

REVIEW



The impact of water crises and climate changes on the transmission of protozoan parasites in Africa

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ABSTRACT

Waterborne protozoa (WBP) are important cause of several outbreaks all over the world. The report system of WBP in Africa is weak. More than one third of African countries (21/54) reported WBP with absent reports in the remaining countries (33/54). The top reported WBP were *Cryptosporidium*, *Giardia*, FLA and *Entamoeba* contaminating different African water resources. Other protozoa were less documented even though it is abundant and robust. More than one protozoa were detected in contaminated African water including drinking sources, a prediction index to popular epidemics and real presence of undocumented WBP outbreaks. Risk factors in Africa were observed to be abundant and multi-factorial 'socioeconomic, governmental, pathogen in water and climate change. Climate change is an important factor impacting Africa. Increasing droughts in Africa with other extreme weather events will lead to water crises. Incidence and transmission of WBP will change, with new manifested strains/species. Recognizing future consequences of water crises in Africa are important. Governments and population unity will be needed to protect against expected raise and spread of WBP diseases and water shortages.

KEYWORDS

Water-borne protozoa; transmission; water; risk factors; climate change; review; Africa

Introduction

Africa, the second-largest continent in the world after Asia, covers 20.4% of the earth's total land area with 54 recognized countries. In 2017, it accounted for approximately 16% of the world's human population being a home for 1.250 billion citizens [1].

This continent has about 9% of the world's fresh water resources [2]. However, the variability of the African climate and water resources characteristics, made some regions have sufficient water, while others like Sub-Saharan Africa (SSA) face numerous challenges concerning water issues that constrict economic growth and limit the livelihoods of its people [3].

Waterborne infectious diseases are the main cause of morbidity and mortality worldwide, causing around 801,000 children to die annually, due to diarrheal diseases [4–7] compounded by malnutrition. Diarrheal diseases were classified as the fourth cause of disability in children after iron-deficiency anaemia, skin diseases and protein-energy malnutrition [8].

In Africa, drinking water might not provide the ideal microbiological quality that guarantee safe water for African communities [9] adding more load of waterborne infectious diseases which already cause death of 2.2 million per annum and far more cases of illness every day [10]. In SSA, World Health Organization (WHO) grouped diarrheal diseases due to viral, bacterial and parasitic causes in group 1 category to cause human death [7].

Waterborne protozoa (WBP) are a group of parasites that cause diarrheal diseases. Diversity of WBP can be found in water. *Cryptosporidium* spp. and *Giardia duodenalis* (*intestinalis*) took the lead among other protozoan parasites to account the majority of waterborne outbreaks (524, 344 outbreaks respectively) [10–12]. Whereas *Acanthamoeba* spp., *Balantidium coli*, *Blastocystis* spp., *Cyclospora cayetanensis*, *Cystoisospora belli*, *Microsporidium* spp., *Naegleria* spp., *Sarcocystis* spp., and *Toxoplasma gondii* are less reported parasites [10–12].

Out of them, *Cryptosporidium* is reported to be the second just after rotavirus to cause moderate to severe diarrhea during the first two years of life. In seven regions of Asia and SSA, *Cryptosporidium* is considered the fourth major contributors to diarrhea [5].

In SSA and Asia (developing settings), the common water enteric pathogenic protozoa include *G. duodenalis* (*intestinalis*), *Entamoeba* spp., *Cryptosporidium* spp., *Cyclospora cayetanensis*, and Microsporidia. Whereas other species such as *Blastocystis* spp. and *Dientamoeba fragilis* are usually isolated from developed countries [13,14].

The transmission path of the previous protozoa is faecal-oral route causing infection to humans and/or animals. WBP utilizes the path to contaminate water through passages of feces that contains shed oo (cysts) from infected animals and/or humans into the water system [11,15,16]. Infections usually are present

where there is no or inadequate access to clean water or good sanitation [17].

The worldwide distribution of WBP outbreaks was published in previous reviews [10–12]. Such reviews covered the occurrence rate of WBP outbreaks in the period of 1954–2014. About 905 WBP outbreaks were recorded to cause human diseases. Association between enteric protozoa and waterborne transmission increased the concern of scientists and two reviews highlighted the currently available information about *Cryptosporidium* and *Giardia* epidemiology, genetic diversity, and distribution in the African continent. Absence of outbreaks in Africa was critically addressed [3,18]. In Latin America as well, WBP as a cause of outbreaks were also highlighted [19].

Even in developed countries, the operational surveillance systems include only a few or no parasitic protozoa, because the main focus is only on infections caused by viruses and bacteria. Frequently enteric protozoa are ignored and overlooked as a cause of diarrhea because these regions have better hygienic conditions [13].

In SSA, there is inadequate water supply, unclean water, underdevelopment, poverty, population density, malnutrition, poor sanitation and water shortage. There is critical absence of governmental systems to document diseases, particularly protozoal infections or waterborne outbreaks. Such factors are negative factors predisposing disease spread among African populations [20].

During the last few decades, the increasing world population steadily strained demands of fresh water creating a real threat of fresh water scarcity to human society [3,12,18,19,21]. It is expected that Africa will have the largest population growth from now to 2050, which will add more population than any world region (1.3 billion). Almost all of this growth will occur in the poorest regions of SSA [22]. This scenario will raise the demand for water sources, a situation require critical response.

