coli*) was the most common *Escherichia* found in drinking water (Cabral, 2010; Haasdijik & Ingen, 2018). It could be commonly found in the gut of humans. However, there were many types of *E. coli*, some were harmless, and some could cause diseases in humans. The harmful types of *E. coli* included enterotoxigenic *E. coli* (ETEC, also known as O148), enteropathogenic *E. coli* (EPEC), enterohemorrhagic *E. coli* (EHEC, also known as O157), and enteroinvasive *E. coli* (EIEC, also known as O124). ETEC could be found in cattle feces and human feces (Bako et al., 2017). So, when the feces were discharged into water sources, the water resources would be contaminated by ETEC. Therefore, without proper water treatment, ETEC could be transmitted to humans through tap water and cause the disease to a human. This situation could have happened in most of the developing countries where cattle farming was the main economic activity and people who lived in the countries could not access clean water and had poor sanitation, due to low financial resources (Bako, et al., 2017; Cabral, 2010). In many developing countries, ETEC was the most common bacterial enteropathogen found in children who were below 5 years of age, and responsible for a hundred million cases of diarrhea and thousands of deaths each year. Besides, it was also the common cause of "travelers' diarrhea," which affected people from developed countries traveling to developing countries (Scheutz & Strockbine, 2005).

Vibrio was another gram-negative bacterium, which was curve-shaped. The common species of

Table 1 Pathogenic bacteria occurrence in water sources in various countries

Pathogenic bacteria	Diseases	Country	Reference
Escherichia coli	Diarrhea and gastroenteritis	Nigeria Kenya Norway Nepal India China	Bamigboye et al., 2020 Da Silva et al., 2020 Paruch et al., 2019 Rahman et al., 2021 Kumar and Shrutikirti, 2013 Guo et al., 2021
Staphylococcus aureus	Nausea, vomiting, stomach cramps	Nigeria Brazil USA South Africa	Bamigboye et al., 2020 Santos et al., 2020 Lechevallier and Seidler, 1980 Ofori et al., 2018
Klebsiella sp.	Urinary infection, pneumonia, bloodstream infection, meningitis	Nigeria India Russia Nigeria	Bamigboye et al., 2020 Kumar et al., 2013 Rakhmanin et al., 2016 Bamigboye et al., 2020
Vibrio cholerae	Cholera and gastroenteritis	Burkina Faso Uganda Haiti	Kabore et al., 2018 Bwire et al., 2018 Alam et al., 2015
Salmonella	Typhoid and paratyphoid fevers and salmonellosis	India Canada Netherland Czech Republic China	Jyoti et al., 2010 Jokinen et al., 2011 Schets et al., 2008 Dolejska et al., 2009 Guo et al., 2021
Shigella	Bacillary dysentery (shigellosis)	Nigeria China South Africa France	Bamigboye et al., 2020 Guo et al., 2021 Nguyen et al., 2021 Delafont et al., 2016

Vibrio which could cause disease through water included *Vibrio cholerae* (*V. cholerae*) and *Vibrio parahaemolyticus* (*V. parahaemolyticus*). There were several types of *V. cholerae*, of which only *V. cholerae* O1 and *V. cholerae* O139 could cause cholera while other types of *V. cholerae* could cause gastroenteritis (Cabral, 2010; Cooper, 2001). Brackish and marine waters were the natural environment for the etiologic agents of *V. cholerae* O1 and *V. cholerae* O139. There were 1.3 million to 4 million cases of cholera each year and 21,000 to 14,300 deaths because of cholera. It happened mostly due to the absence of safe water, proper sanitation as well as proper waste management (Ali et al., 2015). Therefore, cholera was also a major health issue in many developing countries as most of the countries did not have proper water treatment. *V. parahaemolyticus* was another *Vibrio* that mainly caused gastroenteritis. It tended to thrive in warmer water and water which was low in salinity (Rincé, et al., 2018). There were 3 to 5 billion cases of gastroenteritis each year and nearly 2 million deaths happened to children who were under 5 years. *V. parahaemolyticus* was a common cause of gastroenteritis in Asia countries, especially in Japan. It was first discovered in Japan in the 1950s and could be usually found in marine and estuarine environments (Rince, et al., 2018; Rezny & Evans, 2020).

