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Review article

Verocytotoxic diarrhogenic bacteria and food and water contamination in developing countries: a challenge to the scientific and health community

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Abstract

Water related issues such as water treatment and distribution have become extremely important all over the world due to population growth, growing urbanization, health and environmental pollutions. Majority of drinking water sources in Africa are still the traditional ones including dams, wells, rivers, streams and ponds which might harbor or are prone to contamination with water-borne and vector born disease agents that introduce various toxins most importantly verocytotoxins into the water bodies. These toxins are responsible for various health problems including diarrhea, hemorrhagic colitis (HC), hemolytic uremic syndrome (HUS) and thrombotic thrombocytopenic purpura (TTP). These conditions often present difficult chemotherapeutic control measures due to physiological complexity development of antimicrobial resistance among the pathogens. Poverty, inadequate portable water supply, unhygienic environments such as slums and refugee camps are predisposing factors abundant in developing countries. There is therefore the need to investigate water bodies for the prevalence of these toxin producing bacteria and their antimicrobial resistance profiles. Medicinal plant sources with potential efficacy in controlling these bacteria should also be investigated with a view to influencing policy and chemotherapy direction for effective control measures.

Keywords: Antimicrobial resistance, environmental pollution, *Escherichia coli*, *Acinetobacter haemolyticus,* slums, poverty.

Abbreviations: CT-SMAC – cefuxime-tellurite sorbitol macConkey agar; DAEC - Diffusely adherent; DRC – democratic republic of Congo; EAggEC - Enteroaggregative; EHEC - Enterohaemorrhagic; EIEC - Enteroinvasive; EPEC - Enteropathogenic; ETEC – Enterotoxigenic; EHEC - enterohemorrhagic *Escherichia coli*; HC - hemorrhagic colitis; HUS - hemolytic uremic syndrome; IMS - Immunomagnetic separation; MDG - millennium development goals; MDR - Multidrug resistant; OECD - Organization for Economic Cooperation and development; PHLS - Public Health Laboratories Services; STEC - Shiga toxin *Escherichia coli*; SMAC - Sorbitol MacConkey agar; TTP - thrombotic thrombocytopenic purpura; USA - United States of America; WHO - world health organization; PCR – polymerase chain reaction.

Introduction

An increasing number of countries can be considered water stressed [1]. Of all environmental questions, those related to water are perhaps the most far reaching in their long-term consequences and the most difficult to tackle from the scientific and medical point of view. In many parts of the world there is a widespread scarcity, gradual destruction and increasing pollution of fresh water sources, and many nations face growing problems associated with guaranteeing an adequate drinking water supply. Today in the developing world, one person in three lacks safe drinking water and sanitation, the basic requirement for survival, health and dignity and the prospects for the future do not look any better [2]. At the turn of the millennium there were approximately 6.2 billion people alive on this planet [3]. By 2025 this number would have risen to 7.9 and 9.1 billion [1]. In the developing countries, the population of people in the urban cities alone stands at 1.9 billion and this figure is expected to increase to 3.3 billion by 2030 [3]. The provision of safe drinking water for all these people will be one of the major challenges facing humanity. In addition, most of the world's 6.9 million displaced people and refugees reside in refugee camps or temporary shelters in developing countries [72]. In these often crowded environments, where provision of sanitation, clean water, food and health care services are typically inadequate, where barriers to vectors and animals carrying infectious diseases are usually absent or insufficient, and where person-to-person contact is amplified, diarrheal infections are common and often devastating. In this paper the dearth in information on the occurrence of verocytotoxin diarrhogenic bacteria in unhygienic water, food and environments in developing countries and the need to step up research in this area with a view to developing proactive preventive measures against widespread outbreaks is highlighted.

