Apparent impact of enteric pathogens in drinking water and implications for the relentless saga of HIV/AIDS in South Africa

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Worldwide, there is a strong association between diarrhoeal diseases and contaminated water, and South Africa is no exception. The majority of households in developing countries, the epicentre of HIV/AIDS, obtain their water from polluted and contaminated sources. These water sources are also used by HIV/AIDS patients to take their medications, such as antiretrovirals, as well as for the preparation of infant feeds. Consumption of contaminated water is usually responsible for morbidity and mortality in different age groups and these impact negatively on the workforce. In South Africa, the government loses about R3.4 billion annually, due to approximately three million diarrhoeal cases and 50 000 mortalities. Diarrhoea is also considered as a signature hallmark of HIV/AIDS because over 80% of patients in developing countries suffer chronic diarrhoea. Diarrhoeic pathogens have been more frequently isolated from stool samples of HIV/AIDS patients and their respective household drinking water than in control groups who are HIV negatives. For these reasons, there is a link between the quality of water, diarrhoea and HIV/AIDS, despite the fact that these aspects do not seem to be connected. This is therefore the focus of this chapter, which highlights the current situation regarding water quality and its impact on the condition of diarrhoeal diseases in HIV/AIDS individuals.

Keywords: drinking water, pathogens, diarrhoea, HIV/AIDS, South Africa

1. Introduction

Water meant for drinking must be safe and free of pathogenic organisms because contaminated water could actually be the vehicle of transmission of a plethora of pathogenic enteric pathogens such as enteric bacteria, protozoa and viruses. It is estimated that 1.1 billion members of the world population do not have access to safe, clean water [1, 2]. Contaminated drinking water has the greatest impact on human health worldwide, especially in developing countries [2].

Consumption of contaminated water affects the quality of human life on many fronts, resulting in limited productivity of natural systems. This hampers economic development due to the socio-economic costs associated with unsafe water and poor sanitary conditions. As contaminated water results in diseases, the productivity of affected individuals is reduced and precious time is lost. Furthermore, the payment of medical bills for the affected individual results in a limited disposable income. In some instances, the individuals that become ill due to contaminated water lose their jobs and earnings totally, thus pushing their families further into economic turmoil. The most crucial effect is loss of life that translates to deprivation of human capital in communities. These costs far outweigh the preventative costs of supplying communities with safe potable water and adequate sanitation.

The microbiological safety of drinking water remains a challenging problem in developing countries, especially in this era of HIV⁄AIDS. The definition of microbiologically safe drinking is unclear when assessing the potential impact of waterborne diseases on public health. It is important to recognize that what appears to be harmless to the healthy individual may be potentially fatal to children, immunocompromised and elderly populations. Due to their weakened immune system, immunocompromised persons such as HIV/AIDS individuals are more susceptible to waterborne illnesses than immunocompetente persons. These secondary infections transmitted through water contribute significantly to the morbidity and mortality of HIV-infected persons [3]. The lack of suitable sanitation, good hygienic practices and an adequate supply of potable water is therefore placing communities, especially immuno-compromised people in developing countries, at risk of waterborne diseases.

In this chapter, the water quality and the HIV/AIDS status of individuals in South Africa will be reviewed. We have endeavoured to critically discuss the occurrence of bacterial waterborne pathogens in drinking water and to appraise their bearing on the health of HIV/AIDS individuals who live in South Africa. Recommendations concerning the strategies for the provision of safe water and care of HIV/AIDS patients are proffered.

2. The status of water quality in South Africa

2.1 Accessibility of safe water supplies in South Africa

The South African Constitution [4] states that every citizen has the right to have access to an environment that is not harmful to his or her health or well-being. This includes a constant supply of clean, safe drinking water. The commitment of the South African Government to improve access to safe water supply is evidenced by the marked reduction in the number of people who do not have access to a reliable source of safe drinking water from over 15 million in 1994 to six million in 2008 [5]. In almost all South African metropolitan areas, water infrastructure is well developed. Safe drinking water that complies with the South African National Standard (SANS 241) Drinking Water Specification is the norm and does not pose a significant risk to public health over a lifetime of consumption, especially for babies and infants, immunocompromised people such as HIV/AIDS individuals and the elderly [6]. However, in many rural areas and some peri-urban areas, the situation is bleak, as the infrastructure is either poorly developed or non-existent. In areas that are not well serviced and which do not normally fall within the boundaries of urban areas, the supply of water is usually undertaken through small water treatment plants defined as water treatment systems. They include water supplies from boreholes and springs which are then chlorinated, treatment plants of small municipalities and establishments such as rural hospitals, schools, clinics and forestry stations. Communities without water infrastructure, on the other hand, depend mostly on rivers and groundwater from boreholes for drinking water. However, such sources of water are not suitable for human consumption as they are usually not treated and are contaminated by human and animal excreta, leading to waterborne diseases with a high prevalence among people living with HIV/AIDS [7,8, 9,].