Africa is a very sensitive continent to climate change, particularly nations of SSA, the waterborne enteric protozoa are susceptible to climate change especially temperature and precipitation. Extreme meteorological changes in Africa with high expectation of drought will lead to spread of diarrheal diseases. Variable precipitation and drought in some regions of Africa influences the availability of fresh water [23]. Death from infection, dehydration and/or malnutrition (due to nutritional effects of drought as reduced dietary range/low affordability) will be an expected outcome.

Our objective is to find out the size of burden of WBP with associated risk factors in Africa, taking into consideration the recent crises of climate change and its impact on abundance and transmission of WBP across this continent.

Literature review

This study is conducted to analyze situation of waterborne protozoa parasites in the African water resources. The search and selection of literature was done using databases as Scopus, PubMed, Google Scholar, Web of Knowledge, African Journals online, Library Genesis Scientific Articles and Egyptian Knowledge Bank. The literature review starts from 1982 to the first trimester of 2018. The literature review was defined using Booleans descriptors and combination of keywords: '*Balantidium coli*', '*Blastocystis hominis*', '*Cryptosporidium*', '*Cyclospora*', '*Dientamoeba fragilis*', '*Entamoeba*', 'free living amoebae, (FLA)', '*Giardia*', '*Isospora belli*', '*Microsporidia*', '*Sarcocystis* spp.', '*Toxoplasma*' and 'name of each one of countries from Africa', and also 'water', 'climate', 'crisis', 'outbreak', 'transmission', 'incidence/prevalence' to collect relevant articles.

Results and discussion

A total of relevant 148 reports were found, including full text and abstracts, in which 120 were selected for analysis of addressed topics and the WBP in Africa to be included in the review. We excluded 28 reports from articles, chapters and reports which contained ambiguous information and poor quality citation 'absence of abstract, full text, no publisher data, and no volume or issue data'.

A total of 21 countries reported presence of WBP in different water bodies (wells, lakes, rivers, taps, and ground water). The countries with higher numbers of publications were Egypt [36] >South Africa [13] >Nigeria [11] and Tunisia [11]. To our knowledge, 33 countries have no documented reports on WBP in their territories.

Data concerning reports distribution among geographical divisions of Africa and incidental rate of each parasite among total number of reports were mentioned in Figure 1. The data on the distribution of WBP reports by African countries is presented in Figure 2. Dominant information on WBP in relation to risk factors is summarized in Table 1. Mechanisms of climate changes and their effect on occurrence and distribution of WBP outbreaks are presented in Figure 3. All of the previous figures and table will be discussed later in the following sections.

Burden of waterborne protozoa in the African continent

In developing countries lack of access to drinking water supplies, lack of adequate sanitation and deficient waste disposal made scientists expect high prevalence rates of waterborne infectious diseases [11].

The present review reports show that North Africa leads other African geographical divisions (West, East, South and Middle) in the reporting of WBP with

