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Emerging Drinking Water Borne Diseases: A Review on Types, Sources and Health Precaution

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The global demand for safe drinking water become increasingly important in the past few years due to the growing world population, civilization and increase the sources of contaminations. Millions of peoples every year suffer from different waterborne disease, which may include microbial or

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disinfectant related diseases. This review, presents an overview on drinking water and their health impact from different aspects, going through different types of physical, chemical, and biological contaminants and their potential effect on human body upon the consumption of their contaminated water. The review also furtherly discusses drinking water treatment techniques such as chlorination, ultraviolet radiation treatment, chlorination, ozonation, heating, and ultra-filtration and the efficiency of these techniques to eliminate different water microorganisms. Drinking waterborne diseases of bacteria, viruses, parasitic protozoa and even some fungi have been also discussed. Finally, health precaution regarding drinking water in term of monitoring of different indicators as well as following the hygienic behaviors was covered to ensure the sustainability and safety of water consumption.

Keywords: Drinking water; water borne diseases; microbial contamination; water quality.

1. INTRODUCTION

The World Health Organization (WHO) reported in 2017 that more than 2.1 billion people cannot access to safe drinkable water free from all the sources of physical, chemical and microbial contaminations, which equivalent to almost third the global population [1]. It has been estimated by WHO that the annual death caused by diarrheal diseases is about 1.8 million, which mainly due to the consumption of contaminated drinking water [2]. People who suffer from chronic diseases that weakening their immunity, such as diabetes, cancer, and AIDS, etc., and the young children as well as elder peoples are particularly more vulnerable to waterborne infections [3]. Environmental factors might also play a significant role, which influence more than 80% of the overall diseases. It was reported that in young children under the age of 5 years, the diseases with the highest environmental contribution including lower respiratory infections (32% of the overall cases), diarrhoeal and GIT diseases (22%), newborn associated conditions (15%), and parasitic-borne diseases (12%) [4]. Several millions of young children die every year from waterborne disease, particularly from acute diarrheal diseases due to the consumption or using of contaminated food or water [5]. These diseases can be transmitted to human through four basic routes including waterborne route by the consumption of water directly to the human body, water-washed route by using contaminated water in washing purposes causing contamination of hands or food-plates, water-based route during the recreational or other activities and insect vector route [6].

The global burden of infectious diseases associated with water is considerable, and even in developed and high-income countries, it continues to be a concern [7]. Countries all over the world are concerning with the potential effects of consuming unclean drinking water as it has been proved to be a main cause of numerous water-borne diseases leading to high range of morbidity and mortality especially in undeveloped and developing counties [8,9]. As a daily consumed material, clean drinking water must be free from infectious pathogens as well as toxic and undesired physico-chemical pollutants [10,11]. Clean drinking water is essential for overall health of the entire human been and plays a substantial role especially in infants and young children health and survival as their immune system is weaker [12]. As such, extensive testing is required to understand the possible routes of the viral contagion, which is very expensive [13]. Therefore, monitoring the spread of COVID-19 early stages in communities through the wastewater-based epidemiology (WBE) approach is useful [14]. Additionally, this could possibly provide rapid results for effective and urgent interventions in the fight against COVID-19 [15].

Many review articles have been published discussing swimming pools associated viral waterborne diseases [16], transmission of protozoan parasites [17], and control of waterborne diseases [18]. Most of previous reviews discuss either location in the world, part from water-borne diseases factors or the outbreak of water borne diseases in particular location. This review delivers an overview on drinking water quality, the basic possible contaminant and their potential health impact upon consumption [19]. It also furtherly discusses waterborne diseases, their classification, drinking water disinfection and treatment techniques and highlight the health precaution regarding drinking water and water-borne diseases.