1.1 Global diarrheal burden and safe drinking water

Safe drinking water or potable water is water that is free of injurious chemicals or microbial contamination [4]. Contaminated or polluted water may contain injurious chemicals or microbial waterborne pathogens. Waterborne pathogens represent a serious and growing hazard, and infectious diseases continue to affect populations throughout the world. Other problems such as aging of water treatment infrastructures, and

Table 1. Global burden of diarrheal diseases in children < 5 years

S/No.			Episode per child			
	Region	Population < 5 (millions)	Snyder & Merson, 1982	IOM, 1986	Bern & Glass, 1994	Annual cases (Millions)
1	Africa	89.8	2.2	5	2.5	197-450
2	Asia	351.0	2.2	3	2.3	772-1053
3	Latin America	62.5	2.2	4	3.9	137-250
	Total					1106-1753

[2]

the increasing occurrence or perhaps, the increasing recognition and detection of organisms resistant to conventional disinfection treatments also increases the indices of these infections. Diarrheal illness thus remain the sixth leading cause of death worldwide, responsible for an estimated 2,219,000 deaths in 1998, representing approximately 4.1% of all deaths, mostly among children under the age of five [5]. Diarrheal illness makes an even greater contribution about 5.3%, to disease burden [5]. Most of this burden of illness (Table 1) falls on the inhabitants of the underdeveloped or developing world, where it is responsible for 8.1% of the disease burden, ranked second only to respiratory illness (9.1%) [6]. Diarrheal illness is often attributed to contaminated water (or food) consumption although the percentage specifically due to waterborne pathogens is still unknown. This is because many countries including the most advanced Organization for Economic Cooperation and development (OECD) countries do not have effective surveillance systems in place to detect waterborne disease [2]. Even in those countries with effective surveillance systems, the systems often fail to identify the sources of infection. There is therefore still considerable uncertainty about the proportion of waterborne disease outbreaks detected and the burden of such disease not associated with sporadic diseases. Protection of drinking and recreational waters from contamination by human or animal waste in sewage, food processing wastes, and storm water runoff is therefore of paramount importance to everyone. Public health concerns include safe water (water that does not contain harmful chemicals or microorganisms in concentrations that could cause illness) and an adequate water supply (one that provides safe water in quantities sufficient for drinking and domestic purposes) [7]. Water is unsafe for human consumption when it contains pathogenic, or disease-causing microorganisms. Pathogenic microorganisms (and their associated disease(s)) may include bacteria, such as *Salmonella typhi* (typhoid fever), *Vibrio cholerae* (cholera), *Shigella* (dysentery, shigellosis), viruses, such as poliovirus or Hepatitis A virus and protozoa such as *Giardia lamblia* (giardiasis) or *Cryptosporidium parvum* (cryptosporidiosis). *Giardia* is a protozoan parasite that infects the upper portion of the small intestine of humans and many other species of mammals [8]. The usual mode of transmission is from person-to-person through what is termed the "fecal-oral route." The least common mode of transmission is waterborne. *Cryptosporidium* is a protozoan parasite, like *Giardia,* both humans and animals may serve as sources of environmental contamination and human infection. In 1993-1994, cryptosporidiosis caused by *Cryptosporidium parvum* was the leading cause of illness associated with contaminated drinking water in the United States [9]. Other disease outbreaks during that time were caused by *Giardia lamblia*, *Salmonella*, *Shigella*, *Campylobacter jejuni*, and *Vibrio cholerae* [10]. Acute diarrhea, the second biggest killer of children under 5 years old worldwide, is very high in urban communities where there is lack of sufficient housing, sanitation and clean water [27, 53]. Of recent concern is the emergence of verocytotoxin (Shiga toxin) producing bacteria that contaminates water and food sources [11]. Verocytotoxin or Shiga toxin-producing bacterial strains are associated with a broad spectrum of human illnesses throughout the world, ranging from mild diarrhea to hemorrhagic colitis (HC), hemolytic uremic syndrome (HUS) and thrombotic thrombocytopenic purpura (TTP) [12, 13]. Currently, hundreds of distinct serotypes of *E. coli* are recognized as Shiga toxin *Escherichia coli* (STEC) associated with human diseases [14]. *E. coli* serotypes such as O157:H7, O111:H8, O26:H11, O103:H2, referred to as enterohemorrhagic *Escherichia coli* (EHEC) and bearing the *eae* gene and the EHEC plasmid, are more frequently related to severe human illnesses [13, 15, 16]. Verotoxin producing *Acinetobacter haemolyticus* (VAH) is also gaining significance due to increasing reports of multi-drug resistance among various isolates. Unfortunately, despite the lethal nature of these diarrheal infections associated with verocytotoxic bacteria, in both adults and children, little research is done in this area in the developing countries. Domestic and wild animals are reported as sources of verocytotoxin producing microorganisms; but cattle, sheep and goat are considered as the main reservoirs [17]. Excreta from these animals frequently contaminate water bodies including drinking and recreational waters especially in Africa. Foods of animal origin, especially ground beef, probably contaminated during the grinding process, have been identified as the main vehicles for transmission of *E.coli* O157:H7 and other non-O157 STEC strains to humans [11, 18]. Foods like raw milk, fruits and vegetables, as well as cross contamination due to inadequate food manipulation, and person-to-person transmission have already been associated with human disease [19]. Infected cattle, via contaminated meat and dairy products, elevate the risk that these foodborne pathogens will enter the human food chain [20]. Food deprivation and transportation to the slaughterhouse stress the cattle's immune systems and induce fecal shedding of the bacteria. Contamination then occurs through interchange of fecal matter between carcasses. Thus water sources, used either for drinking, recreational or domestic purposes can also be affected [21]. Human sewage is also source of fecal contamination and is known to contain pathogenic microorganisms. Direct and indirect exposure to sewage has been associated with illnesses from drinking and recreational water sources [22].

