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Parasitology

An Overview of the Potential Role of Water as a Vehicle of Zoonotic Protozoa

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ABSTRACT

The quality of life for both humans and animals is greatly influenced by the availability of safe and clean water to drink. Waterborne infections pose a significant risk due to protozoan pathogens. The incidence of parasitic infections is on the rise globally, affecting both immunocompromised and immunocompetent individuals. More than 524 parasite outbreaks brought on by tainted water had been documented by the year 2010. Thirty percent of the cases in these epidemics were in Europe alone, while nearly ninety-three percent happened in North America. *Giardia intestinalis* (40.6%) and *Cryptosporidium parvum* (50.8%) are the two kinds of protozoan parasites responsible for the majority of these epidemic outbreaks. Additionally, *Entamoeba histolytica*, another frequent aquatic protozoan, was found in 2.8–0.6% of the cases, which in no way lessens the significance of those diseases. The existence of surveillance programs to track water contamination with pathogenic protozoa and diagnostic capabilities is probably the reason for variations in the frequency of outbreaks throughout nations. Enhancing water safety and reducing the effects of waterborne protozoan diseases need greater focus and coordinated efforts. Public health experts can locate the source of the contamination and put the required controls in place to stop the spread of the infection and stop outbreaks by conducting appropriate surveillance on water contaminated with protozoa.

Key words: Prevalence, Protozoa, Water, Waterborne epidemic, Zoonoses.

INTRODUCTION

The quality of life for both humans and animals is greatly influenced by the availability of safe and clean water to drink (Zin Eldin et al., 2023 and El-Abbassy et al., 2024). According to Surah Al-Anbiya (20:30) of the holy Quran, "We made from water every living thing.", The UN Secretary-

General, Ban Ki-moon, highlighted this when he stated, "Water is life," during the opening session of the 2014 High-Level Meeting on Sanitation and Water for All (Moreira and Bondelind, 2017). Water is utilized for a variety of things, such as drinking, farming, industrial processes, irrigation, and maintaining the integrity of the global ecology. All people have the fundamental right to access clean drinking water (WHO, 2022 and Zin Eldin et al., 2023).

Hurricanes, volcanoes, forest fires, or a heavy leaf fall can all contaminate a body of water. Nonetheless, spontaneous biodegradation of these organic molecules occurs (Smyth and Wakelin, 1994). Numerous chemical, microbial, and parasitic organisms have the ability to contaminate water supplies (Zin Eldin et al., 2023). In nature, there are two kinds of water: groundwater and surface water. The headwaters of most river systems contain the surface water. There may be some bacteria, protozoa, or algae even if the quantity of pathogens is usually modest (Zin Eldin et al., 2023 and Ramzy et al., 2025). Human waste is the primary cause of water contamination in developing nations due to poor sanitation infrastructure (WHO, 2002). In developing nations, biological pollution are the cause of a number of deadly pediatric illnesses (Zin Eldin et al., 2023 and Ramzy et al., 2025). Nearly 40% of people worldwide lack adequate sanitation, and about 18% lack access to safe drinking water (WHO and Unicef, 2000). The majority of emerging nations have unhygienic environments. Numerous microorganisms, such as viruses, protozoa, and parasite eggs, are present in human excrement, particularly that of youngsters (Clinton, 1997; Zin Eldin et al., 2023 and Ramzy et al., 2025).

Protozoans are unicellular eukaryotes that were once placed in the subkingdom Protozoa but are now divided into several clades within the Eukaryota lineage (Byomi et al., 2018; Eissa, 2024c; Rossi et al., 2024 and Ramzy et al., 2025). Some protozoans are aquatic parasites that can enter the intestinal tracts of their hosts by mechanical entry, adhesion, or enzymatic digestion (Byomi et al., 2018; Baig et al., 2024; Elgendy et al., 2024; Eissa, 2024c and Ramzy et al., 2025). The infectious stages of protozoans are their oocysts and cysts, which are discharged into the environment by the excrement of infected hosts and resistant to external chemicals and disinfectants (Chique et al., 2020).

As a result of their tendency to cause malabsorption in children, particularly in developing nations, the World Health Organization (WHO) classified several protozoan parasites that are frequently spread through contaminated water in 1987. These parasites include *Cryptosporidium* spp., *Entamoeba histolytica*, and *Giardia intestinalis* (also known by their common names, *G. lamblia* and *G. duodenalis*) (Brožová et al., 2023 and Ramzy et al., 2025). These microbes induce intestinal parasite infections (IPIs), which hinder children's growth by causing protracted diarrhea (Das et al., 2023 and Ramzy et al., 2025).