2. DRINKING WATER QUALITY

Water quality is a general term used to describe the physical (such as turbidity, color, suspended solids, etc.), chemical (such as organic contaminant, inorganic contaminant, heavy metals, etc.), and biological (such as bacteria, plankton, algae, fungi, etc.) parameters may present in water [20,21]. The consideration of water quality in most of cases corresponds to the origin and the purpose of water. However, the general instruction about drinking water standards have been published by many organizations such as United States environmental protection agency (USEPA) and the WHO, etc, [22]. The quantity of microorganisms have been reported to affect the taste and odor of water, variety of microbes produce certain pigments that cause changes in water color [23,24]. The contamination of drinking water with the feces of hot blood organisms including animal and human is consider the main route of transmission of water borne diseases to human beings [25]. Abu-Amr and Yassin [26] concluded that self-reported diseases are well associated with insufficient chlorination of drinking water, intermittent water supply and sewage flooding. However, many developing countries have the issue of chronic shortages of fresh water, even costal country in Africa and southern Asia; the readily accessible resources are another major issue which been heavily polluted in most of times [27]. The treated drinking water pumped into the network of distribution system, which may contain different physical loads (dissolved or suspended), microbial loads (bacteria, yeasts, fungi or protozoa) and nutrient loads (different organic and inorganic nutrients), and thus many people use house hold purification system in order to maintain the desired quality of their water [28]. Fig. 1 presents the main types of drinking water contamination.

2.1 Physico-chemical Contamination of Drinking Water

The contamination of drinking water with different physical and chemicals agents released from different anthropogenic contamination sources has become a global concern [29]. The contamination of drinking water resources may also occur due to the unsuccessful treatment or even after treatment, which has important repercussions for both environment and human health [30,31]. Gul et al. [32] reported that different anions are present in drinking water including heavy metals such as Co, Cd, Cr, Ni, Zn, Hg, Pb, etc. These heavy metals have significant adverse effects on human health if its exceeded the quality guild lines either through deficiency or toxicity. Lu et al. [33] studied the potential for cancer risk related to the presence of carcinogenic metals when it consumed with drinking water, and revealed high risk at certain levels. In different study, Arshad and Imran [34] evaluated the effect of fluoride-contaminated drinking water consumption in a rural population of Pakistan on the arenicolids and skeletal/dental fluorosis, and concluded that the consumption of high amounts of fluoride can lead to serious health issues. Nitrate (NO3) and nitrites (NO2) are another two parameters naturally found in water [35], the reduction of nitrate to nitrite tern it toxic to human health [36]. It has been reported that nitrite involve in the oxidation of hemoglobin and transform it to met-haemoglobin, a modified compound which is unable to transport oxygen to the cells and tissues [37]. Refer to Table 1 for the health effect of different physic-chemical contaminant if it is present in drinking water in high levels.

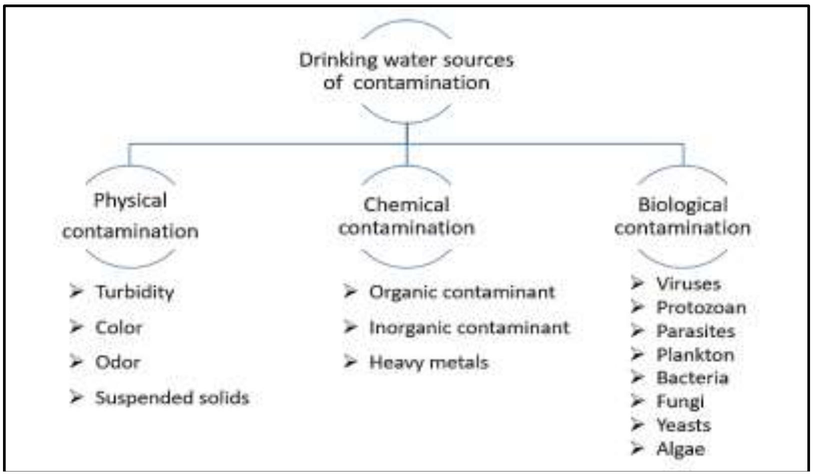

Fig. 1. Sources of drinking water contamination

Table 1. Potential health effect of physico-chemical contaminant upon consumed in high levels in drinking water

Contaminant	Potential health risk	Ref
Chlorine	Bladder, colon and rectum cancers in addition to adverse effects on reproduction	[38]
Sodium	Excessive intake of sodium lead to raise in blood pressure, kidney damage, stroke, headache and edema, etc.	[39]
Nitrates and nitrites	Major health problems such as Methemoglobinomia and increase the risk of abortion and even cancers.	[40]
Fluoride	Long-term consumption can lead to dental and skeletal fluorosis, Alzheimer and neurological problems.	[41]
Trihalomethanes	Increased risk of bladder cancer	[42]
Sulfate and calcium carbonate	Excessive intake of these element in water may lead to indigestion and severe diarrhea in consumers.	[43]
Heavy metals	Different heavy metals associated with different impact such as toxicity, stability, and carcinogenic and bioaccumulation.	[44]