Salmonella was another gram-negative bacterium as well, which was rod-shaped. It could cause two types of salmonellosis (symptomatic infection caused by *Salmonella*), typhoid and paratyphoid fever, and gastroenteritis. There were only two species in the genus of *Salmonella*, which were *Salmonella enterica* (*S. enterica*) and *Salmonella bongori* (*S. bongori*). *S. enterica* could be divided into 6 subspecies, which included *S. enterica* (subspecies I), *S. salamae* (subspecies II), *S. arizonae* (IIIa), *S. diarizonae* (IIIb), *S. houtenae* (IV), and *S. indica* (VI). *Salmonella* could be found in both environments and a wide range of animals. Therefore, it could transmit to humans in many ways, including water contaminated by animal feces (Crump & Wain, 2017).

Shigella was a gram-negative bacterium, which was rod-shaped, and was the oldest human-specific pathogen. It could cause bacillary dysentery (also known as shigellosis) in humans. There were four species within the genus, which were *Shigella dysenteriae* (*S. dysenteriae*), *Shigella flexneri* (*S. flexneri*), *Shigella boydii* (*S. boydii*), and *Shigella sonnei* (*S. sonnei*). The most prevalent *Shigella* species in the world were *S. flexneri* followed by *S. sonnei*, which accounted for the most *Shigella* incidence worldwide outside of an outbreak setting (Cabral, 2010; Kotloff et al., 2018; Mumy, 2014). According to several studies, different types of *Shigella* species were located at different parts of the world, which could be due to the number of interplaying immunologic, virulence, and environmental pressure factors. *S. flexneri* was then usually found in low- and middle-income countries while *S. sonnei* was usually found in high-income countries. All the species were transmitted to humans mostly by the direct fecal–oral route, such as drinking water that was contaminated by *Shigella* (Thompson et al. 2015; Percival & Williams, 2014).

2.2 Viruses

Water-transmitted viruses are classified as adenovirus, astrovirus, hepatitis A and E viruses, rotavirus, norovirus and other caliciviruses, and enteroviruses, including coxsackieviruses and polioviruses. These viruses could mostly cause gastroenteritis, which could lead to diarrhea and other symptoms such as abdominal cramping, vomiting, and fever. However, some of the same viruses could cause more severe illnesses such as encephalitis, meningitis, myocarditis (enteroviruses), cancer (polyomavirus), and hepatitis (hepatitis A and E viruses) (WHO, 2011). These virus-based diseases were mostly happen in developing countries as most of the countries might be facing widespread malnutrition and large populations of HIV-positive people. Tap water (which contained viruses) could transmit viruses to humans via direct consumption, inhalation (activity such as showering), and contact with skin and eyes (activity such as swimming) (Gall et al., 2015). Table 2 shows the viruses' occurrence in water sources in various countries. Hepatitis A virus and hepatitis E could both cause liver disease and could be transmitted to

Table 2 Viruses' occurrence in water sources in various countries

Viruses	Diseases	Country	Reference
Hepatitis A	Fatigue, fever, nausea, diarrhea, appetite loss	Sweden Italy Canada France	Hennechart-Collette et al., 2020 Masciopinto et al., 2019 Leblanc et al., 2019 Hennechart-Collette et al., 2020
Hepatitis E	Acute pancreatitis, neurological complications, glomerulonephritis, thrombocytopenia	Italy Sweden France India	Masciopinto et al., 2019 Wang et al., 2020 Fenaux et al., 2019 Tripathy et al., 2019
Norovirus	Acute gastroenteritis, diarrhea, nausea, vomiting, abdominal pain	Italy Canada Canada USA Japan France	Masciopinto et al., 2019 Emelko, et al., 2019 Leblanc et al., 2019 Varughese et al., 2018 Canh et al., 2021 Hennechart-Collette et al., 2020
Rotavirus	Severe, watery diarrhea and vomiting	Italy Canada Mexico	Masciopinto et al., 2019 Leblanc et al., 2019 Espinosa et al., 2008
Enterovirus	Fever, runny nose, sneezing, cough, and body and muscle aches	Italy USA Japan	Masciopinto et al., 2019 Varughese et al., 2018 Canh et al., 2021
Adenovirus	Illness of the respiratory system, fever, sore throat, bronchitis, pneumonia, diarrhea, and pink eye	Italy USA Japan	Masciopinto et al., 2019 Varughese et al., 2018 Canh et al., 2021