Acute, long-term, and secondary infections can be brought on by these organisms (Das et al., 2023). Additionally, some investigations found that individuals with colorectal cancer (CRC) and other gastrointestinal cancer types had considerably higher prevalences of *Cryptosporidium* spp. and *C. parvum*, respectively. The latter supported the growth of colorectal cancer in a model of mice (Berrouch et al., 2020 and Ramzy et al., 2025).

The main supply of water for agriculture, drinking, and fishing in Egypt is the River Nile. Thus, in order to prevent epidemic infections, it is imperative that the protozoan biodiversity in fresh water be regularly monitored (El-Abbassy et al., 2024). Therefore, the purpose of this research was to gather the most recent data on the incidence of protozoan infections worldwide, diseases they cause, and preventative strategies.

1.Waterborne zoonotic Protozoan Infections

1.1. Entamoeba histolytica

a. Taxonomy according to Schoch et al. (2020):

Kingdom: Protista

Sub-kingdom: Protozoa

Phylum: Sarcomastigophora

Sub-phylum: Sarcodina

Class: Archamoebae

Order: Amoebida

Family: *Entamoebidae*

Genus: *Entamoeba*

Species: *E. histolytica*

b. Life cycle:

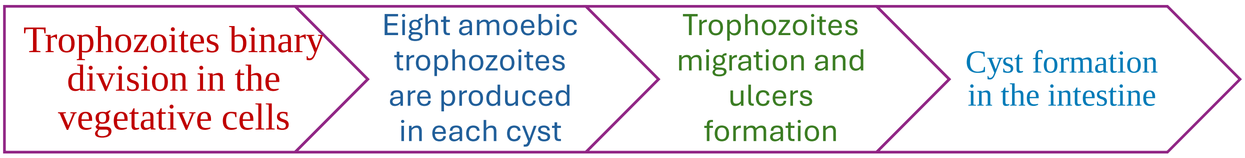

Figure (1): Shematic view of life cycle of *E. histolytica*.

According to Krishnan and Ghosh (2018), *E. histolytica* has a straightforward life cycle that consists of binary division in the vegetative cells known as trophozoites or a transition between the trophozoites and resistant cyst phases. For the trophozoites to exist, develop, and form cysts, all *Entamoeba* species require a single host (Mitra et al., 2010). Transmission happens by oral–anal sexual contact or ingestion of gastric cysts, which typically happens with infected food or drink (Tanyuksel and Petri Jr, 2003). According to Mitra et al. (2010); Byomi et al. (2018); Eissa (2024c) and Elgendy et al. (2024), these non-invasive parasite cysts go from the stomach into the small intestine, where secretions of bile, bicarbonate, and water lead to the excyst's escape.

Eight amoebic trophozoites are produced when telanucleated amoeba starts to split from the cyst wall and leave through a tiny pore (Bruckner, 1992). Next, there is nuclear division and cytoplasmic division. As the trophozoites descend the colon, they proliferate through binary fission and disperse throughout the host intestine (Pritt and Clark, 2008). Trophozoites migrate, adhere, and infiltrate the intestinal epithelium via the pseudopods in the colon. They also catch and consume food particles and red blood cells (Clark, 2000). Trophozoites can occasionally cause ulcers by damaging intestinal tissue and becoming invasive. Because tissue degradation can lead to trophozoites entering the bloodstream of the host and injuring other organs, especially the liver, other organs may suffer future damage (Pritt and Clark, 2008 and Eissa, 2024c).

Following their exposure to environmental stimuli, such as galactose-terminated compounds like mucin, the trophozoites enter the cystic stage (Coppi and Eichinger, 1999). The cell shrinks to 10–16 µm during the precyst stage due to the expulsion of feeding vacuoles, chromatoid bodies, and ribosome aggregates. It's a developed cyst. During the maturation phase, the cyst divides its nucleus twice to form a tetranucleated, with each nucleus carrying around 25% of the total DNA (Tanyuksel and Petri Jr, 2003). When cyst development is complete, the cytoplasm loses all of its organelles, and the chitin-rich wall encircling the cyst renders it osmotically resistant (López-Romero & Villagómez-Castro, 1993 and Eissa, 2024c).