2.2 Biological Contamination of Drinking Water

Microorganisms may introduced into water distribution system, through the main source of raw water or by side contamination source, which all will undergo different changes in viability, density and diversity of the microorganisms due to the selective pressures of the system [45]. Phiri et al. [46] assessed the presence of drinking waterborne pathogens in New Zealand and tracked the potential sources of contamination. The authors reported the presence of *Escherichia coli* in more than half of the collected samples, which was used as an indicator organism. The same authors added that the use of water filters alone was not associated with the likelihood of compliance. In different study, Ward et al. [47] conducted a nine-month drinking water quality monitoring programme in rural Malawi and revealed highly abundance of E. coli as well as other fecal coliform bacterial in the tested samples. The application of water treatment will lead to dramatic decrease in the microbial load [48]. The increase in microbial growth after water treatment has been termed as regrowth, it happened due to unsuccessful treatment process, which consider as a major problem and one of the main causes of many diseases [49]. Qin et al. [50] investigated the occurrence and distribution of water opportunistic pathogens in water storage tanks using species-specific qPCR assay. The authors determined the occurrence of many pathogens including *P. aeruginosa*, *Legionella spp*, *Mycobacterium spp*, and Acanthamoeba spp, etc., with 88% detection of Mycobacterium spp in the sediments and water samples, which was the most frequently detected pathogen. The same authors reported that microbial communities possibly influenced by constituents within the water in storage tank sediments, the compositions and diversity of microbial community and the types of elements may also influence the microbial water quality [51].

3. MICROBIAL WATER QUALITY

The World Health Organization/ the United Nations Children's Fund (WHO/UNICEF) report of 2017 regarding monitoring program of drinking water supplies and hygiene revealed that roughly 844 million people all over the world lack access to clean and drinkable water and 2.3 billion (about third of global population) lack basic sanitation services [1]. Two major indicators for microbial water quality monitoring usually used, total microbial counts and the presence of coliforms [52]. Coliform bacteria are group of rod-shaped gram-negative microorganisms, they are the most regular bacterial species ranged from harmless to pathogenic species. Coliforms have been widely isolated from soil and other environment in the defecation of creatures of warm blood [53]. They can be classified based on their origin to fecal and non-fecal coliforms, total and fecal coliforms assessment is the most used prominent method to measure and assess the drinking water bacteriological quality [54]. Wen et al. [55] furtherly discussed water quality indicator systems in variety of countries all over the world, the review focused on different microbial indicators including bacteria, protozoa, and enteric virus, etc., that being tested and used in Asian, European and American countries to monitor water quality.

Various microbial indicator species such as, *Enterococcus spp*, coliforms, *Escherichia coli* and total counts of water bacterial are the most frequently monitored as detection or monitoring of many other water pathogens are expensive or impractical. Although the presence of *Escherichia coli* and fecal coliforms in drinking water indicates its contamination and its unsuitability for drinking, their absence does not particularly preclude the presence of one or more other harmful organisms [56]. Microbial biomass in water and liquid media is typically measured using heterotrophic plate counts technique, which detect and quantifies the viable bacteria in drinking water [57]. The actual bacterial species quantified by heterotrophic plate counts depends on the type of cultivation medium, as well as incubation time and temperature [58]. Potential concerns have been associated with the abundance of above 500 cfu/ml, which mainly due to the potential interference with the analytical detection of various pathogens such as total coliforms [59]. Various drawbacks have been associated with heterotrophic plate counts technique such as the requirement of a well-equipped laboratory as well as time consuming as the analyses typically take several days [60]. Faster methods such as flow cytometry cell counts method and adenosine tri-phosphate assessment method have been also developed but still relatively complex to interpret and implement, which prevent their widespread and usage for drinking water quality monitoring [61,62].