A recent survey involving 181 small water-treatment plants across seven (Mpumalanga, Limpopo, North-West, Free State, KwaZulu-Natal, Eastern Cape and Western Cape) of the nine provinces of South Africa revealed the failure of the majority of these plants to produce drinking water that complies with SANS 241 in terms of coliform bacteria at the points of treatment and in distribution systems [10]. The results of this study are illustrated in Figures 1 and 2 below and they indicate that the drinking water supplied by many small water supply systems may be a threat to the health of consumers.

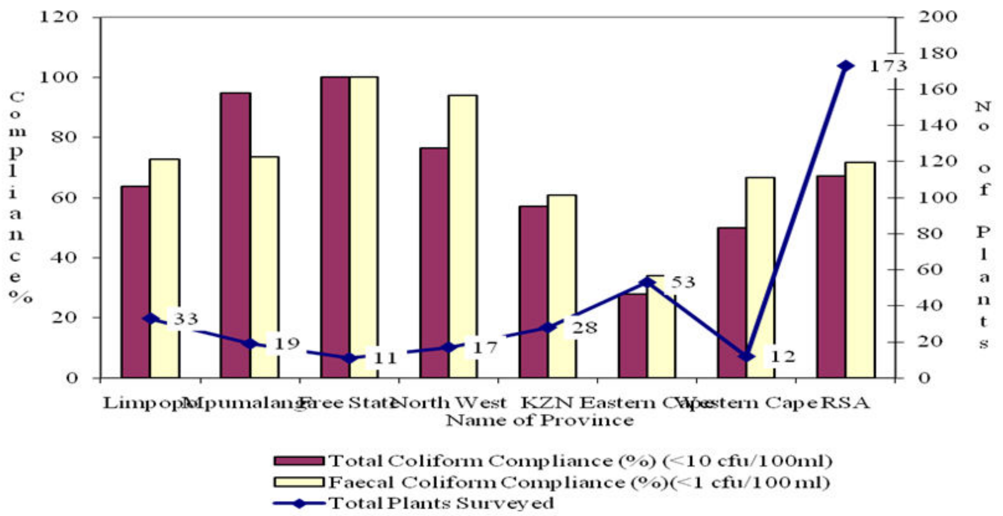

Figure 1 Total and faecal coliform compliance at the point of treatments (Source: Momba and co-workers [10])

The efficacy of drinking water treatment plants in non-metropolitain areas is plagued by several technical and management problems, which include the inability of plant operators to calculate chlorine dosages, determine the flow rate and estimate free chlorine residual concentrations, undertake readings of turbidity and pH values, and to effect repairs of basic equipment. In addition, there appears to be a lack of understanding of process selection, design, chlorination techniques, process quality monitoring and evaluation. Others problems are poor working conditions, the frequent depletion of chemical stock, the lack of a maintenance culture, the lack of emergency preparedness and poor communication [10]. Some water service authorities (WSAs) lack detailed expertise of effective drinking water management [11]. Furthermore, there is inadequate asset management and monitoring tools for drinking water services. The detection of poor drinking water quality is not necessarily followed by intervention in rural areas [11]. The lack of suitable sanitation, good hygienic practices and an adequate supply of potable water therefore places rural communities at risk of waterborne diseases [12]. These challenges are compounded by inadequate sanitary facilities in rural and peri-urban areas of South Africa, and increase the risk of contamination of surface or ground water [13].