Ultimately, the mature cyst exits the host along with its feces, completing the life cycle and perhaps contaminating food or water to initiate a new one. According to biochemical research conducted on *Entamoeba* during their differentiation process, chitin makes up about 25% of the dry weight of the cyst wall and chitinase enzyme activity rises in environments that encourage the formation of cysts (López-Romero and Villagómez-Castro, 1993).

c. Worldwide distribution (Epidemiology of E. histolytica):

One of the top 15 causes of diarrhea in the first two years of life is *E. histolytica*. Breastfeeding offers protection against this parasite, which affects roughly 50 million people and kills 100,000 people annually globally, though it is more prevalent in tropical and subtropical regions. According to Tharmaratnam et al. (2020), the prevalence of *Entamoeba* spp. varied from 0.43% in Belgium to 82.64% in Malaysia. People who live in communities are more likely to contract infections, and contaminated food is the most prevalent means of transmission—especially when food handlers don't practice good hygiene (Lin et al., 2022).

The incidence of *E. histolytica* infection is endemic and does not change with the seasons in Iraq. According to Flaih et al. (2021) real-time PCR, the prevalences of E. histolytica was 35.0%, respectively. The prevalence of *E. histolytica* in 1-to-10-year-old children from Sulaimani Province, Iraq, was 19.3% and significantly associated with raw vegetable consumption (Aziz et al., 2022).

According to Balarabe-Musa and Onyeagba (2020), the prevalence of *E. histolytica* in children in Abuja, Nigeria, was 12%. *E. histolytica* was shown to be more common in HIV patients and substantially linked to diarrhea in northern South Africa (Samie et al., 2020). The overall prevalence of *Entamoeba* complex infections was 21.3% among schoolchildren in Arsi Town, Ethiopia (Roro et al., 2022) and Perak, Malaysia among children aged 7 to 12 (Tokijoh et al., 2022). Hand washing practices and *E. histolytica* infection were found to be substantially correlated (Roro et al., 2022).

Based on 36 studies from Brazil, India, Ethiopia, Cote D'lvoire, Kenya, Lesotho, Mexico, Vietnam, Colombia, Ecuador, Cuba, Chile, Cambodia, Iraq, Nigeria, South Africa, Uganda, and Yemen, a systematic review and meta-analysis was conducted. The results showed that the prevalence of intestinal *Entamoeba* spp. infection was significantly correlated with the lack of toilets and positively, though not significantly, correlated with the lack of safe drinking water (Atabati et al., 2020).

The cause of infection in an outbreak that affected 250 individuals in the Iranian village of Idahluye Bozorg was network drinking water tainted by sewage pipe erosion (Azizi et al., 2019). The existence and survival of *Entamoeba* spp. in water likely suggests this component (Chowdhury et al., 2022).

1.2. Cryptosporidium parvum

a. Taxonomy according to Schoch et al. (2020):

Kingdom: Protista

Sub-kingdom: Protozoa

Phylum: Apicomplexa

Class: Conoidasida

Order: Eucoccidiorida

Family: *Cryptosporidiidae*

Genus: *Cryptosporidium*

Species: *C. parvum*

b. Life cycle

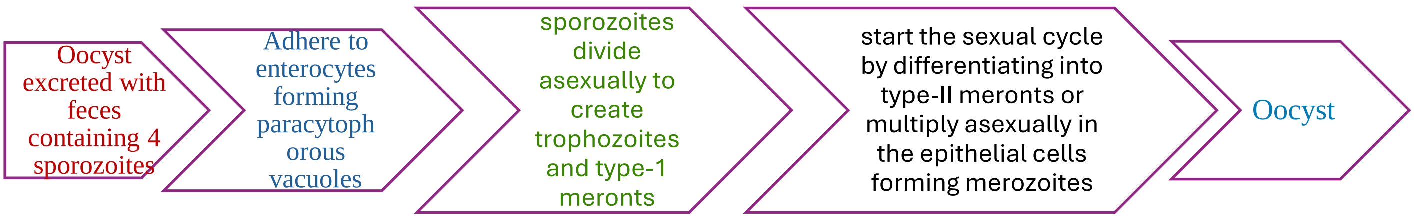

Figure (2): Shematic view of life cycle of *C. parvum*.

The life cycle of *Cryptosporidium* consists of two phases: asexual and sexual. The infectious stage of this organism, which is excreted with the feces of infected hosts, is represented by the thick-walled oocyst. Four sporozoites are contained in the oocyst, and they are discharged into the host's digestive tract after consumption (Helmy and Hafez, 2022 and Ramzy et al., 2025). These adhere to the surface of the enterocyte and are integrated into parasitophorous vacuoles that originate from the membrane of the host cell. Here, the sporozoites divide asexually to create trophozoites and type-1 meronts, which are made up of eight merozoites that either start the sexual cycle by differentiating into type-II meronts or multiply asexually in the epithelial cells. Through asexual division, these give rise to four merozoites that infect other enterocytes and develop into micro- and macrogametes. Mature microgametes exit their host cell and fertilize macrogametes to generate zygotes, which undergo meiosis to become oocysts. There are two types of oocysts: those with thick walls can infect new hosts through excretion, whereas those with thin walls lead to autoinfection. Up to a thousand oocysts can be shed by one infected host (Helmy and Hafez, 2022). For *C. parvum*, the estimated infectious dose in healthy volunteers was 132 oocysts (Costa et al., 2020 and Ramzy et al., 2025).