1.2 The challenges of supply of portable water and the risk of diarrheal infections

A water supply may come from (i) rain or snow, (ii) surface water (shallow wells, rivers, ponds, lakes and wastewater), (iii) ground water (deep wells and springs). Generally surface water contains more microbes, than does either underground or rain

Table 2. Reported microbiological quality of domestic water sources in developing countries

S/No	Country	Water source	Fecal coliforms per 100 ml
1	Gambia	Open, hand-dug wells	Up to 100,000
2	Nigeria	Open, hand-dug wells	200-580
3	Philippines	Open dug wells	190[a]
4	Uganda	Hand-dug wells	8-200
5	Tanzania	Open wells	343
6	Tanzania	Protected wells	7
7	Lesotho	Unprotected springs	900
8	Lesotho	Protected springs	200
9	Philippines	Springs	72[a]
10	Philippines	Boreholes	3[a]
11	Philippines	Municipal piped water	3[a]
12	Philippines	Community piped water	188[a]

[a] = Geometric mean fecal coliform concentration per 100 ml [2].

water [23]. Surface water contains many microbes from the soil, and in the vicinity of cities is often contaminated with sewage bacteria. Generally sources for microbes in water are many - soil, air, decaying bodies and excreta of humans and animals, consequently building up pathogenic populations [24]. Water related issues such as water treatment and distribution have become extremely important all over the world due to population growth, growing urbanization, health and environmental pollutions. Municipal water supplies are purified or treated to get rid of harmful substances or reduce them to the minimum permissible limit to make them safe and fit for human consumption or suitable for the intended general domestic uses [25]. However, majority of drinking water sources in Africa are still the traditional ones including dams, wells, rivers, streams and ponds which might harbor or are prone to contamination with water-borne and vector born disease agents [25, 26]. In addition to the poor water supply, there is a limited resource for water treatment and distribution and worst still, inadequate sanitation that usually results in the fecal contamination of surface and ground water. From the global perspective, waterborne disease remains one of the major health problems in the developing world, especially for young children [27-29]. It is estimated that 80% of all illnesses are linked to use of water of poor microbiological quality [30]. The World Health Organization (WHO) currently estimates that 1.1 billion people worldwide lack access to improved water supplies and 2.4 billion do not have access to proper sanitation facilities [31]. In Africa, despite the efforts made by some countries, approximately 340 million people are without access to safe drinking water and only 26 countries will reach the water target. The situation of sanitation is even more worrying as 580 million people do not have access to improved sanitation facilities, and only six countries will achieve the 'millennium development goals (MDG)' target for sanitation [32, 33] set by most governments. Under these circumstances, water supplies can become a very efficient means of transmitting enteric infections within and between communities. Several estimates have been made of global pediatric morbidity associated with diarrheal disease. One of the estimates by Bern and Glass [34], suggest that the number of diarrheal episodes per child per year ranges from 2.3 in Asia to 3.9 in Africa (Table 1). The magnitude of the overall disease burden associated with pediatric diarrhea, estimated to be between 1106 and 1753 million cases per year, is staggering, and the proportion of this disease that is directly or indirectly associated with poor water quality and inadequate water quantity is difficult to determine [30].