humans in many ways, including contaminated water (fecal contamination). Hepatitis E could usually cause more severe liver damage than hepatitis A. WHO (2020) estimated that 7134 people died from hepatitis A virus in 2016 while 44,000 people died from hepatitis E virus in 2015. The differences between hepatitis A virus and hepatitis E virus were in terms of biology, epidemiology, impact on morbidity, and mortality of humans in different parts of the world. Hepatitis A was a major issue in low- and middle-income countries with poor sanitary conditions and hygienic practices while hepatitis E was found worldwide, but it was more common in East and South Asia (Naoumov, 2007; Simmonds, 2012). Rotavirus was considered the leading cause of severe childhood gastroenteritis and accounted for about one-third of diarrhea episodes requiring hospitalization. The virus was normally transmitted to humans through drinking contaminated water (fecal contamination). Although it was equally distributed worldwide, the vast majority of rotavirus deaths occurred in developing countries due to poor quality of health care (Parashar, 2016). Norovirus could cause diarrhea in humans. It was responsible for 18% of diarrheal diseases in the world. It was estimated that for each year, the virus accounted for 64,000 diarrheal cases which required hospitalization, 900,000 clinic visits among children in developed countries, and around 200,000 deaths of children who were under 5 years old in developing countries. Just like other viruses, the main mode of transmission of norovirus to humans was the fecal–oral route. Therefore, the virus could be transmitted to humans through drinking water (fecal contamination) (Lopman et al., 2016; Wikswo et al., 2011).

2.3 Parasites

Parasites could be transmitted to humans in many ways, including direct consumption of contaminated water. They account for 842,000 deaths each year (Omarova et al., 2018). The parasite occurrence in water sources in various countries is listed in Table 3. *Giardia intestinalis* (also referred to *Giardia duodenalis* and *Giardia lamblia*) could cause giardiasis. It caused to nearly 2% of adults and 8% of children in developed countries and about 33% of the population in developing countries. It was transmitted to humans mostly through the fecal–oral route, usually through contaminated water (fecal contamination) (Dunn & Juergens, 2020). *Entamoeba histolytic* could cause amoebic dysentery. It was the third leading cause of death from parasitic infections in the world. It was estimated that nearly 100,000 people died from the parasite each year (Ghosh et al., 2019). The parasite could be transmitted to humans through the fecal–oral route, usually through contaminated water (fecal contamination). Therefore, it was prevalent in countries

Table 3 Parasite occurrence in water sources in various countries

Parasite	Diseases	Country	Reference
Giardia	Abdominal cramps, bloating, nausea, and bouts of watery diarrhea	Brazil Greece Spain	Ogura & Sabogal-Paz, 2021 Ligda et al., 2020 Ramo et al., 2017
Entamoeba	Intestinal and extraintestinal infections	Cameroon Egypt Nigeria Zimbabwe	Nsoh et al., 2016 Khalifa et al., 2014 Bishop & Inabo, 2015 Dalu et al., 2011
Cyclospora	Watery diarrhea, weight loss, stomach cramps/pain, bloating, increased gas, nausea, and fatigue	USA Italy Egypt Zimbabwe Ghana	Kahler et al., 2021 Giangaspero et al., 2015 Khalifa et al., 2014 Dalu et al., 2011 Ndur et al., 2015
Cryptosporidium	Highly contagious intestinal infection	Brazil Greece Spain Luxembourg	Ogura & Sabogal-Paz, 2021 Ligda et al., 2020 Ramo et al., 2017 Burnet et al., 2014
Blastocystis	Diarrhea, abdominal pain, itching around the anus (back passage), weight loss, excess gas	Cameroon Egypt	Nsoh et al., 2016 El-Shazly et al., 2007

of low socioeconomic status and poor public health, as most of the people in the countries could not access clean and safe water (Chou & Austin, 2020). *Cyclospora cayetanensis* could cause cyclosporiasis, which was a gastro-enteric disease and associated with diarrhea. It was a major health concern in developed countries due to the ingestion of imported food from developing countries. While in developing countries, the transmission of *Cyclospora cayetanensis* was endemic, which was likely associated with water and sanitation (Karanja et al. 2007; El-Karamany et al. 2005). *Cryptosporidium* could cause cryptosporidiosis, which was a diarrheal disease.

There were more than 30 species in the genus *Cryptosporidium* but only two of the species, *Cryptosporidium parvum* and *Cryptosporidium hominis*, usually infected humans. *Cryptosporidium* was transmitted primarily to humans through the fecal–oral route, usually through contaminated water (fecal contamination) (Gerace et al., 2019; Ryan et al., 2014). Therefore, the prevalence of *Cryptosporidium* was significantly higher in developing countries compared to developed countries, as most of the people in the developing countries could not access clean water and had poor sanitation (Bouzid et al., 2018).