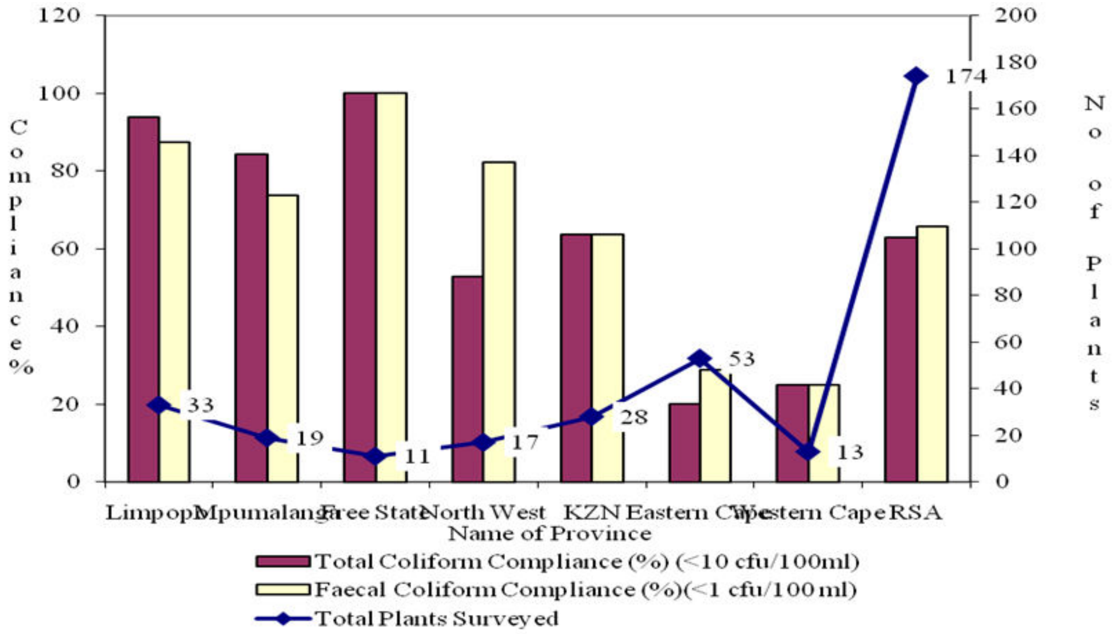

Figure 2 Total and faecal coliform compliance in distribution systems (Source: Momba and coworkers [10]

2.2 Impact of unsafe drinking water on the health of people living in South Africa

Bacterial pathogens in water tend to cause gastrointestinal infections such as diarrhoea, dysentery, typhoid fever, shigellosis and human enteritis [12, 14]. There is therefore a very strong link between diarrhoeal diseases and unsafe drinking water and poor personal and domestic hygiene, with ripple effects on the health of affected communities. At the global level, diarrhoeal diseases are associated with an estimated 1.0 billion episodes of people infected annually [15, 16, 17]. Of these diarrhoeal cases, approximately 2.2 million deaths occur in a single year. These diarrhoeal diseases also account for an estimated 63 345 722 Disability Adjusted Life Years (DALYs), which indicate the measure of population health and life lost from premature fatalities and life lived with disabilities in one year [15, 16, 17].

The most common cause of illness and deaths in the developing world in general and in South Africa in particular is cholera, which is caused by a bacterial pathogen classified as *Vibrio cholerae*. Between August 2008 and January 2009, an estimated 1 608 cases of cholera were reported in South Africa [18]. A plethora of other microorganisms has been isolated in drinking water supplies in rural communities of the Eastern Cape and Limpopo provinces, which are among the poorest provinces in the country. These include *Escherichia coli*, *E. coli* 0157:H7, *Shigella* spp., non-typhoidal *Salmonella* strains, *Aeromonas* spp., *Campylobacter jejuni, C. coli*, *Vibrio cholerae, V. parahaemolyticus* and *Plesimonas shigelloides* [7, 9, 19, 20, 21, 22, 23, 24]. A recent study by Khabo-Mmekoa and co-workers [25] has reported the occurrence of *Enterobacter cloacae, Shigella flexneri, Sh. dysenteriae, E. coli* O157:H7*, Pseudomonas alcaliphila* and *Bacillus subtilis* in household-container-stored drinking water at Ugu district municipality, in the KwaZulu-Natal Province. The presence of these pathogens in household-container-stored water emphasizes the level of microbiological contamination of this drinking water supply in rural communities of South Africa. Unsafe water therefore increases the risk of diarrhoeal diseases in South African rural communities. This is a matter of concern, especially for HIV-infected individuals in these communities.

3. The status of HIV/AIDS in South Africa

3.1 Prevalence of HIV in South Africa

It is well documented that South Africa is the epicentre of the HIV/AIDS burden in the world. In South Africa, HIV-1 subtype C is the predominant Clade and it accounts for approximately 95% of HIV infections [26, 27]. Its mode of proliferation is mainly heterosexual relationships and perinatal transmission [27]. The HIV/AIDS epidemic estimates for South Africa vary depending on the epidemiological source of the data. However, all the data indicate 'a mature and generalised epidemic' of HIV/AIDS [28].