The thick-walled oocysts are immune to every anti-coccidial medication on the market. These are rendered inactive by ultraviolet (UV) radiation and exposure to 64.2 °C for longer than 5 minutes or 72.4 °C for a minute. Oocysts of *C. parvum* can endure as long as -20 °C, but not as long as -70 °C. Only ozone effectively kills Cryptosporidium oocysts in water; the amounts and exposure times required for hydrogen peroxide, chlorine dioxide, and ammonia are not practicable (Helmy and Hafez, 2022 and Ramzy et al., 2025).

c. World distribution (Epidemiology of C. parvum):

In Europe, there were 2.3 occurrences of cryptosporidiosis for per 100,000 individuals in 2012. A total of 6,605 cases from 21 different countries were confirmed. Great Britain was reported to have the highest infection rate (ECDC, 2012). In 2012, there were 9,591 confirmed cases of cryptosporidiosis in Europe, or 3.15 cases per 100,000 individuals. The majority of the instances were children under the age of five and happened in Ireland. In Slovakia, twelve cases were confirmed in 2013 compared to just one case discovered in 2012 (ECDC, 2012). Only one instance of *Cryptosporidium* infection was reported in Slovakia in 2014 (Kalinová et al., 2015).

One of the earliest instances of cryptosporidiosis was the pandemic that struck Carrollton, USA, in 1987, infecting 13,000 people. According to Hayes et al. (1989), the infection was brought on by a species of *Cryptosporidium* that contaminated river water. The biggest and most well-known pandemic happened in Milwaukee, USA, in 1993 as a result of *Cryptosporidium* oocyst pollution of lake water. Over 400,000 persons had the disease, and 112 of them lost their lives (Mac Kenzie et al., 1994).

The first outbreak in Europe was documented in 1995 in Emilia Romagna, Italy, where 294 cases happened at a rehabilitation center. HIV infection resulted in the deaths of seven people. According to Pozio et al. (1997), the infection was brought on by contamination of covered water tanks. In Kelowna, Canada, the infection affected 4,000 individuals in 1996. 2,000 persons were infected in Cranbrook, Canada, during an outbreak that same year. The tainted water in the lake and tank was the source of the virus in both epidemics (Craun et al., 1998). 563 persons in Dracy le Fort County, France, contracted *Cryptosporidium parvum* oocyst infections in 2001 as a result of sewage-contaminated public water supplies (Dalle et al., 2003). In 2010, about 12,700 instances of *Cryptosporidium* infection were found in the Swedish town of Östersund. Drinking water that had been tainted by sewage was the source of the infection (ECDC, 2012). In Saitama, Japan, outbreaks occurred in 1996 due to oocyst contamination of the drinking water, resulting in 8,705 cases of infection (Smith and Rose, 1998).

1.3. Giardia duodenalis

a. Taxonomy according to Schoch et al. (2020)

Kingdom: Protista

Sub-kingdom: Protozoa

Phylum: Sarcomastigophora

Class: zoomastigophora

Order: Diplomonadida

Family: *Hexamitidae*

Genus: *Giardia*

Species: *G. intestinalis*

b. Life cycle

Figure (3): Shematic view of life cycle of *G. intestinalis*.

The trophozoite, which produces the symptoms, and the cyst, which symbolizes the infectious form secreted with the host's feces, make up the basic life cycle of *G. intestinalis*. The low infective dose of 10 to 100 cysts in humans and the vast quantity of cysts shed by a single individual—2.5 × 107 *Giardia* cysts annually according to a study conducted in the Netherlands—both favor the organism's capacity to induce infection. significant levels of environmental contamination are indicated by significant levels of shedding by various animal hosts, including insects. Furthermore, it has been claimed that drinking water and food can harbor cysts for weeks or even months at a time. The 8–12 µm length of *G. intestinalis* cysts enables them to pass through and survive in water filters like sand filters. Furthermore, their survival under refrigerated environments is determined by their capacity to withstand low temperatures (Ryan et al., 2019).

c. World distribution (Epidemiology of G. intestinalis):

In 2010, there were 5.68 occurrences of giardiasis per 100,000 people in Europe; the majority of these cases happened in Bulgaria and among children under 4 (EDCD, 2012). In the United States, 2.96 cases per 100,000 individuals were reported in 2010. According to Yoder et al. (2012), untreated surface water or water used for recreational purposes was the most frequent source of illness.