Furthermore, it has been reported that ⅔ of diarrheal outbreaks, ½ of hospitalized cases, ½ of "dysentery" cases and 4/5 of outpatient cases in the developing countries remain undiagnosed further compounding the problem [35]. A closer examination of data from 22 studies of diarrhea incidence in Africa, Asia and Latin America indicates that the highest disease rates are in children 6 to 11 months of age [2]. This vulnerable time in a child's life is when water and weaning foods are introduced into the child's diet. At this time levels of maternal antibodies are declining as the child's immune system begins to produce its own antibodies. In addition, the child begins to crawl, thus coming into contact with dusty and dirty floors as well as objects that are frequently introduced into the child's mouth. Thus multiple transmission routes of infectious agents and poor sanitary state of the mother increases the disease burden in the infants [2]. Water supply in developing countries is bedeviled by several problems as compared to the developed world. 1. There is a wide spectrum of drinking water sources used in developing countries. Many of these water sources are unprotected, often have high levels of fecal contamination, and are used with little or no treatment. The microbiological quality of these water sources can be quite poor. Fecal or thermo tolerant coliform concentrations in drinking water sources have been reported up to 100,000 per 100 ml (Table 2). But, the WHO guidelines for drinking water quality recommend that, no thermo tolerant coliform bacteria be detectable in any 100-ml sample [2]. Piped water supplies in developing countries are also vulnerable to contamination due to illegal connections and pressure loss. 2. In tropical areas, ambient water temperatures are warmer (typically around 30ºC) than waters in temperate climates. Traditional measures of microbiological water quality such as total or fecal coliform indicator bacteria may not be appropriate for tropical source waters because of higher ambient temperature and nutrient loads in the water. 3. Many households do not have a water tap or pump within the house or compound. Water is collected and transported within a variety of vessels. Transport and storage of water in contaminated vessels has been shown to be a source of water contamination [29, 36-37]. 4. Fecal pathogens are transmitted by multiple routes due to poor sanitation, food hygiene and personal hygiene. These routes are closely linked to waterborne transmission and make it difficult to assess the risk of disease associated solely with drinking water. Often both inadequate water quality and water quantity contribute to waterborne disease [2]. Despite innovations of strategies which include the provision of protected sources such as boreholes,

Table 3. Epidemiology of *E. coli* pathotypes causing diarrhea in developed and developing countries

S/No	*E. coli* pathotype	Epidemiology	
		Developed Countries	Developing Countries
1.	Diffusely adherent (DAEC)	? Up to 10% of cases in the UK	?
2.	Enteroaggregative (EAggEC)	Rare - mostly sporadic cases	Common - persistent diarrhea
3.	Enterohaemorrhagic (EHEC)	Rare epidemics in contaminated food	Rare
4	Enteroinvasive (EIEC)	Rare - food borne	Endemic
5.	Enteropathogenic (EPEC)	Very rare	Common cause of persistent diarrhea
6.	Enterotoxigenic (ETEC)	Common	Very common

[53]

standpipes, protected wells and springs for tackling this problem, the facilities however, are located some distances requiring transportation to homes [38]. During transportation, water gets contaminated with bacteria which grow and proliferate during storage in the homes, consequently posing a risk of infection with water-borne pathogens [29, 37]. Many parts of Africa have been associated with high pit latrine coverage [39]. These latrines often collapse because of poor soils (sand) on which they are dug. Leaching of pit latrine contents and flooding of human and animal wastes into drinking or recreational water sources during rainy season could be possible sources of contamination [40]. Furthermore, recreational waters can also be contaminated considering that fingers are prone to faecal contamination during toilet use, cross contamination of water bodies is therefore very easy thus promoting occurrence of diarrhoeal disease outbreaks. The potential of water to harbour microbial pathogens and causing subsequent illness is well documented for both developed and developing countries. Dysentery caused by *Shigella* spp. (fecal bacteria) for example is a public health problem in many regions of the world, and is very significant in the developing countries [41]. Several pathotypes of *E. coli* are also responsible for the rising incidences of infantile diarrhea all over the world and especially in developing countries (Table 3). The problem is becoming complicated with the rapid increase in multidrug resistance among pathogenic microbes, rendering most antibiotics currently used for treatment less or ineffective [42]. Monitoring of these water bodies for pathogenic microbes and antimicrobial resistance is therefore very important. Inadequate diagnosis of verocytotoxic bacteria in clinical, food and environmental samples is a widespread problem in Africa. *E. coli and Acinetobacter* infections have assumed a very threatening clinical significance especially in Africa, due to the deplorable hygienic conditions, inadequate water supply and over crowding particularly in rural areas. Increasing multi-drug resistance, verocytotoxin production and ability to withstand harsh and unfavorable environments and antibiotic selective pressure in hospital environments has further heightened the prowess of the organisms to cause human infections. Reports on African dysentery outbreaks attributed to *Shigella* spp sometimes indicate that specimens were not tested for verotoxic bacteria or do not describe laboratory methods that are suitable for detecting EHEC [43-44]. This is unfortunate because the spectrum of clinical illness resulting from *Shigella* spp infection overlaps considerably with that of *E. coli* and mixed outbreaks have been reported [43].