2.4 Parasitic Worm

Parasitic worm or helminth infection is one of the crucial health issues in many developing countries and low-income communities. A previous study showed parasitic worm occurrence in water sources in various countries as shown in Table 4. *Ascaris lumbricoides*, *Ancylostoma duodenale*, *Strongyloides stercoralis*, *Enterobius vermicularis*, *Taenia* spp., and *Trichuris trichiura* were the most common helminth found in the water source. These species caused health impacts on humans such as abdominal swelling and pain, nausea, vomiting, diarrhea, a dry cough, and skin rashes (Akinsanya et al., 2021; Bishop & Inabo, 2015).

3 Health Effects of the Biological Pollutants

Most of the diseases caused by biological pollutants involved diarrhea. The diseases involved in diarrhea include cholera, gastroenteritis, salmonellosis, shigellosis, giardiasis, cyclosporiasis, and cryptosporidiosis (Chow et al., 2010). Each year, nearly 1.7 billion children were diagnosed with diarrhea and about 525,000 of the children died from it. Besides, about 991,265 adults died from diarrhea in 2017. Diarrhea could last for several days and without proper treatment, it would leave the body without the water and salts (dehydration) that were necessary for survival, and therefore, lead to death. There were three clinical types of diarrhea, which were acute watery diarrhea (usually lasted for several hours or days, which was usually caused by cholera), acute bloody diarrhea (caused by shigellosis),

Table 4 Parasitic worm occurrence in water sources in various countries

Worm	Diseases	Country	Reference
Ascaris lumbricoides	Abdominal swelling and pain, nausea, vomiting	Nigeria Burkina Faso Ghana Sudan	Akinsanya et al., 2021 Kpoda et al., 2015 Ndur et al., 2015 Mohamed et al., 2016
Ancylostoma duodenale	Localized skin rash, abdominal pain, diarrhea	Burkina Faso Sudan Zimbabwe	Kpoda et al., 2015 Mohamed et al., 2016 Dalu et al., 2011
Strongyloides stercoralis	Abdominal pain, bloating, heartburn, intermittent episodes of diarrhea and constipation, a dry cough, and skin rashes	Nigeria Ghana Sudan	Bishop & Inabo, 2015 Ndur et al., 2015 Mohamed et al., 2016
Enterobius vermicularis	Sleep disorders, restlessness, and insomnia	Nigeria Tunisia	Bishop & Inabo, 2015 Khouja et al., 2010
Taenia spp.	Cysticerci, abdominal pain, nausea, diarrhea, constipation	Algeria Tunisia	Hamidi-Chergui et al., 2019 Khouja et al., 2010
Trichuris trichiura	Abdominal pain, tiredness, and diarrhea	Nigeria Algeria	Akinsanya et al., 2021 Hamaidi-Chergui et al., 2019

and persistent diarrhea (usually lasted for 14 days or longer). Among the diarrhea, acute watery diarrhea was fatal which could kill a person within hours if treatment was not given. The treatments of diarrhea included rehydrating with oral rehydration salt solution (which only cost a few cents per treatment), consuming nutrient-rich food, consuming zinc supplements, and more (WHO, 2017). Most of the diseases caused by biological pollutants involved fever as well. The diseases involved in fever include gastroenteritis, salmonellosis, shigellosis, cyclosporiasis, and cryptosporidiosis. Fever was an elevation of body temperature which exceeded the normal range (36.5–37.5 °C), which could normally cause symptoms such as sweating, shivering, headaches, muscle aches, poor appetite, rash, restlessness, and general body weakness (Cabral, 2010; Gerace et al., 2019). Many types of fever could cause different grades of fever. Table 5 shows different grades of fever in terms of body temperature. The diseases caused by the biological pollutants which could cause low-grade fever include gastroenteritis, cyclosporiasis, and cryptosporidiosis (Stuempfig & Seroy, 2020; McConnaughey, 2014; Desai et al., 2012). The diseases which could cause high-grade fever included salmonellosis and shigellosis. High-grade (40.1–41.1 °C) fever could even lead to symptoms such as confusion, excessive sleepiness, irritability, and convulsions (seizures). The treatments for fever included drinking plenty of water or fruit juice to prevent dehydration and cool down the body temperature, eating light foods that were easy to digest, taking medication such as ibuprofen (Advil, Motrin, or others), acetaminophen (Tylenol), or aspirin according to label directions, and more (Desai et al., 2012; McConnaughey, 2014). Most of the diseases caused by the biological pollutant could cause aches in the body and muscle.