Since 1990, the Department of Health (DoH), which is the major source of HIV/AIDS information, has been conducting antenatal seroprevalence surveys annually. The results of the surveys that were carried out among pregnant women attending antenatal clinics have indicated an increase in the HIV/AIDS epidemic prevalence from under 1% in

1990 to 29.5% in 2004 [29]. Based on these data, the South African National Department of Health estimated that, by the end of 2004, there were 5.7 million South Africans living with HIV [29]. A summary of the age-related estimated HIV prevalence among women attending antenatal clinics is shown in Table 1. The prevalence of HIV among women attending antenatal clinics has shown an increase from 2001 to 2007 with the highest prevalence being witnessed in the 30-34 years age group (Table 1) [30]. This may be due to the conservative nature of women in this age group who usually find it challenging to moderate cultural circumstances surrounding sexual behaviour, and this may lead to a higher probability of contracting HIV/AIDS [30].

Table 1. Summary of age-related estimated HIV prevalence among women attending antenatal clinic[1]

Age group (years)	2001 Prevalence %	2002 Prevalence %	2003 Prevalence %	2004 Prevalence %	2005 Prevalence %	2006 Prevalence %	2007 Prevalence %
<20	15.4	14.8	15.8	16.1	15.9	13.7	12.9
20-24	28.4	29.1	30.3	30.8	30.6	28.0	28.1
25-29	31.4	34.5	35.4	38.5	39.5	38.7	37.9
30-34	25.6	29.5	30.9	34.4	36.4	37.0	40.2
35-39	19.3	19.8	23.4	24.5	28.0	29.6	33.2
40+	9.8	17.2	15.8	17.5	19.8	21.3	21.5

[1] Adopted from HIV and AIDS Statistics for South Africa,[30]

As results from antenatal clinics vary considerably between the different age groups, these findings cannot be directly extrapolated to men, neonates and children. For this reason, studies named the National HIV Surveys of the General Population were sought in South Africa. The studies endeavoured to collect representative samples by proportionally sampling large numbers of people across the society from each geographical, racial or social group [30]. So far, three surveys were conducted, namely in 2002, 2005 and 2008 [31, 32, 33]. A summary of the age-related estimated HIV prevalence among the total South African population is shown in Table 2.

Table 2 Age-based prevalence of HIV among South Africans during 2002, 2005 and 2008[2]

AGE	2002	2005	2008
	Prevalence (%)	Prevalence (%)	Prevalence (%)
Children (2-14 years)	5.6	3.3	2.5
Youth (15-24 years)	9.3	10.3	8.7
Adults (≥25 years)	15.5	15.6	16.8
Total (≥2 years)	11.4	10.8	10.9
15-49 years	15.6	16.2	16.9

[2]Adopted from Shisana and co-workers [33]

The results of the three surveys carried out in 2002, 2005 and 2008 showed that the prevalence of HIV among the total South African population aged 2+ years has been constant at approximately 11% with a prevalence of 11.4% in 2002, 10.8% in 2005 and 10.9% in 2009 [31,32,33]. A reduction in the prevalence of HIV was observed among individuals aged 15-24 years from 2005 to 2008 (Table 2) [33]. However, the prevalence of HIV increased by 1.3% in adults aged 25+ years from 2002 to 2008 (Table 2) [33].

3.2 Impact of HIV/AIDS in South African communities

The consequences of HIV/AIDS for those infected by the virus and those directly and indirectly affected are severe, particularly for individuals living in developing countries. The costs of medical treatment for HIV/AIDS individuals are high. In addition, funeral costs as well as loss of income from former healthy individuals are a burden for families of HIV/AIDS patients. Expenditures in HIV/AIDS households usually shift from schools fees, food and water quality issues to focusing on taking care of the health, nutritional and medical needs of the infected individuals.

The middle-aged generations are mainly affected by HIV/AIDS, leading to a transfer of the parenting role to the very young and the elderly [34]. Child-headed households create major social problems because the very young and elderly are unable to engage in intensive productive ventures and they rely on the government support for their livelihood [35, 36]. One of the challenges of these households is a lack of awareness of safe water handling procedures and sanitation due to a lack of knowledge by the very young and the elderly.

The high prevalence of HIV/AIDS in South Africa results in an erosion of social capital due to the loss of knowledge and skills. Indeed, social capital is fuelled by people in the productive years (20-50), yet, ironically, this is the age group that is most affected by HIV/AIDS [35, 36].Consequently, various industrial sectors are negatively affected on many fronts. For instance, the rate of employee turnover increases, and this in turn increases the workload on the available workforce and necessitates the training of more people. This causes costly productivity delays and unsafe work practice [37, 38](.

The field of water management (treatment and delivery) and analysis is not immune to the negative impact of the HIV/AIDS scourge. The loss of a skilled workforce may result in unsafe drinking water, especially in rural areas in South Africa, where the water quality does not comply with SANS 241 Drinking Water Specification. This results in waterborne diseases that are known to impact more negatively on immunocompromised individuals.