Among 15000 species of protozoa present on earth, only four classes have been identified as they have significant impact on health including Flagellata, Sarcodina, Infusoria, and Sporozoa [63]. However, the most common drinking water-related parasitic infections among adults and children are cryptosporidiosis and giardiasis [64]. Cryptosporidium and Giardia are two zoonotic agents that mostly identified during contaminated drinking water outbreaks, particularly causing diarrheal disease among young children in developing countries [65]. The cysts and oocysts of protozoa are found in different water sources including waste water, surface and groundwater sources, even after treatment of drinking water, it has been reported the presence of these parasitic forms in many drinking water samples after treatment with conventional methods [66,67]. As these methods mainly focus on removing of pathogenic bacteria such as *Salmonella spp*, *Vibrio cholera* and *Escherichia coli* [68], parasitic protozoa such as *Giardia lamblia* and *Cryptosporidium parvum* are able to resist chlorine of particular concern [69].

3.1 Drinking Water Disinfection Techniques

The quality of drinking water is a globally major concern and has a significant impact on human health [70]. Many plans have been developed for drinking water treatment, the suitable operation and design is normally determined based on various considerations such as the physical, chemical, and microbiological parameters of the water source [71]. It has been reported that weak sanitation and polluted water provisions are the main cause of more than 80% of the diseases in the poorest nations [72]. The maturation and developing of advanced municipal water purification approaches in the last few years has authorized developed countries to overcome most of water related disease. Many methods have been used for microbial disinfection of drinking water including chlorination, ultraviolet radiation, chlorination, ozonation, chlorine dioxide or ultra-filtration [73]. Refer to Table 2 for the summary of these techniques.

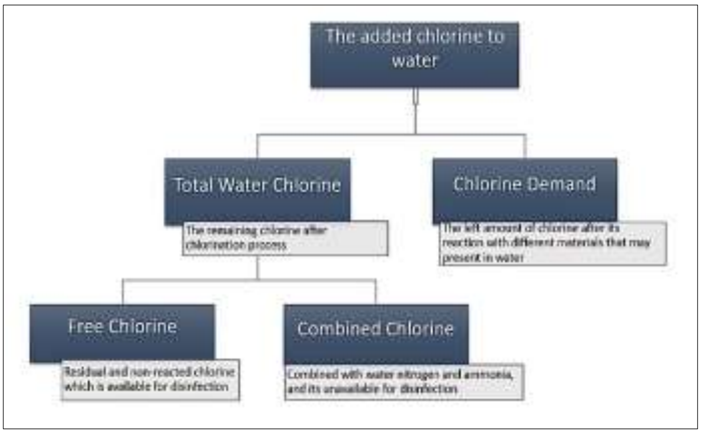

Fig. 2. The chlorine addition to drinking water

Table 2. Drinking water disinfection techniques

Technique	Remark	Ref
Chlorination	Addition of chlorine or its products reacts with water to form hypochlorite ions and hypochlorous acid, which able to disinfect many water microorganisms.	[74]
Ultraviolet radiation	Exposing the water to shortwave radiation, which kill water microorganisms by directly affecting its DNA, it is non-residual in water and does not cause any harmful products in the drinking water.	[75]
Chloramination	It is the reaction of chlorine and ammonia under well-controlled conditions result in formation of monochloramine, which able to reduce microorganisms and it doesn't form any harmful by-products.	[76]
Ozonation	Using ozone (O_3) as a powerful oxidizing agent for readily oxidizes various microbes, chemical residuals and organic matter in low concentrations and short contact times.	[77]
Heating	Heating up the water till boiling temperature for certain time to kill microorganisms, is a widely used methods among the consumers of municipal water	[78]
Ultra-filtration	Filtration of water microorganisms present in water by passing the water trough small pores do not permit passing of microbes	[79]

Chlorination has been reported as the most widely used all over the world, many countries follow their own guild-lines for the added concentration of chlorine [80]. Gagnon et al. [81] reported that the presence of low concentration levels of chlorite in drinking water seemed not to be effective in elimination of heterotrophic bacteria, and indicated the need to maintain higher concentrations of chlorine dioxide residual in drinking water distribution systems for better control of microbial regrowth. A portion of the chlorine at the point of its addition to water responds first with different natural and inorganic materials, as well as metals that may present in water, the rest of the remaining chlorine is known as total chlorine [82]. Mazhar et al. [38] reported that total chlorine present in drinking water is a sum of free chlorine and combined chlorine. From one side, the combined chorine possesses weak disinfection properties and mostly consider inaccessible for disinfection especially when it combines with many inorganic and organic materials such as nitrates and urea, etc. From the other side, the free chlorine possess stronger disinfection properties and accessible to inactivate water pathogens, it is the left over chlorine, in which a measure of the potability of the water. For instance, if we are utilizing totally clean drinking water, which free from any contaminants, its chlorine demand will be zero, and it will has zero combine chlorine as well due to the absence of organic and inorganic material in that water [83]. Fig. 2 summary the addition of chlorine to water as disinfectant [84].