Table 5 Different grades of fever in terms of body temperature

Grade of fever	Body temperature (°C)
Mild/low-grade fever	38.1–39
Moderate-grade fever	39.1–40
High-grade fever	40.1–41.1
Hyperpyrexia	> 41.1

These diseases included gastroenteritis, salmonellosis, giardiasis, amoebiasis, shigellosis, cyclosporiasis, and cryptosporidiosis. Gastroenteritis could cause headache, muscle aches, abdominal pain, or joint aches, which could normally last anywhere from 1 to 10 days, while the rest of the diseases could cause abdominal pain, which could last for several days (Percival & Williams, 2014).

4 Treatments of Biological Pollutants in Tap Water

Several ways could be applied to remove the biological pollutants, such as oxidation treatment, ultraviolet radiation, distillation, and biologically active carbon filtration (Sharma & Bhattacharya, 2017 Lai et al., 2021; Salman et al., 2022; Sivamani et al., 2022; Zainip et al., 2021). Oxidation treatment involved using oxidizing chemicals such as chlorine and ozone, to kill pathogenic microorganisms which included bacteria, viruses, and parasites. It was known as chemical disinfection treatment (Kerwick et al., 2005). These oxidizing chemicals could oxidize the cell membrane of the microorganisms, which could destroy or weaken the cell wall and lead to cell lysis and death. Each of the oxidizing chemicals had benefits and limitations respectively. Chlorine, chloramine, or chlorine oxide was the most common strong oxidant for the disinfection process due to its low price and ease of implementation. However, excessive use of this disinfectant could cause an unpleasant taste and irritating effect on the mucous membrane. Ozone was another powerful oxidizing chemical that was effective to kill microorganisms. Using ozone as a disinfectant would leave no disinfectant residual in the water but it was a significant air pollutant that can irritate skin, eyes, respiratory system, and mucous membranes (Sharma & Bhattacharya, 2017). Ultraviolet water treatment was known as one of the physical disinfection treatments which used germicidal ultraviolet light to kill microorganisms (Kerwick et al., 2005). When the biological pollutants were exposed to the light, the light would damage the genetic components of the microbes (Fig. 3). There were several benefits of using the UV light as a disinfectant, which included the ability to inactivate many pathogenic microbes, degrade some organic contaminants, had no effect on minerals in water, and no

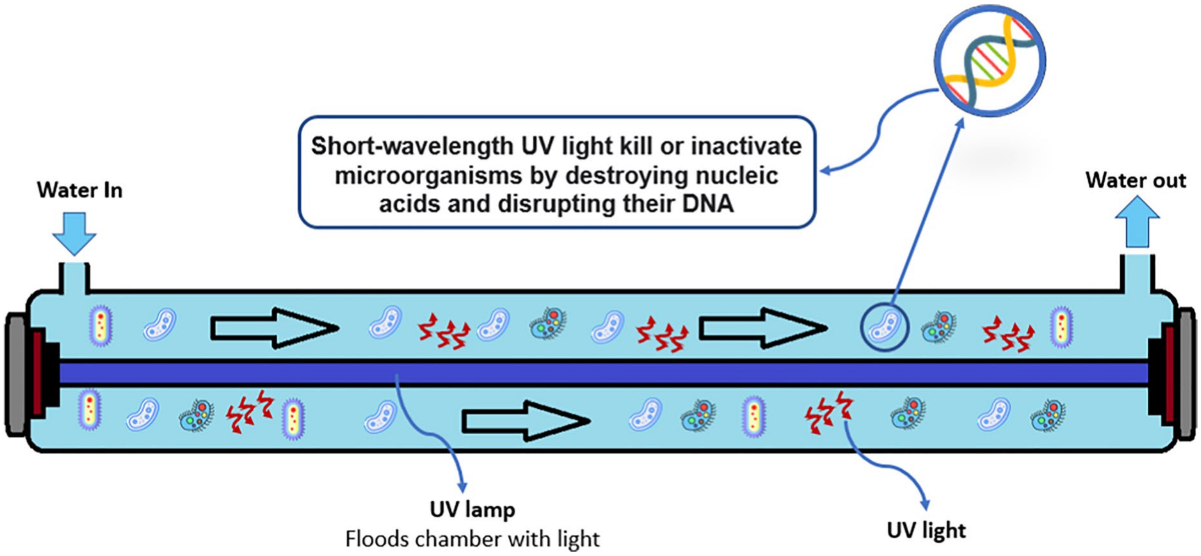

Fig. 3 Mechanism of ultraviolet light water purification [icon from Flaticon Basic License CC3.0 (Creative Commons)]