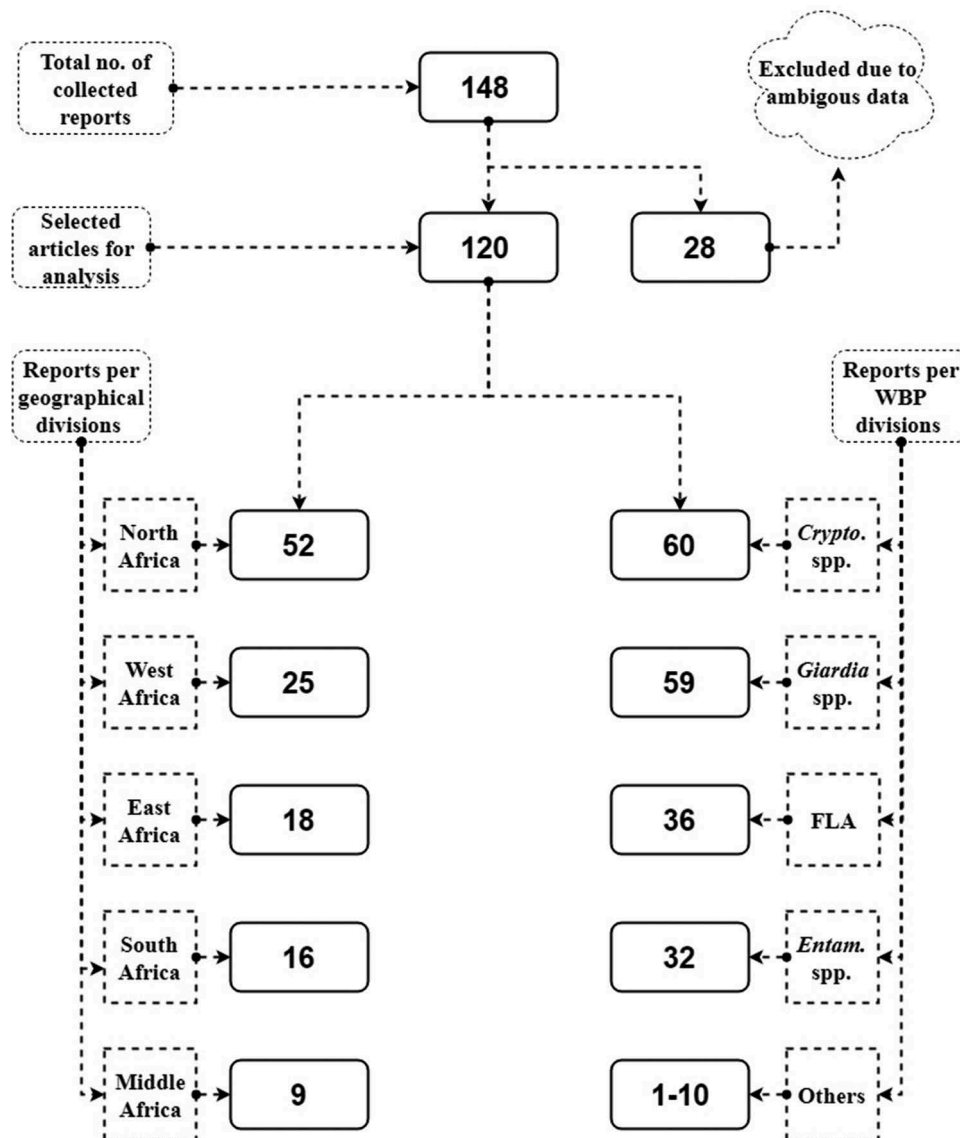


Figure 1. Analytical results of WBP reports in Africa and its numerical distribution according to geographic and parasitic divisions Sub-title: Crypto: *Cryptosporidium*, FLA: Free living amoebae; Entam: *Entamoeba* spp.; Other: *Balantidium coli*, *Blastocystis hominis*, *Cyclospora cayetanensis*, *Dientamoeba fragilis*, *Isospora belli*, *Microsporidia*, *Sarcocystis* spp. and *Toxoplasma gondii*.

significant statistical difference (P value ≤ 0.05) (Figure 1). According to country classification, Egypt took the lead to document nearly 1/3 (36/120) of WBP reports in Africa. South Africa, Nigeria and Tunisia were the subsequent top countries in reporting WBP forming another 1/3 (35/120). It is noted that 33 African countries have no documented reports about WBP (Figure 2).

On the African continent, a large number of countries still face huge challenges attempting to achieve the United Nations water/sanitation-related Millennium Development Goals (MDGs). Although Africa is a major region trailing improvement in accomplishing the MDGs on sanitation by 2015, there is a noticeable gap between North Africa (90%) and SSA (30%) coverage (<http://www.un.org/waterforlifedecade/africa.shtml>).

Based on the Human Development Index (HDI), most of the top reporting countries are the most developed in Africa. However, HDI is an economic tool represents a small part of human development [24].

SSA is identified to be the poorest and the least developed region in the world. Living sustenance of half of its population is less than one dollar/day. The deep and widespread poverty severely restricts many countries of SSA to provide proper water and sanitation services (<http://www.un.org/waterforlifedecade/africa.shtml>). Clear picture about institutional capacity of health system research, financial resources and political security will provide adequate relevant research findings for decision makers and explain the shortage in documentation present in more than half of the African countries [25]. In such countries usage of contaminated water justified the infection of the population and contamination of their food. For example in Eritrea, agriculture reuse of untreated wastewater was a major cause for the increase of giardiasis among farmers of this area [26].

Concerning the WBP in African reports, *Cryptosporidium* spp. and *G. duodenalis* were reported

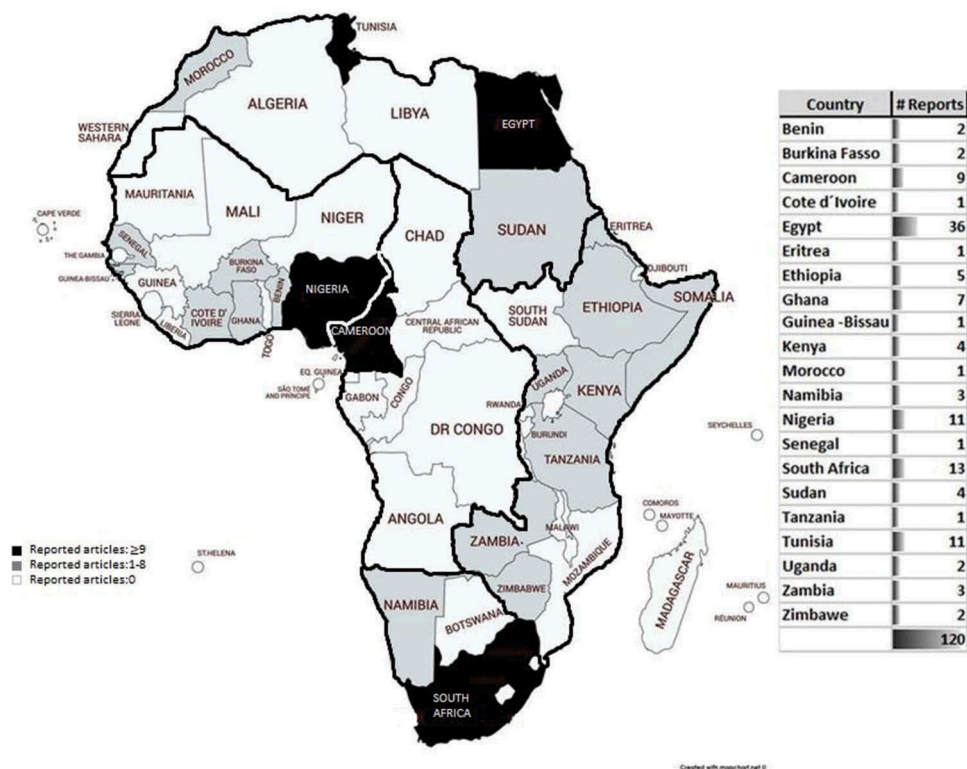


Figure 2. Allocation of WBP reports in different countries on the African map.