Microbial communities in drinking water have been reported to be highly sensitive to the changes in the physiochemical and microbiological parameters (i.e., types and concentration of disinfectants, nutrients concentration, inorganic elements composition), which all could influence the types, numbers and growing rates of microbial population [85]. Wang et al. [86] reported reversible shifts in microbial communities in water upon the temporary switching between chlorination and chloramination. Yang et al. [87] concluded that in extreme case, discoloration of water could arise the increase of sulfate levels in feed water, which caused noteworthy increase of various types of sulfur-oxidizing and sulfate-reducing bacteria as well as and iron-oxidizing bacteria. The authors explained this increased, as it was associated with the presence of iron erosion, which cause discoloration of the water [88].

4. WATER-BORNE DISEASES

Water-borne or water related diseases encompass illnesses resulting from both direct and indirect exposure to water. It have been reported that the exposure of human to water-borne infections may occurs by direct contact or consumption of contaminated drinking water, food contain contaminated water or even from recreational water [89]. Apart from microorganisms, water-borne diseases also includes diseases associated with toxic substances presented in water [90]. Ghernaout et al. [91] reported that roughly, two billion people throughout the world don't reach protected potable water, leading to the death of 20 million babies annually, because of waterborne diarrheal diseases such as dysentery, cholera and typhoid fever. Maramraj et al. [92] estimated that around 1.7 billion cases of diarrheal diseases and 2.2 million deaths globally from acute diarrheal disease are being recording every year. World health organization reported that lack of access to clean and quality drinking water, in addition to inadequate sanitation and hygiene are the are the leading causes of acute diarrheal disease [93]. Bivins et al. [94] estimated the median daily risk of infection of diarrheal disease attributable in people who consume fecally contaminated tap water without using suitable filter of good treatment approach. The authors reported 3 main reference pathogens including Cryptosporidium, Campylobacter, and rotavirus as a standard conservative risk proxies for infections for protozoa infection, bacterial infection, and viral infection respectively. The same authors concluded that around 17.20 million infections annually causing more than 4.52 million cases of diarrhea and almost 1560 deaths, underscoring the importance of water safety management specially in developing countries and the potential benefits of point-of-use treatment to mitigate risks [15]. A variety of drinking and daily used water reservoirs have been widely linked to nosocomial outbreaks including dialysis water, potable water, tub immersion, sinks, showers, faucet aerators, ice and ice machines, swimming pools, water baths, flower vases, and dental-unit water stations [95]. Decker et al. [96] reported that transmission of waterborne pathogens from contaminated water reservoir in direct or indirect contact and the ingestion of these pathogens with water, food or even or inhalation of aerosols will lead to waterborne infections.

4.1 Water Disinfectant Associated Diseases

Although there are numerous ways have been used to sterilize drinking water such as filtration, heating and the addition of chemical and physical methods [97]. Many countries are still using chlorine in their water distribution systems and tanks to sterilize drinking water [98]. In the past few years, a strong correlation between residual free chlorine used in drinking water sterilization and the negative effects on health have been confirmed [82]. Water chlorine react with organic matters that may found in water producing chlorinated hydrocarbons, which have been linked with many water borne diseases [82]. Disinfection by-products formed when water chlorine react with organic matter have been reported to cause an adverse reproductive effect to pregnant women including intrauterine growth retardation, spontaneous abortion and low birth weight [99]. Refer to Table 3 for the effect water chlorine on the human body.