4. The link between water quality and HIV/AIDS

4.1. Overview of the connection between water and HIV/AIDS

From a simplistic point of view, there appears to be no link between HIV/AIDS and water, when one considers that HIV is mainly transmitted sexually, while water is a natural resource that plays a significant role in life [39]. However, the consumption of water that is contaminated with faeces results in severe waterborne diseases such as diarrhoea. Diarrhoea is one of the signature characteristics of HIV/AIDS and likewise it is the hallmark of the clinical symptoms of waterborne diseases, particularly in developing countries [2]. This is because HIV-positive people have a compromised immune system; hence, they are more prone to a plethora of common infections such as diarrhoeal diseases than their HIV-negative counterparts [39, 40, 41]. This trend is even more pronounced among the poor, as they usually represent individuals most affected by HIV/AIDS. For example, in Lima, Peru, waterborne pathogens such as *Salmonella typhi*, *S. paratyphi* and *Clostridium* spp. were more prevalent in HIV/AIDS patients than in the control group [42]. For these reasons, there is a relatively greater need for the availability of potable water to HIV-positive individuals, as this leads to a decline in childhood and adult deaths [37, 35, 43]. In addition, detailed insight into the progression of HIV has shown that a strong relationship exists between HIV/AIDS and water quality [39]. Therefore, a systematic approach of gaining an understanding of the intricate links between HIV/AIDS and water may lead to the development of holistic methods that could reduce the burden of unsafe water on HIV/AIDS patients.

An intricate relationship also exists between water quality and HIV/AIDS during the administration of medication used to treat HIV patients. For anti-retroviral (ARV) medication and the treatment of opportunistic infections associated with HIV/AIDS to be effective without threatening public health, safe water must be used. In addition, safe water is required for improved hygienic behaviour such as washing hands and safe disposal of stools by people living with HIV/AIDS, as they are more prone to opportunistic infections [44]. Infant feeding also highlights the link between unsafe water and HIV/AIDS. When unsafe water is used to prepare food and beverages for infants, the risk of diarrhoeal diseases and deaths is increased, especially among HIV/AIDS patients. The stigmatization of HIV/AIDS leads to a legacy of shame attached to those infected by HIV and their families. For this reason, some family members of deceased HIV and AIDS victims conceal the deaths of these individuals, and bury them in unofficial graveyards. These graveyards may become sources of contamination of groundwater supplies. It is important to note that although this dictum does not infer the potential transmission of HIV to groundwater, there may be an association of elevated nutrient levels and bacterial contamination from graves permeating groundwater systems, hence the link between HIV/AIDS and water [45].

Diarrhoea is one of the signature characteristics of HIV/AIDS, and this accounts for approximately 90% of HIV/AIDS patients in developing countries, especially in Africa [46]. It is responsible for malabsorption, marked by weight loss and other opportunistic infections in approximately 95% of HIV/AIDS-affected individuals in the developing world [47]. The relatively poor water quality, sanitation and hygiene conditions in addition to inadequate availability of drugs for treatment exacerbate the incidence of diarrhoea in HIV/AIDS patients in developing countries, particularly those living in rural areas.

In developing countries, HIV/AIDS poses significant risk factors for waterborne bacterial diarrhoea such as nontyphoid salmonellosis [39] and campylobacter-associated diarrhoea [48]. Therefore, the substantial degree of morbidity and mortality due to diarrhoeal diseases in developing countries is compounded by the HIV/AIDS epidemic. Some studies have shown that there has been an increase in the frequency and severity of non-typhoid salmonellosis as well as salmonellosis, due to *S. typhimurium* and *S. enteritidis* in AIDS patients [49, 22, 23]. Indeed, it is believed that the isolation of *Salmonella* in some individuals may actually be the first manifestation of AIDS. Furthermore, the most prevalent species isolated from HIV/AIDS patients have been *S. typhimurium* and *S. enteritidis* in related studies [49, 22, 23]. There are numerous studies that show the link between the presence of some diarrhoea-causing bacteria pathogens in the stools of HIV-positive individuals and those found in their household drinking water (Table 3) [22, 23, 40,41]. Some of the case studies are discussed below to ascertain the link between water quality and HIV/AIDS.

4.2. Case studies to ascertain the link between water quality and HIV/AIDS

Table 3 illustrates a summary of the incidence of bacterial pathogens isolated from both water and the stools of HIV individuals in South Africa.

Table 3 Summary of the incidence of bacterial pathogens isolated from both drinking water and stools of diarrhoeic HIV/AIDSpatients[3].