toxic and nontoxic chemical additives. However, the UV light was not suitable for water which contained high turbidity and high dissolved and suspended solids (Sharma & Bhattacharya, 2017). Distillation was the most common separation technique used to remove microorganisms in water. It was a process of heating contaminated water to boiling point and producing steam. Heat could inactivate the microorganism and the produced steam would rise and enter a cooling section that contained condensing coils. After a certain time, the steam would then cool and condense back to a liquid state. This liquid (water) could have up to 99.5% of impurities removed (Dvorak & Skipton, 2013). However, the method had some limitations. The first limitation was that the method required a lot of energy to heat and cool the water. Second, some contaminants could be carried into the condensate. Third, the method required careful maintenance to ensure purity. Biologically activated carbon filtration utilized granulated active carbon (GAC) to capture microorganisms (Sharma & Bhattacharya, 2017). GAC provided a good solid surface for biofilm formation to protect itself from shear stress or toxic substances (Gibert, et al., 2013). The biofilm formation on GAC consisted of microbial cells which were either immobilized on the surface of the GAC or embedded in an extracellular organic polymer matrix of microbial origin (Gilbert et al. 2013; Wu et al., 2014). Therefore, the microorganisms were attached to the biofilm when they passed through the biofilm. The benefits of the filtration included avoiding chemical disinfection of water treatment processes, reducing the possibility of bacterial regrowth, eliminating the need for coagulant in source filtration processes, and extending the service life of the GEA media (Sharma & Bhattacharya, 2017). The only limitation was that it was necessary to control the growth of the microorganisms on the surface of GAC.

For the disinfection of bacteria, pathogens, and viruses, several techniques have been proposed, including several disinfectants and UV radiation, with chlorination being the most used disinfection approach. However, there is a pressing need to overcome the limitations and risks given by traditional disinfection approaches, which result in the development of toxic disinfection byproducts (DBPs). Chemical disinfectants such as chlorine, chloramines, and ozone, while effective in reducing microbiological infections, can react with diverse elements in natural water to generate DBPs. These typical disinfectants have a high oxidation tendency, which leads to the creation of multiple DBPs (Block & Rowan, 2020; Sills et al., 2020). Electrochemical water disinfection is described as the eradication of germs by passing an electric current through the water and being treated using appropriate electrodes (Kraft, 2008). The electric current causes the electrochemical creation of disinfecting species from the water itself or species dissolved in the water at the phase boundary between the electrodes and the water (Fig. 4).

On the other hand, various nanoparticles have demonstrated outstanding disinfectant qualities without producing dangerous by-products, bringing disinfection's reliability and robustness to new heights. These nano-disinfectants are gentler oxidants that are water inert (Adhikari et al., 2014; Kristanti et al., 2021). Disinfectants induced by nanoparticles have a different mechanism than traditional disinfectants. These nanoparticles can either directly interact with or penetrate the cellular membrane, disrupting the electron transport pathway or causing cell harm by releasing reactive oxygen species (ROS) (Malka et al., 2013). The mechanism of antibacterial actions by NPs is bacterial membrane disruption, production of ROS, bacterial cell membrane penetration by metal ions, and development of intracellular antimicrobial effects, including interactions with DNA and proteins (Fig. 5).

Antibacterial activities of NPs have been proven against gram-positive and gram-negative bacteria in particular. ZnO NPs have been reported to inhibit *Staphylococcus* species, and Ag NPs have antibacterial action against *E. coli* and *Pseudomonas aeruginosa* which is dose-dependent. According to a previous study, ROS also plays a key role in the interaction between DNA and bacterial membrane cells (Pramani et al., 2012). Additionally, ROS promotes the production of oxidative protein genes, which is a significant role in bacterial cell death (Malka et al., 2013). ROS can specifically target proteins and block the operation of periplasmic enzymes that are essential for bacterial cells to retain their regular shape and physiological functions. ROS can be generated in a variety of ways by NPs. At the moment, the photocatalytic theory is the most frequently held belief. When light irradiation energy greater than or equal to the bandgap is accepted by metal oxide NPs, such as zinc oxide and titanium oxide, the electrons in the valence band are stimulated and transition to the conduction band, resulting in a corresponding hole in the valence band and producing highly reactive reactants on the surface and inside the catalytic material. The antibacterial mechanism of NPs is ROS-induced oxidative damage. Different types of NPs produce different types of ROS by reducing oxygen molecules, and ROS is a generic term for molecules and reactive intermediates with strong positive redox potential. The superoxide radical (O_2), hydroxyl radical (OH), hydrogen peroxide (H_2O_2), and singlet oxygen (O_2) are the four kinds of ROS that have distinct levels of activity and dynamics. Table 6 depicts the benefits and drawbacks of various treatment options.