Table 3. Adverse health effect of chlorinated water drinking and/or exposure

Method of contact	Body system	Remark	Ref
Inhalation of high concentrations of chlorine	Respiratory system	Irritation and inflammation may occur of the throat and nose membranes in addition to possible occurrence of bronchitis and asthma.	[100, 101]
Swallowing high amount of chlorine	Digestive system	Vomiting, chest pain, irritation of the pharynx and esophagus, in addition to various types of cancer risk.	[102, 103]
Swallowing high amount of chlorine	Intestinal Microbiota	Development of food allergy in infancy, and increased risk of asthma.	[42]
Washing or during swimming	Eyes	Mild burns in the corneal membranes, but it may lead to an ulcer or even leave scars.	[104]
Bathing and ablution	Skin and hair	Potential scalp, skin redness and allergies in chlorine sensitive peoples. Destruction of hair proteins leading to dryness, fragile, losing color, and dandruff.	[38, 105]
Drinking and washing	Teeth	Decay and weakness of tooth, in addition to the possible loss of enamel by corrosive disintegration.	[106]
Swallowing high amount of chlorine	Reproductive system	Adverse reproductive effect in pregnant women, including, retardation of intrauterine growth, low birth weight and even spontaneous abortion.	[99, 107]

4.2 water Microbes Associated Diseases

Different microorganisms may present in drinking water and transmitted to human body either via drinking or upon consumption of food, if it washed or prepared with contaminated water [108]. Diverse range of drinking water pathogens have been isolated and studied, mainly include bacteria, viruses, parasites and in rare cases fungi. Some of these microbes has a serious health impact, which may be mortal, while other could be only meld [109].

4.2.1 Bacteria

Bacteria is the widest occurring pathogenic microbes affecting all water source types in almost all developed and developing countries [110]. Escherichia coli and Enterococci are two fecal coliforms commonly present in oceans as well as in fresh lakes and rivers water [111]. However, the presence of any amount of these bacterial in drinking water make it unsuitable for consumption. Fecal indicators have been used as an indicators for human or hot-blood animal wastes in drinking water, many scientists have linked the consumption of fecal coliform contaminated water with many diseases such as diarrhea, cramps, nausea, and headaches [112]. Odonkor et al. [113] used *Escherichia coli* as a tool for assessing disease risk for drinking water, and revealed that main causes of drinking water faecal contamination in all the studied samples were purported to be anthropogenic. Sometimes bacterial contamination of drinking water causes a serious kidney disease such as hemolytic uremic syndrome, and could be also cause potential lifelong complications [114]. Other water bacteria such as *Salmonella typhii*, *Vibrio cholera* and *Shigella spp* have been linked with water poisoning, cholera, typhoid fevers and bacillary dysentery [115]. Pedati et al. [116] investigated the outbreak resulted from Campylobacteriosis from municipal water supply, and reported various symptoms of diarrhea, abdominal cramps, pain and fever. Numerous species of Mycobacterium have been isolated from hospital water distribution systems as well as from the potable water, which can cause nosocomial infections [117]. *Anabaena circinalis* is another cyanobacterium that widely living in freshwater reservoirs in many countries all over the world [118]. The main health impact of this bacteria is the ability to produce neurotoxins, which cause respiratory arrest, and in most cases followed by death [119].

4.2.2 Viruses

Viruses are very small pathogens that can pass through all water filters, which retain bacteria. According to the reports of Centers for Disease Control and Prevention (CDC) viruses were responsible for more than 9% of all in the united states reported drinking water outbreaks from 1993 till 2012 [120]. Most drinking waterborne viruses have been reported to follow the typical fecal-oral route of infection [121]. Gall et al. [122] reported that more than 1.8 billion people worldwide rely on sewage-contaminated water, which is used in drinking, washing and/or cooking of food. Owing to their small size, viruses are persistent in the environment and able to significantly resist many of water treatment disinfection processes, making them difficult to remove or eliminate by particle separation [123]. Enteroviruses are types of non-enveloped viruses, which have been linked with number diseases as one of the drinking water borne pathogens [124]. Pearce-Walker et al. [125] reported the ability of these viruses to transmit mainly by fecal–oral routes, especially with drinking water and/or food, as well as ophthalmic secretions, dermal lesions, or soil. Many literatures have reported variety of diseases that caused by different types of enteroviruses; Echoviruses usually associated with aseptic meningitis diseases, encephalitis respiratory diseases, and common cold [126]. Coxsackieviruses have been reported to cause hand-foot-mouth disease, acute hemorrhagic conjunctivitis, aseptic meningitis, gastroenteritis, respiratory system infections, and heart diseases [127]. In many of East Asian countries including China, Korea, Japan, and Taiwan, enteroviruses associated diseases are predominantly found during summer compared to the other seasons, suggesting that meteorological variables and the parameters of drinking water quality might influence the frequency and spread as well as distribution of enteroviruses [128-130].