in 12 and 16 African countries with high incident rate. Half of African reports of different water sources documented both parasites (Figure 1). *Cryptosporidium* and *Giardia* are known to be the most prevalent WBP in developing countries [11]. The multiple routs of exposure of both parasites might explain their abundance in African water. Besides, African populations suffer multiple risk factors (explained later) which result in cycling of these two parasites and increase their burden in water ecosystems. Moreover, small size of oo (cysts)/spores (1–17 μm) and their resistance against common water disinfectants, increase their penetration into multi-barrier water treatment systems [27,28]. *Cryptosporidium* and *Giardia* oo (cysts) are able to maintain viability in water up to 6–12 months (*Cryptosporidium* oocysts even longer) with high stability. Characteristics possibly cause epidemics even after consumption of purified drinking water [29].

FLA (*Acanthamoeba* and *Naegleria* spp.) ranked the 3rd leading cause of waterborne protozoal contamination forming more than 1/3 of the documented reports in ten African countries (Uganda, Tunisia, Sudan, South Africa, Namibia, Guinea Bissau, Ethiopia, Egypt, Central African Republic, and Benin).

FLAs are common protozoa present in fresh water bodies. While encysted FLA become resistant to conditions of extreme temperature, osmolarity and pH [30,31]. FLA protozoa have been observed in different water bodies (dental water lines, haemodialysis water, and tap water) in African reports [32–34]. Pathogenic

forms of FLA are opportunistic and can cause fatal encephalitis and sight threatening infection (keratitis) [35]; however, in the previous African reports species were not identified. Noted cases in different African countries displayed infection with FLA. Such cases were reported as *Acanthamoeba* keratitis in Tunisia [36], Ghana [37], and South Africa [38] and as *Acanthamoeba* meningoencephalitis in Senegal [39]. Raised reports might explain the obvious interest of researchers to stress work on FLA and hence increase its reporting data.

Entamoeba spp., were presented in ten African countries (Zimbabwe, Tunisia, Sudan, Nigeria, Morocco, Ethiopia, Egypt, Cote d'Ivoire, Cameroon, Burkina Fasso). Diarrhea and dysentery are the most common symptoms after infection with this parasite. Extra-intestinal complications are less frequent to occur; however, high mortality can be associated. In recent cross sectional study in South Africa, *E. histolytica* was highly loaded in the diarrhea samples [40]. In Ethiopian patients, *Entamoeba* spp. were the highest predominant protozoa in the diarrhea samples from adults [41] and one of the most identified parasites in children under five years [42]. In Cameroon, Egypt and Sudan, *Entamoeba* spp., were detected in drinking water [42–44]. Direct wet mount/iodine is a simple, cost effective popular method used in African reports to identify cysts of *Entamoeba* spp. in water samples which probably raises its reporting numbers.

There are scarce reports in Africa concerning other WBP (*Balantidium coli* '7', *Blastocystis hominis* '4', *Cyclospora cayentanensis* '10', *Dientamoeba fragilis* '1', *Isospora belli* '4', *Microsporidia* '3', *Sarcocystis* spp. '2' and *Toxoplasma gondii* '4' ranging from (1–10 reports). These parasites are abundant and robust in the environment augmenting the potential for waterborne transmission. The (oo) cysts/spores of these WBP are similar to, or larger than those of *Giardia* and *Cryptosporidium* [12]. Even though these less frequent WBP have been the aetiology of waterborne outbreaks [10,11], information about its detection and prevalence are not available in sufficient way. African researchers are less attentive to these parasites – except *E. histolytica* – giving much more focus to *Cryptosporidium* and *Giardia*. The lack of sensitive methods to recover and detect their exogenous stages in water possibly is the cause of their under-reporting [45].

All examined water bodies in the 21 African countries were contaminated with one or mixed waterborne protozoa. A clear fact emphasized well in previous reviews [3,18]. Most important is drinking water which was co-contaminated with more than one protozoa and have been published in several African reports [33,43,46]. In this situation, co-infections will be highly expected in people, who use these water sources for drinking. There is danger of an epidemic, particularly if popular sources are used (ex. sachet water).

Finally, even though WBP caused a significant number of outbreaks (905) documented worldwide until 2014 [10–12] and although the high reporting of protozoa incidence in African waters that are explained in this review, there are still no reported outbreaks in the African continent.

Monitoring disease outbreaks is dependent on having efficient and reliable surveillance and notification system. Despite an efficient surveillance system, a degree of under estimation should be considered [47].

We can surmise that no functional surveillance system to report waterborne disease outbreaks in Africa exist, which is well established in some European countries (e.g. Germany, UK, Sweden), however, indirect prevalence data, reporting incidence, together with the level of contamination may be used as risk predictors [18].

Predisposing factors in the favor of waterborne protozoa distribution

Africa leads the world in terms of diarrheal diseases. Infections by WBP are highly prevalent among rural communities in warm and humid regions mainly due to water, inadequate hygienic and sanitation facilities. The absence of environmental sanitation facilitates the increase of rubbish, other wastes, sewage and wastewater which not properly treated [6,9,13,33,48–50].