Diarrhoea-causing water-borne microorganism	Technique used for characterization of microorganism	Author
E. coli O157:H7	• Classical microbiological techniques • PCR amplification of protein-coding genes	Momba *et al.*, 2008; Abong'o and Momba, 2008
E. coli	• Classical microbiological techniques • PCR amplification of *LT* genes	Obi *et al.*, 2007; Obi and Bessong, 2002, Obi *et al.*, 2007a
Salmonella spp.	• Classical microbiological techniques	Obi *et al.*, 2007; Obi and Bessong, 2002
Salmonella enteritidis	• PCR amplification of *sef* genes	Obi *et al.*, 2007a
Salmonella typhimurium	• PCR amplification of *fliC* genes	Obi *et al.*, 2007a
Shigella dysenteriae	• PCR amplification of *vir A* genes	Obi *et al.*, 2007a
Shigella spp.	• Classical microbiological techniques	Obi and Bessong, 2002
Campylobacter spp.	• Classical microbiological techniques	Obi *et al.*, 2007
Campylobacter jejuni	• Classical microbiological techniques •	Obi and Bessong, 2002
Campylobacter coli	• Classical microbiological techniques	Obi and Bessong, 2002
Aeromonas spp.	• Classical microbiological techniques	Obi *et al.*, 2007; Obi and Bessong, 2002
Plesiomonas shigelloides	• Classical microbiological techniques	Obi *et al.*, 2007; Obi and Bessong, 2002

[3]: In general, most of the waterborne pathogens were isolated in both HIV confirmed and unconfirmed cases, but the prevalence was higher in individuals with HIV infection.

In a study by Momba and coworkers [24], the authors investigated the prevalence of *E. coli* O157:H7 in drinking water from selected distribution systems in the Amathole district of the Eastern Cape in South Africa. The possible impact of these bacteria on the condition of diarrhoea in HIV/AIDS individuals living in the same area was also predicted. One hundred and eighty water samples from standpipes and untreated groundwater were collected and tested for *E. coli* O157. In addition, 360 stool swabs from confirmed and unconfirmed HIV/AIDS patients with diarrhoea were tested for *E. coli* O157. Culture-based methods using immunomagnetic separation (IMS) and selective media, followed by biochemical tests, showed that out of the 180 samples of drinking water, 25.56% were positive for *E. coli* O157. Out of the 360 stool swabs from confirmed and unconfirmed HIV/AIDS patients with diarrhoea, 131 (36.39%) were positive for *E. coli* O157. Of these positive *E. coli* O157, 56.5% (74/131) were from confirmed HIV/AIDS patients with diarrhoea, while 43.5% (57/131) were from unconfirmed HIV/AIDS patients with diarrhoea. Molecular methods were also used for characterisation of the representative *E. coli* O157 isolates from both water and stool swabs that were identified by biochemical tests. For this purpose, the polymerase chain reaction targeting $fliC_{H7}$, $rfbE_{O157}$ and *eaeA* genes indicated that the prevalence rates of *E. coli* O157:H7 were 36% (9/25) and 17.24% (5/29) for diarrhoeic confirmed and unconfirmed HIV/AIDS patients respectively. Findings of this study therefore indicate that the microbiological quality of drinking water in the Eastern Cape in general and in the Amathole district in particular might be the source of *E. coli* O157:H7 found in the stool samples of diarrhoeic confirmed and unconfirmed HIV/AIDS patients. This may be an indication of a possible relationship between diarrhoeic HIV/AIDS patients and the presence of *E. coli* O157:H7-contaminated drinking water.

In a related study by Abong'o and Momba [40], the authors established the prevalence and molecular relatedness between *E. coli* O157:H7 isolated from water, meat, meat products and vegetables and from stools of diarrhoeic HIV/AIDS confirmed and unconfirmed patients. For this purpose, classical microbiological methods and PCR amplification of $fliC_{H7}$, $rfbE_{0157}$ and *eaeA* genes were used. One hundred and eighty water samples collected from the Amathole district in South Africa were analysed. In addition, 180 vegetable samples and 180 stools were also analysed for the presence of *E. coli* O157:H7. Culture-based methods revealed that 35% of meat products, 25.5% of water, 21.7% of vegetables as well as 56.5% and 43.5% of stools of confirmed and non-confirmed HIV ⁄ AIDS patients, respectively, were presumptively positive with *E. coli* O157. Molecular results indicated that 10.3%, 8.6% and 7.8% of the vegetables, water and meat products examined carried *E. coli* O157:H7, which had homologous *fliCH7, rfbEO157* and *eaeA* genetic loci to the genes of some *E. coli* O157:H7 isolated from 12.2% and 8.8% of the stools of confirmed and non-confirmed HIV ⁄ AIDS patients, respectively. Findings of this study show that confirmed HIV/AIDS individuals had a higher prevalence of *E. coli* 0157:H7 compared to individuals with unconfirmed HIV/AIDS status. The results of the study illustrated that water, meat, meat products and vegetables were the probable sources of *E. coli* O157:H7 that caused diarrhoea in humans, particularly those who are HIV/AIDS-positive. The study revealed the need to exercise great caution regarding the quality of water administered to HIV/AIDS individuals, as they are particularly susceptible to infections.