4.2.3 Protozoan parasites

Protozoan parasites have been identified as the second most etiological responsible of the mortality among young and infant children in developing countries [131]. They are responsible for about 1.7 billion cases world wide of diarrhea, leading to annual of 842,000 deaths [17]. Bartram et al. [66] reported that drinking water transmitted parasitic diseases, particularly protozoa cause endemic and epidemic diseases not only in developing countries but all over the world. However, the former have better hygienic conditions, and thus parasitic protozoa in most of causes not considered as a major reason of these diseases [132]. Markedly high rates of protozoan associated diseases have been reported in the latter, where the consumption of both treated and untreated water occur [133]. Owing to their small size (1-17 µm), the cysts and oocysts of Giardia and Cryptosporidium can easily penetrate through the water treatment system, leading to purified drinking water outbreaks and epidemics [134]. The infection begins with drinking of cysts or oocysts with contaminated water, or by using such water in cold food preparation. Each single cyst produces two trophozoites inside the small intestine of the host, which undergo fast multiplication through longitudinal binary fission, and remain in the lumen (free or attached to the mucosa). Upon the transition of parasites toward the colon, encystation occurs and both trophozoites and cysts are suspended in the feces [135]. Cysts and oocysts in feces spread into the external environment and contaminate water, food or directly infect other hosts [136]. Fig. 3 present the life cycle of Giardia as one of typical drinking water pathogenic parasitic protozoa.

4.2.4 Fungi

Fungi have been reported to ubiquitously occur in different environments, including water, and many of fungal species are pathogenic and cause serious health problems [137]. De Toni et al. [138] investigated the effect of fungi on drinking water quality and reported that their present can significantly change the smell and taste of drinking water, which makes it becomes unpleasant for drinking. However, many health issue have been reported in term of the consumption of fungal contaminated water, Oliveira et al. [139] linked fungal contaminated water with respiratory illness, allergies and life-threatening meningitis, in addition to mycoses, invasive and contagious infections. Mycotoxins are one of many fungal secondary metabolites, which may cause food poisoning and be a life treating substances. Magwaza et al. [140] studied the occurrence and diversity of fungal waterborne in African and revealed their impact in many respiratory problems. Other studies have linked mycotoxins with more serious health issues such as reducing the immunity and even cancers [141,142]. In most countries water microbial standards are based on bacterial indicators, such as fecal bacteria for the quality and safety of water for drinking and the presence of pathogenic bacteria and intestinal protozoa [143]. Thus, only the oral-fecal route is mostly taken in consideration, and as it is not the main path for most fungal entry into water systems, not much has been done regarding investigation and monitoring of drinking water fungi.

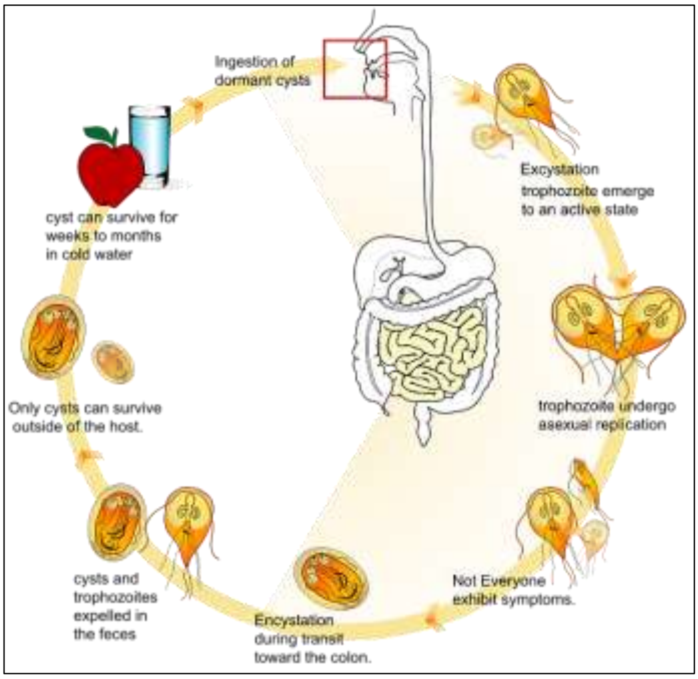

Fig. 3. Schematic illustration of the life cycle of Giardia as one of typical drinking water pathogenic parasites