1.3 Challenges of unhygienic environments

Most developing countries are bedeviled with poor and unhygienic conditions. This is predicated largely on poverty and ignorance where people are more concerned and preoccupied with struggling for survival. In addition, most inhabitants live in slums. In such areas unhygienic practices such as disposal of filled septic tanks directly into gutters, throwing of faeces wrapped in polythene bags directly into streams, rivers or the nearby bush or burying the solid faecal matter in soil are very common. Most urban centers are also characterized by huge refuse dumps in which faeces, left over and decaying foods, animal carcasses and rotting vegetable parts are left for ages. Such practices and environments facilitate the rapid spread of gastrointestinal pathogens amongst the population especially the enteric bacteria. Food and water bodies easily gets contaminated due to runoffs or floods thus serving as ready sources of human infection. Outbreaks of diarrhea and cholera have been reported especially among school children or refugee camps in various developing countries such as Nigeria, Rwanda, Congo, Zimbabwe, Sudan Afghanistan, Chile and Brazil [25, 53, 73]. Urban populations in developing countries are characterized by much higher densities of people, poor housing, inadequate sanitation and solid waste removal, and unsafe drinking water, thus more people are forced to share the same toilets or spaces in rented apartments or slums. In such conditions, diarrheal and other bacterial infections are much more easily transmitted. It has been reported that of the population of the developing countries, 1·1 billion people do not have access to safe drinking water, and 2·4 billion are without adequate sanitation [53]. This underlies the need to investigate drinking and recreational water food, water bodies and wastes for the presence of important diarrhogenic agents including verocytotoxygenic bacteria. Although occurrence of Shiga toxin producing bacteria in different animal reservoirs have been reported [45-47], data concerning isolation of these microorganisms from drinking and recreational water bodies especially in Africa is limited and in most cases absent. In addition, though there are few reports on multi-drug resistant EHEC (Table 4), there is none on *Acinetobacter* spp and reports on research into antimicrobial resistance (including susceptibility to traditional herbs) amongst verotoxin producing bacteria is completely lacking. Even where Shiga toxin producing *E. coli* were reported, the information was scanty in most regions of Africa, and totally absent in others. The few studies carried out were also concentrated on

Table 4. Status of research on verocytotoxic diarrhogenic *E. coli* and other bacteria in African countries

S/No	Region/Country	Type of Sample Investigated	Method used	Authors
A	**South Africa**			
1	South Africa	Stool	Sorbitol MacConkey agar (SMAC) pulsed field gel electrophoresis patterns.	[54]
2	Swaziland, South Africa	Stool, water	Molecular techniques, culture on CT-SMAC agar, chromogenic	[55]
3	Gouteng, South Africa	Stool	Rainbow agar O157 medium,	[56]
4	South Africa	Water, sewage	Immunomagnetic separation (IMS), PCR, Immunoassay	[57]
B	**East Africa**			
1	Kampala, Uganda	stool (infants, cattle)	Sorbitol MacConkey agar (SMAC)	[58]
2	Nairobi, Kenya	milk	PCR	[59]
3	Ifakara, Tanzania	stool	Sorbitol MacConkey agar (SMAC	[60]
4	Ifakara, Tanzania	beef	Sorbitol MacConkey agar (SMAC	[61]
C	**West Africa**			
1	Lagos, Nigeria	stool (children and adults)	Sorbitol MacConkey agar (SMAC)	[62]
2	Lagos, Nigeria	stool	Sorbitol MacConkey agar (SMAC), colony blot hybridization	[63]
3	Lagos, Nigeria	Stool (children and adults)	Sorbitol MacConkey agar (SMAC)	[64]
4	South Western Nigeria	stool	cytotoxicity in verocells, PCR	[65]
5	Lagos, Nigeria	Stool (cattle)	Sorbitol MacConkey agar (SMAC), PCR	[66]
6	Cote d'Ivoire	Stool (children and adult)	Sorbitol MacConkey agar (SMAC), PCR	[67]
7	Gabon	Stool (children and adult)	Sorbitol MacConkey agar (SMAC)	[68]
C	**Central Africa**			
1	Zémio, DRC Congo	Stool (bloody diarrhea)	Sorbitol MacConkey agar (SMAC)	[69]
2	Cameroun	Stool (bloody diarrhea)	Sorbitol MacConkey agar (SMAC)	[70]*
D	**North Africa**			
1	Middle Egypt	stool	Sorbitol MacConkey agar (SMAC)	[71]