5 Conclusion

Ensuring the elimination of emerging biological contaminants from environmental concerns

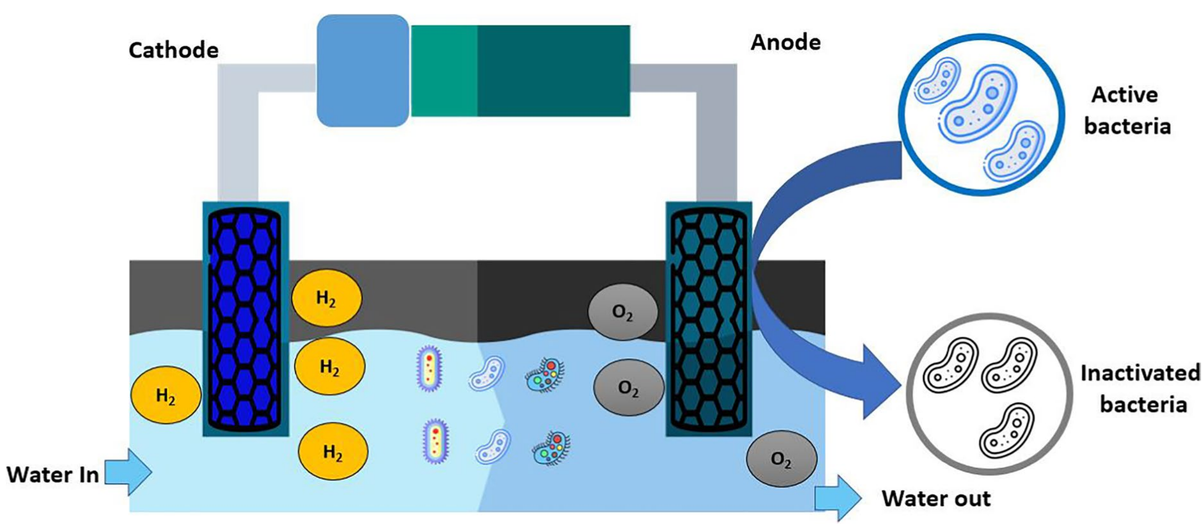

Fig. 4 Electrochemical inactivation of bacteria in drinking water [icon from Flaticon Basic License CC3.0 (Creative Commons)]