(Available online: http://en.wikipedia.org/wiki/File:Giardia_life_cycle_en.svg)

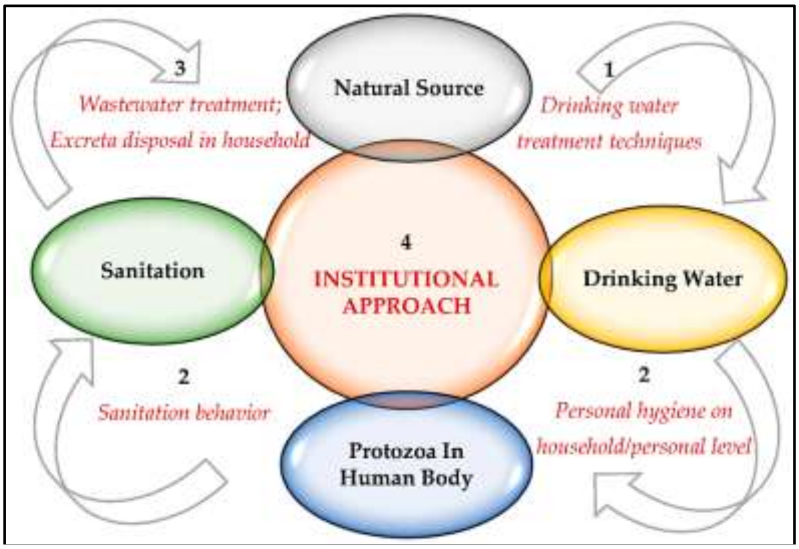

Fig. 4. Schematic illustration of systems approach to ensure improved drinking water, sanitation and hygiene. Adapted from [63]

4.3 Health Precaution

Treatment of drinking water may decrease or eliminate most or even all the microorganisms presented in water however, recontamination of treated water may occur during the distribution in the network on the way to consumers, or even if the consumers not following the suitable hygienic behavior [144]. Obtaining rapid and affordable frequently assessments of the microbiological quality of drinking water at the point of treatment as well as at the point where it reach the consumers is necessary to ensure the safety of consumed drinking water [145]. Indicator bacterial species such as, *Enterococcus spp*, coliforms, *Escherichia coli* and total bacterial count are the most frequently monitored, as the rest of pathogenic indicators tend to be more expensive or impractical. However, detection of other types of pathogens such as parasites and viruses is not performed in many countries, as it requires special labs and advanced skills [146]. Although the presence of *Escherichia coli* and fecal coliforms in drinking water indicates its contamination and its unsuitability for drinking, their absence does not particularly preclude the presence of one or more other harmful organisms [56]. Generalized monitoring system must be developed that can be affordable and easy to use among different technicians in developed and developing countries [147]. Omarova et al. [63] discussed the possibility to achieve drinking water free from bacteria, protozoan parasites, and even viruses as presented in Fig. 4. Following non hygienic personal behaviors will affect the person himself and the surrounding people who share the same water source. Effective drinking water treatment technique and hygienic behavior from all the consumers are necessary to maintain and achieve drinking water sustainable development goals.

5. CONCLUSION

The inaccessibility to safe and clean drinking water has been always a big challenge facing humanity in past and current the centuries. This paper reviewed different types of drinking water contaminants, including physico-chemical and biological contaminants and their effects on human health, and the most used water treatment technologies in term of microbial disinfection. In addition, this review presents water borne diseases resulted from both drinking water disinfectant and water microorganisms, and highlight health precaution regarding drinking water microorganisms. Many countries only uses bacterial indicators to judge the quality of drinking water, and ignore the other pathogenic microorganisms such as parasitic protozoa, viruses and even fungi. However, this review highlighted the health impact of drinking water disinfectant that commonly used for water treatment and presented the health precaution to ensure the sustainability and safety of water consumption.

CONSENT AND ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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