In Slovakia, there were 169 cases in 2010, or 3.21 cases per 100,000 individuals (EDCD, 2012). In 2012, Slovakia had a total of 243 cases; the majority of these incidents happened in the Žilina region. Giardiasis has also been linked to significant waterborne outbreaks. The initial outbreak happened in Portland, USA, in 1954–1955, and the source of the virus was discovered to be insufficiently treated drinking water (Smith, 2020). Over 5,000 individuals in Roma, USA, contracted the disease in 1974–1975 as a result of drinking inadequately filtered and treated water (Shaw et al., 1977). *Giardia* cysts found in the drinking water were the source of two epidemics that occurred in Berlin, USA, at the same time in 1977. 5,000 individuals in Vail, USA, contracted an infection in 1978 as a result of sewage poisoning the water supply. After beaver feces contaminated a water supply in Bradford, USA, 3,500 people became ill a year later (Yoder et al., 2012).

At a ski resort in Sälen, Sweden, around Christmas 1986, 1,400 people contracted giardiasis. Sewage seeping into the water supply system was the cause of the simultaneous giardiasis and amoebiasis epidemics (Andersson and De Jong, 1989). *Giardia* cysts infected 1449 people in New York (USA) in 1995 as a result of improper lake water treatment (Levy et al., 1998). During the outbreak in Bergen, Norway, 1,300 persons contracted the disease. Giardia cysts contaminated the water supply, which was the source of the infection (Nygård et al., 2006).

2. Water Pollution Mechanisms

Giardiasis and cryptosporidiosis are spread by sick humans or animals that excrete oocysts and invasive cysts in their feces. *Giardia* and *Cryptosporidium* are spread by fecal-oral contact. Swimming in open pools can result in waterborne infections by ingesting or drinking it (Karanis et al., 2007). Protozoa can get past filters at drinking water treatment facilities because of their microscopic size. According to a Japanese study (Hashimoto et al., 2002), *Giardia* cysts were found in 12% (3/26; geometric mean concentration: 0.8 cysts/1000 L) and *Cryptosporidium* oocysts in 35% (9/26) of filtered water samples (geometric mean concentration: 1.2 oocysts/1000 L). They can also sustain their viability in the aquatic environment for at least six to twelve months, and they have a high degree of stability in water. *Giardia* cysts and *Cryptosporidium* oocysts have a strong wall surrounding them, which explains why. The creation of this barrier aids in the "freezing" of protozoa's metabolism, causing them to remain in what is known as "suspended animation" (Chauret et al., 2001).

Feces in the water supply and poor hygiene are the primary causes of waterborne and water-washed illnesses (Cairncross and Feachem, 1993; Byomi et al., 2018; 2019a; 2019b; Zin Eldin et al., 2023 and Elgendy et al., 2024). There are a number of ways that feces can get into the water, including overflowing sewage systems, clogged storm drains, and agricultural effluent. Protozoan disease-causing substances can seep into the soil and aquifers, as can liquid sewage from livestock farms, cesspools, and poorly designed toilets. Particularly hazardous are untreated animal wastes from establishments adjacent to communities that rely on the upper aquifers for water supply. The quality of drinking water can be compromised by precipitation and melting precipitation that seeps into groundwater aquifers. Between the confining strata, confined water is an underground reservoir with a relatively high water quality and a level that is constant throughout time. The best water, both hygienically and parasitologically, is confined. However, if the integrity of the confining strata is compromised or old wells are not supervised, cysts and oocysts may seed even of confined water (Mazayev et al., 2005 and Eissa, 2024c).

As was already established, the high degree of uncertainty surrounding interactive WASH components makes it challenging to evaluate statistics on the direct causes of diarrhea outbreaks. The industrialized world accounts for the bulk of cases with laboratory confirmation. For example, between 1990 and 2012, 411,041 instances of *Giardia* and *Cryptosporidium* outbreaks linked to drinking water were reported in the USA (Mazayev et al., 2005). These results indicated that the most frequent cause of outbreaks was a lack of therapy. Evidently, there are a lot more waterborne or water-washed parasitic protozoan illness epidemics in low- and middle-income nations. Regretfully, we lack similar results for the emerging countries.

3. Parasitic Protozoans in Immunocompromised Patients (Zoonotic hazard):

According to WHO estimates, water-related diseases are the world's biggest cause of sickness and death, accounting for almost 3.4 million deaths annually. Approximately 1.4 million of these fatalities are in children (Berman, 2009). According to Ramírez-Castillo et al. (2015), the primary causes of death for humans are poor sanitation and a lack of clean, safe drinking water, surpassing the combined effects of terrorism, and conflict.