*only study with antimicrobial susceptibility testing of verocytotoxic bacteria including Enterohaemorrhagic *E. coli* and MDR *S. dysenteriae* type 1 and *S. boydii*

stool samples, not much research was carried out on water samples. With the prevalence in abundance of predisposing factors such as poor hygiene, poverty, inadequate medical care and portable water, Africa is highly vulnerable to such and other bacterial infections. *E. coli,* member of the enterobactereaceae family in addition to diarrhea and other gastroenteritis, is also associated with urinary tract and ear infections. Other serotypes also produces Shiga toxin and has been implicated amongst other enteric bacteria in many water and food contaminations. Of recent, *Acinetobacter haemol yticus* of the Moraxellaceae family has also been reported to produce Shiga toxins and the bacterium is also reported to be a notorious causative agent of multidrug resistant nosocomial infections [16, 48]. There is thus the need to investigate

drinking and recreational water sources for the occurrence or contamination by members of Enterobactereaceae (*Escherichia coli*) and Moraxellaceae (e.g. *Acinetobacter haemoliticus)* both known to be causative agents of gastroenteritis and nosocomial infections, for Shiga-toxin production and other virulence and resistance factors including resistance genes and beta lactamase enzymes, and susceptibility of these Shiga-positive isolates to some medicinal plants traditionally used in treating diarrhea-related infections. Such study approach will provide information such as whether: i). There are *Acinetobacter haemolyticus* and *Escherichia coli* present in some wastewater samples in South Africa. ii). the *Acinetobacter haemolyticus* and *Escherichia coli* isolates produces extended spectrum betalactamases, verocytotoxins and other virulence factors. iii). There are multidrug antimicrobial resistant strains among the *Acinetobacter haemolyticus* and *Escherichia coli* isolates. iv). low-temperature exerts any stress on the viability and virulence of the *Acinetobacter haemolyticus* and *Escherichia coli* isolates. v). chemical agents, ionic salts and phytochemicals have any impact on the viability and virulence of the *Acinetobacter haemolyticus* and *Escherichia coli* isolates and vi). Phyto-chemicals have any effect on the verotoxin and betalactamase producing-multidrug resistant strains of the *Acinetobacter haemolyticus* and *Escherichia coli* isolates

1.4 Current status of research on verocytotoxic bacteria in Africa

Since the first reported case and description of *E. coli* O157: H7 in the United States of America (USA) in 1982, EHEC has become an important public health problem worldwide. Morbidity and mortality associated with O157:H7 and the threat to public health of infections with EHEC O157 and other EHEC in particular, led the Public Health Laboratories Services (PHLS) to develop interim guidelines for control [49]. Given the magnitude and severity of recent outbreaks of *E. coli* O157: H7 infection, there is an urgent need to reduce the human hazard caused by this pathogen (44). Despite the increasing medical significance of these agents, only few reported outbreaks of *E.coli* O157 in Africa have been documented (Table 4), and there is relatively no information on the occurrence of *Acinetobacter* and other verocytotoxin producing bacteria.