Addressing previous threats to surface water is a major challenge in Africa and it depends significantly on recognizing the following predisposing factors and taking action to overcome it. Africa similar to other developing regions worldwide, hold an important route of transmission of WBP, summarized in the following points:

- (i) Water problems
 - i.i. Insufficient water resources controlled by climate change
 - i.ii. Poor quality of potable water controlled by inadequate water industries and bad human practices around water supplies
- (ii) Social and behavioral aspects of people
- (iii) Geographic locations, which can cause isolation of people
- (iv) Governmental inequality in distributing financial resources

Recent publications about risk factors in Africa have been illustrated in Table 1. Equally other developing regions suffered similar risk factors [16,19].

For better comprehension, the frequent reported risk factors have been grouped in categories: Behavioral, Governmental, Socioeconomic, Sanitation-Water/Pathogen factors.

Behavioral factors (hazards habits of African native population)

Behavior contributes significantly in elevating (oo) cysts level in water sources. Hazardous habits were reported in numerous articles that lead to contamination of water systems with human fecal waste resulting in protozoal threats.

Uncontrolled sewage discharge is a major risk factor that leads to increase prevalence of protozoa in water sources. WHO/UNICEF reported that practicing open defecation is linked to a higher risk of stunting or chronic malnutrition, leaving 161 million children worldwide with irreversible physical and cognitive damage (www.WHO.int).

Direct defecation on the ground, sewage spills and usage of pit latrines; dominate human to human transmission of (oo) cysts [58]. Half of SSA population still use pit latrines as a mean of excreta disposal, particularly among low income areas [59].

In Uganda, drainage of sewage directly to water bodies from hotels and fishing communities, using shallow latrines and run off excreta of wild and domestic animals from land to water explained contamination of natural bodies of water (river, lake, and channel) and tap water resources with free living amoebae, *Cryptosporidium* spp. and *G. duodenalis* (*intestinalis*) [33]. The distribution of *Cryptosporidium* and *Giardia* (oo) cysts in the Mfoundi mainstream/Cameroon returns to the anthropogenic activities

Table 1. Factors present in Africa that jeopardize the infection with WBP.

Country/Region	Risk factor (s)	Population studied	WBP	Reference
Western-Kenya	Contact with Animals (feces): Goats, sheep, chicken, ducks, donkeys, dog, cats	Children <5 years and adults	<i>Giardia</i> and <i>Cryptosporidium</i>	[79]
Dagoretti, Nairobi, Kenya	Social and gender determinants: gender, age and role in the household.	Children <5 years and 50–60 years	<i>Cryptosporidium</i>	[81]
Chencha town, Southern Ethiopia	Absence of washing facility, home cleanness condition and type of latrine	Children <5 years	<i>E. histolytica/dispar</i> , and <i>G. lamblia</i>	[78]
Kumasi Metropolis-Ghana	Irrigation water into the food chain, wastewater	Farmers	<i>Cryptosporidium</i> spp.	[49]
Settat, Morocco	Irrigation with raw wastewater in agriculture	Children between 3–9 years	<i>Giardia intestinalis</i>	[51]
Fulanis in Kuraje rural settlement of Zamfara state, Nigeria	Poor housing and sanitary conditions (open air defecation), lack of potable water and illiteracy	Children <5 years and adults	<i>Giardia lamblia</i> , and <i>E. histolytica</i>	[52]
Nigeria	Co-infection with malaria, stunting, younger age <2, low levels of maternal education and socioeconomic status.	Children <5 years	<i>Cryptosporidium</i> : <i>C. parvum</i> and <i>C. hominis</i>	[53]
Ibadan South East Local Government Area, Nigeria	Type of toilet facility used, source of drinking water, and knowledge of parasite transmission patterns	Children <5 years and adults	<i>Isoospora</i> , and <i>Cryptosporidium</i>	[54]
Archetypal African urban slum in Nigeria	Unsafe drinking water, education, bad environmental hygiene	School aged children	<i>E. histolytica/dispar</i> , <i>G. duodenalis</i> , <i>Entamoeba coli</i> , and <i>Blastocystis hominis</i>	[55]
Eastern Cape Province of South Africa	Farm animals contact	>18 years old and HIV infected	<i>Cryptosporidium</i> spp.	[56]
Rural western Kenya	Clinical, environmental and behavioural conditions	Children from 0 to 5 years old	<i>Cryptosporidium</i> spp.	[57]

carried out by waterside inhabitants who open their toilets directly into the streams and throw their waste into the waterways [60].

Transmission of specific species dynamics and host specificity play a role in the movement of protozoan pathogens between hosts. Humans, animals and wildlife can contribute to environmental transmission of protozoa [58].

In Egypt, pasturing infected animals, watering infected livestock, contact with their manure and its usage as fertilizers contribute to increase the prevalence of *E. histolytica* and *G. duodenalis* in drinking ground water [61].

The absence of garbage treatment mechanisms put communities at risk of severe gastroenteritis [62]. Swimming in lakes and ponds, cleaning of utensils, throwing dead animals and garbage and dumping sewage in canals, ponds, wells and rivers are reported behaviors in the Egyptian communities [9,61], Botswana [58], Uganda [33,59], Nigeria [63], Cameroon [64,65] raising the exposure to different WBP.