An estimated US$ 12 billion in economic losses are caused annually worldwide by water-borne illnesses like diarrhea, gastrointestinal disorders, and systemic illnesses (Alhamlan et al., 2015). *Giardia*, *Entamoeba*, and *Cryptosporidium* species are among the protozoan parasites that are frequently blamed for diarrheal outbreaks in wealthy nations (Karanis et al., 2007). According to Al-Rifai et al. (2020), the two most frequent parasite infections that cause diarrhoea in water-borne cases are *Giardia* and *Cryptosporidium*. According to Patil et al. (2023), the most frequent infections causing diarrhea in kidney transplant recipients were *G. intestinalis* and *Cryptosporidium*.

Opportunistic infections, which are described as "serious, usually progressive infections by a microorganism that has limited (or no) pathogenic capacity under ordinary circumstances, and that has been able to cause serious disease as a result of the predisposing effect of another disease or of its treatment" (Symmers, 1965; Byomi et al., 2018; 2019a; 2019b; Bedair et al., 2021; 2024; Eissa and Harb, 2023; Eissa, 2024a; 2024b; 2024c; Elgendy et al., 2024; Salman et al., 2024a; b and Zin Eldin et al., 2024), can be caused by intestinal protozoan parasites (Chatterjee et al., 2023). Therefore, it is important to take precautions to avoid exposing immunocompromised people to these pathogenic pathogens. However, intestinal protozoans, such as *Cryptosporidium* spp., were more common in HIV-positive diarrhea patients in South Africa than in non-infected controls (Johnstone et al., 2023). Similarly, a high prevalence of intestinal protozoans, such as *Cryptosporidium* spp., *E. histolytica*, and *G. intestinalis*, was found in HIV-positive patients in central Ethiopia (12.9%). Consuming raw food on a regular basis was a risk factor that these patients' protozoan infections were substantially linked to Mesfun et al. (2022).

According to case-control studies conducted in Ghana and Libya, individuals with diabetes had a higher prevalence of *Cryptosporidium* spp. than non-diabetic controls. This difference is likely due to the chronic inflammation associated with diabetes, which reduces phagocyte activity and cytokine production (Konadu et al., 2023). Patients with diabetes had a higher frequency of coinfection with distinct parasites (Konadu et al., 2023). According to Taghipour et al. (2024), a global systematic review and meta-analysis, patients with diabetes had a greater prevalence of *Cryptosporidium* spp. than people in good health.

Protozoan parasites observable by unstained microscopy were considerably more prevalent in children with chronic liver disorders (CLD) of various etiologies than in children without CLD; this finding is likely because CLD impairs immunity (Sror et al., 2019; Byomi et al., 2019a and b). In a Polish case-control study, patients with hematological malignancies, particularly those with large B-cell lymphoma and plasma cell myeloma, had significantly higher prevalence of pathogenic protozoans *G. intestinalis* and *Cryptosporidium* spp. than did healthy controls (Łanocha et al., 2022).

In addition, *E. histolytica* has a straightforward life cycle that involves a quadrinucleated cyst that is excreted by infected hosts along with their feces. The cyst then undergoes excystation in the large intestine where it releases trophozoites that proliferate through binary fission. They pierce the intestinal mucosa and create the characteristic flask-shaped sores there. Trophozoites can enter the liver through the portal circulation from the intestine, where they can trigger an inflammatory response that results in hepatocyte necrosis and the formation of an abscess (amoebic liver abscess, ALA). Dysbiosis, decreased cell-mediated immunity, and the makeup of the intestinal microbiome are some of the variables that affect how the disease progresses. Most infected people have no symptoms, and the intestinal infection is more common (Tharmaratnam et al., 2020).

4. Mechanisms of Drinking Water Treatment (Prevention strategies):

4.1. Traditional methods of water treatment:

Several procedures are used in traditional drinking water treatment systems. They help lower the number of bacteria that are harmful to the public's health when added to sources of raw water (Betancourt and Rose, 2004 and Zin Eldin et al., 2023). When particles settle under gravity, settling, flocculation, and coagulation work to separate the solids from the liquid phase. Protozoa, bacteria, and viruses are examples of microbial agents that can be eliminated through sorbing into coagulation or flocculation. The clearance effectiveness of *Giardia* cysts and *Cryptosporidium* oocysts is approximately 90% (Carr et al., 2004).