In another study by Obi and co-workers [22], the researchers established the scope and frequency of gastrointestinal bacterial disease-causing microorganisms isolated from stools of diarrheic and non-diarrhoeic HIV-positive (330) and HIV-negative (160) individuals. In addition, the household drinking water in rural communities in the Limpopo Province, where the study group resided, was tested for the scope and frequency of enteric pathogens. *Escherichia coli*, *Salmonella* spp., *Campylobacter* spp. and *Aeromonas* spp. were significantly linked to diarrhoea in HIV-positive individuals and their household drinking water. However, *P. shigelloides* did not show any close link with diarrhoea in HIV-positive individuals. Although the same profiles of diarrhoeic-causing bacteria pathogens were isolated from HIV-negative individuals, the frequencies were much lower compared to those isolated from HIV-positive individuals. Indeed, HIV-positive individuals are known to be more susceptible to opportunistic infections such as those caused by enteric pathogens. Hence, they require more rigorous monitoring [50, 51]. This study therefore demonstrated a possible in-depth link between HIV and water quality as exemplified by the significant association of water-borne enteric pathogens isolated from the stools of HIV-positive individuals and their household drinking water when compared to their HIV-negative counterparts in rural areas of the Limpopo Province.

The relationship between enteric bacterial pathogens from diarrhoeic and non-diarrhoeic HIV-positive individuals and their household drinking water in rural communities of the Limpopo Province was determined using the polymerase chain reaction [23]. In addition, the Kirby Bauer disk diffusion method was used to determine the antibiotic susceptibility profiles of the enteric bacteria. The study consisted of 330 HIV-positive diarrhoeic and non-diarrhoeic individuals. Likewise, 160 diarrhoeic and non-diarhhoeic HIV-negative individuals were included. For *Salmonella enteritidis*, the *sef* gene was targeted, while the *flicC* gene was targeted for *S. typhimurium*. Heat labile toxin genes were targeted for *Escherichia coli* and the *Vir A* genes of *Shigella dysenteriae* were targeted for PCR amplification. The researchers showed that PCR amplification of species-specific genes of *Sh. dysenteriae*, *S. enteritidis*, *E. coli* and *S. typhimurium* isolates from stools of diarrhoeic and non-diarrhoeic HIV-positive and HIV-negative individuals were found in the household drinking water of the study cohorts. For this reason, water may be the source of the bacteria in the stools and it was therefore tempting to hypothesize that there was a link between the isolates from household drinking water and those from stool samples. However, more robust molecular methods such as restriction fragment length polymorphism (RFLP), randomly amplified polymorphic DNA (RAPD) and sequencing may be required to establish an unequivocal relationship between the strains from water and those isolated from stools of HIV/AIDS patients.

In another study by Obi and Bessong [12], the authors showed a plethora of enteric pathogens and antibiotic-resistance patterns isolated from stools of HIV-positive patients in rural communities in the Limpopo Province, South Africa. Classical microbiological techniques were used for identification of probable enteric bacterial pathogens isolated from the 60 diarrhoeic HIV-positive patients. Bacterial pathogens that cause diarrhoea were isolated from 80% of the stools of the 60 HIV-positive patients. These bacterial pathogens consisted of *C. jejuni*, *C. coli*, *P. shigelloides*, *Aeromonas* spp., *E. coli*, *Shigella* spp. and *Salmonella* spp. Results of this study supplied preliminary data regarding the scope of enteric bacterial pathogens and their antibiotic susceptibility patterns in HIV-positive patients living in rural areas of Limpopo Province in South Africa. As diarrhoea is mainly transmitted via the faecal-oral route through the consumption of water and food contaminated with human excreta, this study may have highlighted a possible link between HIV/AIDS and poor water quality.