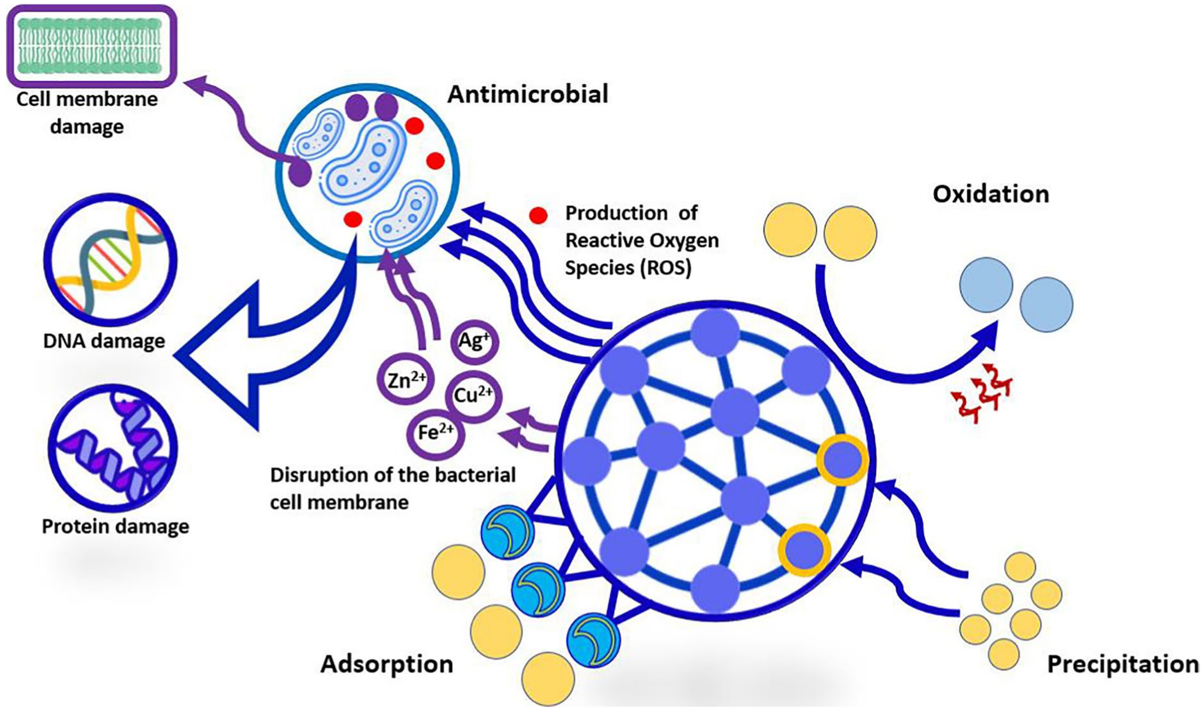

Fig. 5 Mechanism of nanotechnology for water purification [icon from Flaticon Basic License CC3.0 (Creative Commons)]

requires future studies and research to develop robust (bio) remediation processes that are designed on a sustainable basis. Consuming tap water without treatment would most likely become infected with pathogenic microorganisms such as bacteria, viruses, and parasites. The most common symptoms of the infection included diarrhea, which can be fatal if left untreated, fever, and aches and pains in the limbs and muscles. Our analysis indicates that emerging pollutants proceed to pose recent and serious difficulties to tap water, natural resources, soil, ecosystems, and human health. Therefore, it is important to ensure that tap water has undergone treatments that remove biological pollutants before it is delivered. Several treatments could be used to remove the biological pollutants in tap water including oxidation treatment, ultraviolet water treatment, distillation, and biologically activated carbon filter. Each of these treatments had advantages and disadvantages. The number of people infected with the pathogenic microorganisms in industrialized countries was significantly low compared to developing countries. This was because most of the people living in the developing world did not have access to clean water and poor sanitation due to low financial resources. Therefore, oxidation treatment (chlorine) could be the best option for developing countries as it is cheap and effective, although using excessive chlorine could produce the characteristic unpleasant taste and irritating effect on human mucous membrane. In addition, the removal of pollutants from a given environment would be made more predictable through the application of multidisciplinary techniques. Nanoparticles showed a potential application due to excellent disinfection qualities without producing dangerous by-products, taking disinfection reliability and robustness to a new level.

Table 6 The advantages and limitations of different types of treatment

Treatments	Advantages	Limitations	Reference
Oxidation treatment	• Easy to implement • Cheap • Leave no disinfectant residual in the water	• Applying excessive chlorine can produce an unpleasant taste and irritating effect on the mucous membrane • It is a significant air pollutant and an irritant to the skin, eyes, respiratory tract, and mucous membrane	Kaarela et al., 2021 Sillanpaa et al., 2017
Ultraviolet water treatment	• Able to destroy or inactivate a wide range of pathogenic micro-organisms • Does not affect minerals in the water • Able to degrade some organic contaminants • No additional toxic and non-toxic chemicals are introduced	• Not suitable for water with high levels of suspended solids, turbidity, color, or soluble organic matter • Could not operate without electricity	Li et al., 2019 Timmermann et al., 2015
Distillation	• Removes a wide range of pollutants • Continuous • Does not rely on physical barriers (filters) • Requires no additional disinfecting process	• Consumes a lot of energy in terms of cooling and heating requirements • Some pollutants can be carried into the condensate • Requires careful maintenance to ensure purity • It is not very effective which is of lower volatility compared to water	Couto et al., 2019 Kumar & Martin, 2014
Biologically activated carbon filtration	• Avoids chemical disinfection water treatment processes • Because of the microbial biodegradation of organic substrates on the GAC media, the service life can be extended • Bacterial regrowth is less possible • Eliminates the need for coagulant in source filtration processes	• It is necessary to control the growth of the microorganisms on the surface of GAC	Wan et al., 2020
Electrochemical	• Inexpensive, economically, and operationally competitive technology • Very efficient in the removal of a wide range of refractory and toxic organic pollutants • Environmentally friendly	• The chemicals used may require high safety specifications • Important dependence on pH of the solution, being effective only in acidic conditions • Sludge production • Hazardous by-products production	de Vidales et al., 2015 Souza et al., 2021
Nanotechnology	• Ensures a high quality of drinking water • Produces less amount of waste per amount of removed contaminants • Much more efficient as compared to traditional techniques • Intensifies industrial production processes	• Formation of toxic sludge, the production of concentrated toxic water	Marcos-Hernández et al., 2021 Patanjali et al., 2019; Chung et al., 2021

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Data Availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing Interests The authors declare no competing interests.

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