Unfortunately, emerging nations are thought to find these strategies to be fiscally unprofitable. Plummer et al. (1995) examined the effectiveness of different conditions when it came to the removal of *Cryptosporidium* oocysts using clarity (sedimentation versus dissolved-air flotation). The study's findings demonstrated that oocyst absorption peaked at pH 5.0 and at doses of coagulants greater than those now employed to eliminate turbidity (Betancourt and Rose, 2004).

4.2. Filtration:

Filtration can act as a reliable and efficient barrier against microbiological infections when it is designed and operated correctly (Yao et al., 1971). Technological elements include the size and density of microorganisms, the size and surface charge of organisms and coagulant particles, the depth of the filter material, and the filtration rate all affect the transfer efficiency (Swertfeger et al., 1999). Microbial infections are not successfully eliminated by fast filtration (Ramzy et al., 2025), such as that of a basic screen filter. When it comes to eliminating microbiological contamination from water, slow sand filters can be quite effective (Carr et al., 2004). Diatom filtration, as opposed to other traditional filtrations or granulated medium, has been demonstrated to be more successful in lowering the concentration of *Giardia* cysts and *Cryptosporidium* oocysts (Ongerth and Hutton, 2001).

In the USA and Europe, the production of drinking water is mostly dependent on pressure-actuated membrane technologies, such as reverse osmosis, ultrafiltration, nanofiltration, and microfiltration (Ongerth and Hutton, 2001). As substitutes for the conventional methods of purifying and eliminating protozoal cysts, reverse osmosis, ultrafiltration, microfiltration, and nanofiltration have drawn a lot of interest (Ongerth and Hutton, 2001). Microfiltration membranes possess the biggest pores and maximum permeability within the 0.1 to 10 µm range. The method of microfiltration works well for getting rid of particles that could interfere with subsequent processing. Clarification, pre-treatment, and the elimination of particles and microorganisms are among the processes in water purification that include microfiltration membranes (Ongerth and Hutton, 2001).

Due to their smaller pores (0.002–0.1 µm), ultrafiltration membranes require higher pressures than microfiltration membranes because of their significantly lower permeability. Currently, particles and bacteria are removed from water by the use of ultrafiltration membranes. Protozoal cysts are thought to be removed mostly by physical sieving. According to Olderth and Hutton (2001), the pore diameters utilized in microfiltration and ultrafiltration for the purification of water range from 0.01 to 0.5 µm, which is at least one order of magnitude lower than the size of protozoan cysts (4–15 µm). The holes on nanofiltration membranes are about 0.001 µm in size. Nanofiltration is frequently used to soften water since it removes divalent ions from the water.

4.3. Reverse osmosis:

The smallest pores in membranes used for reverse osmosis are around 0.0001 µm in size. Because reverse osmosis can remove monovalent ions from saltwater, brackish water, or groundwater, it is necessary for the preparation of drinking water from these sources (Thorsen and Flogstad, 2006).

4.4. Disinfection:

In (1991), LeChevallier et al. studied 66 conventional water systems in the United States and discovered that filtered water was not guaranteed to be free of water-related protozoa even if the conditions outlined in the Surface Water Treatment Rule (SWTR) were followed. For this reason, either high disinfection levels or more potent disinfection techniques were required to shield people from water-borne protozoa like *Giardia* and *Cryptosporidium*. Since most pathogens in water cannot be eliminated by granular filter material alone, disinfection is a crucial component of most treatment plants, particularly those that use surface water. The primary cause of the reagent approaches' extensive use in drinking water disinfection is how simple it is to continuously evaluate their efficacy. Water quality monitoring based on epidemiological indicators needs to be done at least once every hour when using a centralized water supply system. When using reagent disinfection techniques, the amount of disinfecting agent that remains in the water is used to gauge how effective the water disinfection was (Ongerth and Hutton, 2001). The concentration of the disinfectant, contact duration, temperature, and pH (depending on the disinfectant) are the primary parameters that affect disinfection effectiveness (Carr et al., 2004).