1.5 Significance of investigating food and water for verocytotoxic diarrhogenic bacteria in developing countries

Research on water contamination by bacteria producing protein toxins and their antimicrobial resistance profiles is of considerable interest for several reasons. A number of the protein toxins are produced by bacteria and are important for severe diseases caused by these organisms [50]. This is, for instance, the case for diphtheria toxin (although vaccination of the population has helped to control this disease), and for pseudomonas toxin, tetanus toxin, botulinum toxin, and Shiga toxin. Verocytotoxins or Shiga toxins are not only produced by *Shigella dysenteriae,* which is the infective agent in dysenteries, but also produced by *E. coli* and some species of *Acinetobacter,* giving rise to infections and diseases resulting into serious health problems in several countries [50]. Knowledge about the toxins and their action on cells is important for the understanding of these diseases. Furthermore, protein toxins have long been used to construct immunotoxins and other toxin conjugates in attempts to find more efficient drugs in the therapy of cancer and other diseases [51]. Also, toxins are very attractive tools in modern cell biology, for instance, with respect to the study of protein translocation across membranes, protein internalization by endocytosis, sorting along the endocytic pathway, and exocytosis. Monitoring organisms for toxins and virulence factors will give more understanding of their physiology for possible development of more effective control measures by research, medical, academic and public health institutions. Monitoring resistance of emerging and reemerging environmental pathogens is important to detect emerging resistance that may pose a concern for human and animal health and to guide in prescribing decisions. Understanding the molecular basis of resistance and virulence amongst the Enterobactereaceae and Moraxellaceae will be created, consequently more versatile control measures developed. More information on bacterial isolates from water with potential for Shiga toxin production and their antimicrobial resistance profile will also be provided for documentation and policy formulation. There are reports of increasing multi drug resistance of Shiga toxin producing bacteria against antimicrobial agents [48, 52]. It is also reported that because antimicrobials may cause the lyses of bacterial cell walls, with the liberation of Shiga toxins, and/or the increased expression of the toxin genes *in vivo*, they are not recommended for treating STEC infections [48]. According to Abong'o, and Momba [33], one of the major problems that accompany *E. coli* O157:H7 infection is the danger of treating such patients with antibiotics. This is because treatment of *E. coli* O157:H7 infections with antibiotics may result in the release of Shiga toxins into the blood stream of the infected individuals. It is believed that the release of such toxins affects the kidneys resulting in a condition described as hemolytic uremic syndrome. This therefore presents a great challenge in the treatment approach to be adopted against these pathogens. Since Africa is richly endowed with medicinal plants, it is therefore pertinent to investigate the potential of these plants in controlling specifically verocytotoxin and other toxin producing bacterial pathogens with a view to discovering novel mechanisms of action against them for effective control.

Conclusion and Recommendations

First estimates of the global burden of childhood mortality and morbidity became available in the early 1980s. Diarrhoeal illnesses accounted for about 4·6 million deaths from around 1 billion episodes of diarrhoea every year in children younger than 5 years. The burden of diarrhoeal illness sits firmly in the developing world, both for morbidity (6–7 episodes per child per year compared with 1 or 2 in the developed world) and mortality. Malnutrition and the wholly inadequate provision of safe water, sanitation, and hygiene highlight the stark inequalities that exist within our world. A quarter of children in developing countries are still malnourished, and a reasonable population do not have access to safe drinking water adequate sanitation (1·1 billion and 2·4 billion, respectively). Furthermore, urbanization in developing countries has resulted in people migrating from the rural to urban centers with its attendant consequences. Urbanization, a process related to economic and political factors, has a direct bearing on the health of urban dwellers which are already confronted with serious problems such as high population densities with inadequate housing, poor or absent sanitation and water supply,

weak health infrastructure, degrading and unhealthy environment with litters around houses. These are well known conditions that favour disease transmission [72]. Water contamination with bacterial agents and their toxins (especially verocytotoxins) undoubtedly accounts for these alarming health problems, especially infant diarrhea. Until improved hygiene and effective control measures are adopted, the goals (MDGs) for sound health by most African governments will continue to remain a challenge. In addition to improved hygiene and provision of clean portable water [44], deliberate and vigorous research efforts by research institutions into verocytotoxin producing bacteria, and their antimicrobial resistance profiles as well as search for effective control agents from the abundant plant resources is one of the important measures to tackle the problem. Important public health measures such as educating the public on the dangers of eating undercooked meat, and drinking unboiled or untreated water, and increasing awareness among clinicians about infections with *A. haemolyticus,* and other *E. coli* pathotypes and mandating case reporting will go a long way in controlling infections associated with these bacteria in Africa.

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