Using unprotected water sources (spring, dam, wells) for drinking water increased prevalence of *G. duodenalis* and *C. parvum* in Ethiopian population [66]. In Zimbabwe, protected and unprotected deep wells, bore holes pose a risk to acquire *G. duodenalis*, *Entamoeba* spp., *Cryptosporidium* spp. and *C. cayatensis* [67].

The selection of consumed water in developing countries depends on its aesthetic quality 'No color appearance of water and no lees', neglecting its

microbiological and/or chemical quality. In Cameroon, 63% of different drinking water sources (wells, boreholes, springs, tap) were contaminated with enteric pathogenic protozoa, even though clean and/or clear its water appearance [43]. Using spring water for drinking without prior treatment is also a habit of the Cameroon population [65].

Land use is an important predictor of water contamination with *Cryptosporidium* oocysts [68]. As human activity increases, water supply will be inadequate with insufficient sanitary resources. Rapid urbanization caused municipal lake pollution with high accumulation of *Cryptosporidium* and *Giardia* spp. in Yaunde, Cameroon [62]. The study of water pollution of the Mingoa River, (springs and wells) further confirms the influence of rampant urbanization and usage of traditional pit latrines on the quality of water and its linkage to the 40% prevalence of diarrhea and parasite infestation [69].

Governmental factors

Governments of African countries have a critical role to play in exacerbating water infectious diseases. African governments are unable to address the growing water scarcity in their countries because of weak political will, pauper institutions and improper governance [70]. The governments in Africa lack consensus to face challenges for providing adequate sanitation infrastructure and hygiene [18]. There is a serious shortage in skilled health care workers and laboratory facilities. African

populations moreover suffer lack of transportation and communication infrastructures [3]. Such deficit causes many diseased individuals to face difficulty in seeking medical advice and have no other option but to use home remedies to overcome diarrheal conditions. True obstacles will definitely hamper accurate diagnosis and underestimate reporting of infectious diseases in African countries. Government corruption and civil wars are actions provoking long term damage to public health and spread of infectious diseases. Such interventions lead to massive loss of life and health, particularly in children and women [71]. The rampant war and conflict present in SSA, harsh dictatorship and unresolved political agendas disrupted health care and education and increased prevalence of gastrointestinal diseases and malnutrition. Under corruption and war conditions, there is scarcity of agricultural amenities resulting in rationing of foods and water. Thereby, chronic hunger and starvation will be aggravated leading to increased morbidity and mortality [20]. Similar scenarios are present among the populations from other developing countries, such as Colombia [72]. These problems exceed the capacity of science or people, because decision makers need to develop human policies and be more aware of their decisions in turn to justify and ensure equal distribution of financial resources.

Socio-economic factors

African populations suffer poverty and illiteracy. Widespread problems have made populations unaware of the danger of using untreated water for household drinking and usage. Certain practices will increase the transmission of diarrheal diseases [73,74]. The concept of large family size is popular among African population. Greater than five persons/household were observed in Africa and Middle East [75]. Hence population has increased, a fact that decrease affordability per person and increase malnutrition among family members particularly children. Shortage in health education programs and lack of personal hygiene help increase emission of protozoa infection and spread of diarrheal diseases [3,76].

Sanitation and water/pathogen factors

Treated water must reach healthy standards before used for drinking. Since 1999, it is a criminal offence if concentration of *Cryptosporidium* and *Giardia* oo (cysts) is greater than 1 (oo) cysts/10 liters [77]. African countries have their own risk factors for transmission of WBP. In Ethiopia for instance school children aged 5–15 years suffer the highest infection rate and worm burden that attributes to poor sanitation and hygiene. The illiteracy of adults and the use of open defecations systems with the lack

of practices such as hand washing using soap put the children at higher risk. Only 19.5% of Ethiopian homes have washing facilities while 80.5% of homes do not have hygienic practices. As a result, people who were poor remain deprived from health, contributing to economic instability and social marginalization [78].

In Kenya, there is high vulnerability to acquire and transmit infectious diseases in different ages/sex. Children under five years, have recognized the exposure to domestic animals mainly faeces of chicken, cats and dogs [79]. Such exposure is a significant risk factor to get diarrheal diseases caused by WBP '*Giardia* and *Cryptosporidium*' [80]. In addition to children, Kenyan farm workers and people aged 50 to 65 years had much contact with cattle. Women as well had greater contact with raw milk with higher risk to exposure to *Cryptosporidium* spp. via involvement in milking activities, feeding and watering of cattle [81].

Poor countries reported difficulty in detecting parasites such as *Giardia*, *Cryptosporidium*, *T. gondii* or *C. cayetanensis* in water [19]. One of the reasons is the use of less effective methods for concentration of (oo) cysts due to inability to follow standardized methods [28,83]. A similar situation is present in Africa. In particular, *Cryptosporidium* is not only difficult to detect, but also to treat and its control is limited due to the lack of specific drugs and/or vaccinations. The profile of distribution of all these parasites is high, and will be higher, if management and control strategies are not implemented or direct political and financial decisions are unable to establish efficient and effective surveillance systems.