4.4.1. Chlorine:

For the treatment of drinking water, chlorine is the most widely used disinfectant in both industrialized and developing nations. Chlorine has been effectively used for a long time to treat water, both for drinking water and effluent (Butterfield and Wattie, 1946). Furthermore, because chlorine is a cheap and simple disinfectant, it is advised for usage in households, particularly in developing nations, for the treatment of water. A further 29% can be taken off the risk of children experiencing diarrhea due to *Escherichia coli* by doing point-of-use chlorine disinfection. However, due to organic content in the treated water, it has a number of drawbacks, including ineffectiveness against protozoa, loss of efficacy, strong odor, and disagreeable taste (Arnold and Colford Jr, 2007). Viruses and bacteriophages are thought to be more resistant than vegetative bacterial cells to chlorine inactivation (Butterfield and Wattie, 1946). *Giardia* cysts been proven to be comparatively resistant to chlorine inactivation, according to Jarroll et al. (1981). Among the water's most resilient microbes is *Cryptosporidium*. Data that have been published indicate that even after 18 hours of exposure to 1.05% and 3% chlorine, *Cryptosporidium* has not been shown to be inactivated (Ongerth and Hutton, 2001). On the other hand, worries about the potential dangers of consuming chlorinated disinfection byproducts over an extended period of time have led to the widespread use of chlorination of drinking water. Because it takes 25–100 times longer to get equivalent inactivation than chlorine, monochloramine is regarded as a weaker biocide than free chlorine (Carr et al., 2004).

4.4.2. Chlorine dioxide:

Many researchers are currently concentrating on alternative disinfectants, such as UV radiation, ozone, and chlorine dioxide (Peeters et al., 1989). In the pH range of 6.0 to 9.0, chlorine dioxide is dissolved in water as an undissociated gas. It is a potent disinfectant and, under most circumstances, is thought to have a biocidal efficiency that is either slightly higher than or equal to that of chlorine (Carr et al., 2004). With 90% destruction of cysts and oocysts, chlorine dioxide is a highly powerful disinfectant against *Giardia* and *Cryptosporidium*. However, this disinfectant produces byproducts such as chlorate and chlorite. Furthermore, according to Peters et al. (1989), chlorine dioxide is five to ten times more expensive than chlorine.

4.4.3. Ozone:

In contrast, ozone is a potent oxidant that is harmful to the majority of waterborne infections, including certain protozoan cysts like *Cryptosporidium*. It is used to eliminate organic and inorganic pollutants from water and to enhance flavor and color. Ozone offers several benefits, but its application in water treatment is restricted by a number of drawbacks, including its high cost, the requirement for infrastructure for operation and maintenance, and the lack of residual protection in the distribution system (Kasprzyk-Hordern et al., 2003).

4.4.4. Ultraviolet radiation (UV):

A alternative perspective is that UV radiation's capacity to pass through cell walls and reach the nucleic acids DNA and RNA, the information center of the cell, causes ultraviolet water contamination. DNA is irreversibly damaged by ultraviolet water-disinfection, which impairs cell division and/or causes cell death (Snicer, 2000). The key benefits of UV radiation include its effectiveness in inactivating protozoan parasites, its lack of need for chemical additives, its comparatively short contact duration, and the absence of any known disinfection by-products. Conversely, its drawbacks include the inability to evaluate the lamp dose in real-world situations, variations in efficiency between different UV lamp types and reactor designs, turbidity interference, and lack of residual protection in the water distribution system (Ongerth and Hutton, 2001).

Regretfully, ozonization and ultraviolet radiation do not possess bactericidal aftereffects; thus, they cannot be employed as stand-alone methods of disinfecting water for use in swimming pools, drinking water supplies, or utilities. Other methods of disinfection include ozonization and UV light therapy. They boost the effectiveness of chlorination and minimize the quantity of reagents containing chlorine that are added when used in conjunction with it (Ongerth and Hutton, 2001).

CONCLUSION

Drinking water sources and sanitation facilities need to be enhanced in order to control and prevent parasite infections that are transmitted through water. This covers the appropriate treatment of wastewater as well as drinking water. Along with the transmission and development of hygiene programs in communities, schools, and institutions, the principles of sanitation and hygiene should be introduced and supported. Since water-borne illnesses are still widespread throughout much of the world, control and prevention strategies need to get extra attention. One of the main causes of the high prevalence of chronic diseases in developing nations is a lack of financial resources, which can also have a significant detrimental impact on the economy, particularly in low-income nations. Numerous nations have already put eradication and control programs into place, and they have been successful in lowering and stopping the quantity of water-borne protozoans.

ABBREVIATIONS

°C, Degree Celsus; µm, micrometer; ALA, Amoebic liver abcess; *C. parvum, Cryptosporidium parvum*; CLD, Chronic liver disorders; CRC, Colorectal cancer; DNA, Deoxyribonucleic acid; *E. histolytica, Entamoeba histolytica; G. duodenalis, Giardia duodenalis; G. intestinalis, Giardia intestinalis; G. lamblia, Giardia lamblia*; HIV, Human Immunodeficiency Virus; IPIs, Intestinal parasite infections; L, Litre; PCR, Polymerase Chain Reaction; pH, Power of Hydrogen ions; RNA, Ribonucleic acid; spp., Species; UN, United Nations; USA, United States of America; UV, Ultraviolet; WHO, World Health Organization.

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