5. Strategies for the sustainable production of safe drinking water

Potable water can be obtained by using several approaches, which include protecting the water source from contamination; properly managing water treatment plants, resulting in effective water purification and disinfection; and ensuring that the integrity of distribution systems is well maintained. In order to ensure that the water source is protected, strategies such as basic sanitation must be in place, the public must be educated regarding personal hygiene and there must be consistent monitoring of raw water quality. The key to ensuring clean, safe and reliable drinking water is to implement multiple barriers during treatment. Coagulation/flocculation, sedimentation and filtration remain the most effective means to reduce pathogen loading in the pre-treated water. Disinfection is then applied to the filtered water to reduce the potential health risk associated with the consumption of drinking water by inactivating pathogens and to maintain a residual in the distribution system [52]. This approach recognizes that, while individual barriers may be inadequate in effectively removing microbial and chemical hazards or preventing contamination, together they provide a greater assurance that the water will be safe to drink. Strategies to ensure sustainable production of safe drinking water also include collection of appropriate information about water sources and their vulnerability and aspects that are required for water treatment [53]. In addition, more data regarding water quality, such as post-water treatment, the presence or absence of hospitals, the presence of areas that utilize untreated water and the associated challenges, must be collected. Furthermore, the technical skills of operators, managers and community members must be consolidated in a concerted effort to obtain potable water. The holistic approach for efficient water treatment also entails designing and implementing a water quality-monitoring programme on a regular basis. This involves training operators and local community members regarding water collection techniques and reviewing and distributing water quality data to relevant groups. In order to produce potable drinking in an efficient and sustainable manner, a holistic approach that consists of various strategies must be followed.

Even when the quality of drinking water at the point of treatment or in the distribution system is microbiologically safe, it can deteriorate during storage in the absence of a residual disinfectant. Consequently, there is a high risk of contamination between the time of collection and the time of consumption in the dwelling. The effect of long-term storage in household containers on the microbiological quality of drinking water is well documented [7, 9; 54]. During storage, the deterioration of drinking water quality is associated with the phenomenon of regrowth and survival of pathogenic microorganisms on the surfaces of household containers [7]. Safe household water management to protect against microbiological contamination should therefore begin with safe storage and handling.

The level of community organization, empowerment and autonomy is important for water sustainability and sanitation interventions. In this regard, community cohesion, stable traditional leadership and respect of ethnic division are of paramount importance because they create social cohesiveness and a good platform for awareness and education campaigns, behavioural change and communication [39]. Consequently, communities' vulnerability to HIV and water-borne diseases may be reduced.

Waterborne pathogens such as coliform bacteria may be curbed by using SOLAIR disinfection, which makes use of a combination of ultraviolet-A and ultraviolet-B radiation from solar and atmospheric oxygen from the natural environment. The advantages of SOLAIR are that efficient microbial disinfection occurs naturally without the addition of chemicals that may be hazardous and there is no need to use expensive and sophisticated equipment [55]. SOLAIR disinfection was applied in South Africa in a rural setup for treating household water from an unlined highly contaminated well [55]. The findings showed a significant decrease of 99.99% of both total coliform counts and total faecal counts within only 4 to 6 hours. The authors did not observe any regrowth after 24 hours. Indeed, after SOLAIR disinfection, the previously contaminated water was found to comply with the requirements of the South African national standards. Therefore, SOLAIR may be an efficient and affordable method for the disinfection of water for millions of South Africans who still make use of water obtained directly from untreated sources such as, boreholes, wells, community taps, dams, rivers and streams.

Nanotechnology, which involves the manipulation of materials at the nanoscale (1-100nm) using the principles of art and engineering, has a plethora of applications that include the treatment of water that is contaminated by toxic metal ions, organic and inorganic solutes and microorganisms [56]. The three categories that are impacted on by nanotechnology are treatment and remediation, sensing and detection, and pollution prevention [57, 58]. Regarding treatment and remediation, nanotechnology may engage advanced filtration materials that have the ability to enhance water reuse, recycling and desalinization, leading to long-term improved water quality. The advantage of nanotechnology as an alternative method for water disinfection is that it may present chlorine-free biocides [56]. The use of chlorine disinfectants may present odours and tastes that are not desirable. Therefore, the effectiveness of nanotechnology in the disinfection of water could play a crucial role in curbing waterborne pathogens, thus improving water quality for millions of people in future.

6. Conclusion

On the one hand, diarrhoea continues to be a public health challenge in South Africa rural and peri-urban areas, due to lack of access to safe water. On the other hand, South Africa is experiencing the highest burden of HIV/AIDS in the world. Diarrhoea is a signature attribute of the clinical manifestations of HIV/AIDS in developing countries, but health authorities in developing countries have not effectively addressed the triad of water quality, diarrhoea and HIV/AIDS in a comprehensive, concerted and coordinated manner to preserve the earth and its people. Public awareness campaigns and other health promotion strategies are warranted to fiercely tackle the hydra-headed saga of diarrhoeal diseases, water quality, sanitation and hygiene and HIV/AIDS, and how they all act in concert to perpetuate poverty and deprivation.

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