The clear challenge is water supply and its quality. The water supplies have been impacted routinely by anthroponotic, agricultural and industrial practices, resulting in the decreased availability of surface and ground water supplies. The treatment of water for human consumption, has been difficult in removing parasites by practical water treatment and mainly in the disinfection process, the use of chlorine has been seriously questioned since 1986 [84]. To efficiently eliminate WBP, high dosages of disinfectant are required, which is impractical and represents hazardous scenario of high organic water content [19,85]. High dosages of such organics in water imply high risk of toxicity per potential disinfection by products (DBPs) formation [86].

The science and new technological possibilities have provided tools to detect, identify and genotype WBP; however, poor countries can't use them despite the fact that they are the most affected with high prevalence of parasitic diseases. At the end, the WBP will continue to take advantage of adapting to the hosts and environment by diversifying genetically, while humans and animals continue to fall ill.

Waterborne protozoa across Africa in terms of climate change

Globally, the temperature will increase by 2–3 °C and relative humidity will rise [87,88], result in provoking marked changes in the surrounding climate. The alteration of climate pattern in return, causes extreme meteorological events 'heat waves, drought, and heavy rain fall' in a way that leads to the occurrence of waterborne and foodborne outbreaks.

By 2030 and 2050, extreme climate is anticipated to cause approximately 250,000 additional deaths per year from malnutrition, diarrheal diseases, heat stress and malaria [89].

The human activities play a significant role in accelerating climate change throughout demographic urbanization, elevating green house gasses emission, and the use of animal sewage and human biosolids as fertilizers to retain crop productivity [12,88,90,91].

Africa is the most sensitive continent to climate change, particularly nations of SSA. Its countries suffer notable critical change in climate with extreme water related weather events (El Niño, cyclones, and hurricanes) [92–94]. As a developing continent, most of its area suffers weak health infrastructure, poverty, armed conflicts and inability of institutional capacity to adapt rapid environmental changes and deal with additional health challenges [95–98].

The extreme water related weather in return will affect precipitation in some regions of Africa and influences the availability of fresh water. Additional water stress will be created in addition to what the SSA already suffers. Currently, over half of SSA populations have no access to safe water and 10% of population still use surface water as drinking source [23].

The climate of the five different geographic regions of Africa is variable; however, climate recently tends to be warmer and drier in all of them with expected high vulnerability to drought. North Africa Mediterranean part (NAMP) are going through a gradual, persistent decrease in rainfall [99]. The climate models of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change approved that there is a sign of forced Mediterranean drying trend with great ambiguity of its rate [100,101]. The situation has forced the population of NAMP to use ground water [102]. Central Africa is known to be the wettest part of Africa. It is predicted to get warmer by 3 °C [103] with rainfall deficits in a large portion of its region [104]. Moreover, central Africa is vulnerable to intense thunderstorms and strong lightning flashes which will influence climate and weather across Africa and the globe [105]. In West Africa, Sahelian storms increase precipitation over the Sahel with consequent warming weather and dryness [105]. Drought will occur as a result, which will critically impact the population of this region exposing them to poor sanitation and limited access to clean water

[106,107]. East Africa has been recently affected with a series of devastating droughts following long rain season [108]. At the horn of Africa, El Niño events induce drought crises. The number of drought affected people has been doubled with critical and emergent food insecurity levels, leaving East Africa's future uncertain [92,108]. South region of Africa as well suffers drought and water scarcity, its governments have declared national drought emergencies. In particular, Madagascar suffers severe drought with critical water scarcity affecting more than 850,000 people [93,94]. During 2017, a dangerous category four tropical cyclone Enawo affected 760,000 people in Madagascar. It was described as the strongest cyclone in the past 13 years. Flooding and water stagnation from such climate crises will end up with outbreaks of life-threatening waterborne diseases [94].

Indeed all previous extreme meteorological events in Africa will significantly alter the seasonal pattern and therefore change the incidence of excreta related diseases [15,108], which by turn will increase the water-borne diarrheal diseases [109] (Figure 3). An impact will clearly appear on the occurrence, transmission and distribution of WBP parasites. Water is often connected to disease spread due to its role in the life cycle of parasites or its direct effect on the health of people [97]. Temperature changes are known to be linked to development rates of the parasite, while relative humidity has been stated to continue parasitic pressure [48,110,111]. In water, (oo) cysts need optimum temperature and moisture conditions to maintain the viability of these infective stages waiting for host to continue the next step of their life cycle [48]. Such linkage influences the richness of parasitic species and intensity of infection [48,90,91,108,112]. The rainfalls and temperatures as well have an impact on the survival, viability and dissemination of parasitic protozoa [113]. In warm and wet locations, precipitation can serve as liable predictor for incidence of WBP [15,91].

Either rainfall or drought in Africa will result in WBP outbreaks (Figure 3) in the form of polluted drinking and recreational water. Hence affected water quality and availability will pose a threat to millions of people [13,114]. African people then either will change their hygienic practices ending with water and food outbreaks [88,91,97,114] or massive migration patterns of populations will occur as a response to climate change. Therefore, it is predicted that many diseases will travel with migrants establishing both, new infectious species or strains, and emergent demand of water resources.

Amebiasis, cryptosporidiosis, giardiasis and toxoplasmosis can all be transmitted through contaminated drinking water. Very low doses of *Cryptosporidium* spp. and *G. duodenalis* (oo) cysts are needed to cause infection to healthy individual [115–117]. In Africa, the

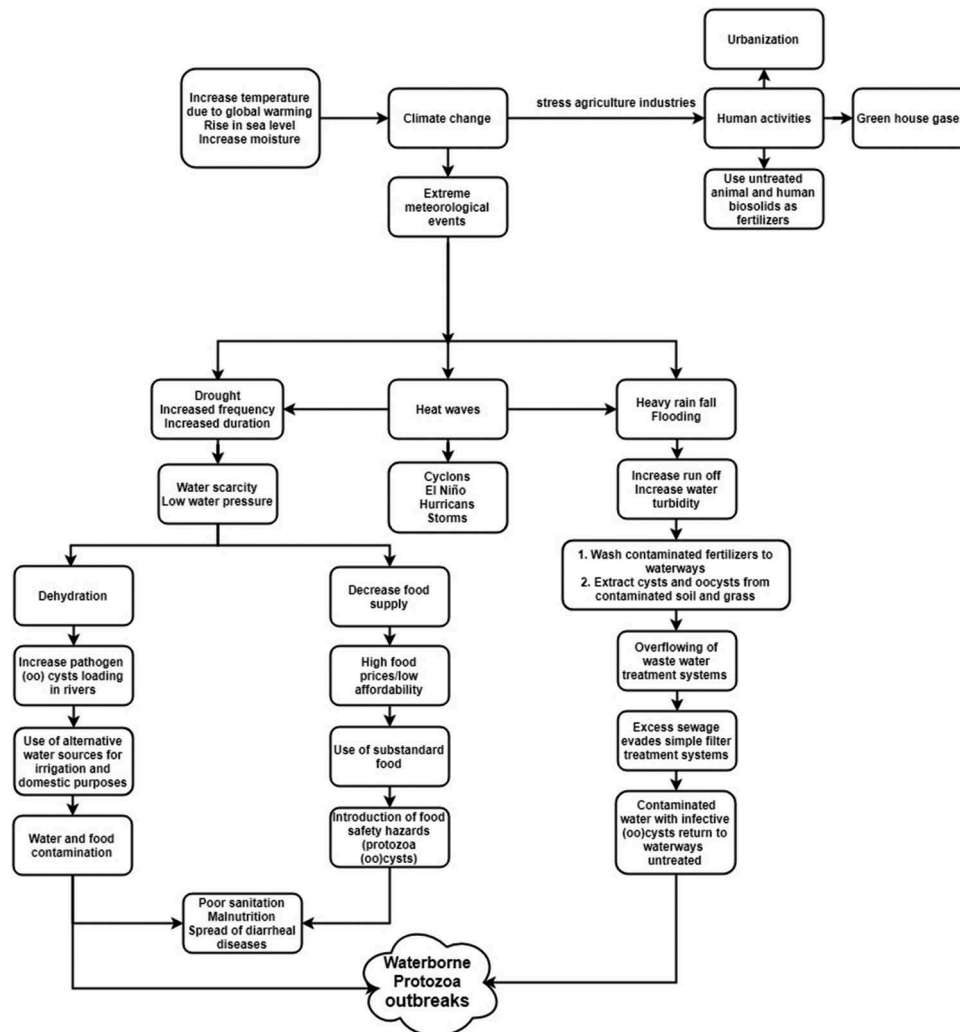


Figure 3. Mechanisms of extreme meteorological events that impact WBP status.

distribution of these parasites in the environment varies significantly depending on climatic season as in other regions of the world. High frequency was reported in summer and spring, while high intensity with viability of the dormant transmissive stages was documented in summer [9]. Other authors documented different seasons: summer and autumn [44], or winter [118,119]. Such variation proves that the occurrence of *Cryptosporidium* and *Giardia* protozoa tends to have a multi-modal pattern in Africa.

Conclusions

The load of WBP is indeed underestimated and under-reported in Africa, 56% of African countries have no WBP reports even though Africa leads the world in terms of death due to diarrheal diseases and malnutrition. *Cryptosporidium*, *Giardia*, FLA and *Entamoeba* were the most reported protozoa in African water resources although, other protozoa were less reported due to deficient effective diagnosis. North African countries reported nearly half of the total reported numbers in the continent. High reporting countries

were known to be the most developed which might explain the raised record of reporting WBP. The rest of African countries still need government recognition of the future burden of waterborne protozoa diseases and react rapidly to detect and diagnose WBP in an efficient way.

Africa suffers poverty, weak institutional infrastructure, political conflict and its populations are illiterate and practice poor hygiene. Moreover the warm climate and future climate changes to drought in Africa will provoke flare up of diseases. All previous risk factors actively affect the quality and the quantity of drinking water despite the fact that Africa has 9% of the world's water resources. Such abundant risk factors in Africa are predisposing factors for WBP outbreaks, however, not a single outbreak has been reported yet.

Water crises in Africa will occur, while African governments will not have the capacity and infrastructure to deal with them. African populations therefore either will use other water sources without adequate treatment or migrate to other places. Diseases and malnutrition will rise and waterborne protozoal

diseases in particular will impact the incidence, transmission and strains or species manifestation.

African countries should unite and put the welfare of their populations as a priority in their political agendas. Financial resources should be distributed equally to assist and protect low income areas. Only then the devastating effects of water-borne diseases and their future consequences could be mitigated in environments of climate change and other risk factors. African population should receive health education to recognize the impact and react immediately to change their habits and work with the government to avert expected water crises.

Disclosure statement

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