Impact of intestinal microorganisms and protozoan parasites on drinking water quality in Harare, Zimbabwe

Tatenda Dalu, Maxwell Barson and Tamuka Nhiwatiwa

ABSTRACT

The presence of microorganisms and their potential impacts on drinking water from boreholes, bowsers, lakes, rivers, springs, taps and wells was investigated in peri-urban settlements around Harare. *Escherichia coli*, *Salmonella* sp., *Vibrio cholerae* and faecal streptococci were present in all water sources except for the boreholes and bowsers. Rivers, lake and wells showed the greatest diversity of 10, 5 and 6 species and relative density (rd) of 90.9, 83.4 and 61.67% respectively for the protozoan parasites. *Cryptosporidium* was identified in groundwater sources; wells (rd = 8.3%) and springs (rd = 41.7%) and identified in tap water (rd = 6.23%) and the Mukuvisi River downstream (rd = 8.3%). *Entamoeba histolytica*, *Cyclospora, Isospora belli*, *Trichuris trichiura* and *Giardia lamblia* were found in all water sources. Eggs/larvae of intestinal parasites; *Ascaris lumbricoides*, *Strongyloides*, *Rhabditis*, *Taenia* sp. and *Schistosoma mansoni* were identified in different water sources. Faecal coliform levels had a significant effect on the water sources' water quality with $p = 0.018$ in all sites except for the borehole whilst faecal streptococci had no significant impact with $p = 0.513$. The presence of at least one microbial pathogenic organism and parasites in most of the water sources poses a threat to the water quality and is a human health risk in the study areas.

Key words | coliforms, drinking water, Harare, microorganisms, parasites, protozoa

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INTRODUCTION

Water is the very essence of life, but is also scarce since it is a finite resource. Its scarcity is exacerbated by increasing anthropogenic impacts (Fruhling 1996). Effective legislative and institutional frameworks to efficiently manage water are critical for both current and the future generations (Chiuta *et al*. 2002). Since 1990, the number of people without access to safe water worldwide has remained approximately 1.1 billion, of whom 2.2 million die of water-borne diseases each year (Mintz *et al*. 2001). Drinking water quality monitoring is a common problem in the southern African region. The biological quality of water is reduced by the presence of microorganisms, such as protozoa and bacteria, most of which come from faecal contamination (Department of Water Affairs and Forestry 1996).

Faecal coliforms and streptococci regularly occur in faeces in varying numbers, and are commonly used as indicators of faecal contamination (Cheesbrough 1984). Intestinal protozoans also cause different waterborne gastrointestinal diseases, such as amoebic dysentery, caused by *Entamoeba histolytica* trophozoites, giardiasis, cryptosporidiosis and balantidiasis (Garcia 1999; Joynson 1999). *Giardia* and *Cryptosporidium* oocysts are resistant to the chlorination methods used to disinfect water supplies, and can remain infective and persist for extended periods in the water column or sediments; they are difficult to detect in water and cross-infect between different animal species (Thurman *et al.* 1998).

The City of Harare lies within its own catchment area and most of the pollution problems being experienced now result from poor planning (Jarawaza 1997). The city recycles its water and as a result, the effluent discharged into rivers affects the quality of raw water. The poor raw water quality has made the cost of treating water very high. Erratic water supply and poor sanitation are largely responsible for the high levels of waterborne diseases (Moyo & Mtetwa 2002).

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Sewage treatment plants in Harare are often overloaded, for example, the Firle Sewage Treatment Works, that treats half of Harare's sewage, was designed to treat 72,000 m^3 of wastewater per day, yet the plant now receives more than 100,000 m^3 of wastewater a day, resulting in the discharge of raw sewage into the Mukuvisi River, which causes eutrophication in Lake Chivero (Moyo & Mtetwa 2002). Other sewage treatment plants in Harare include Crowborough, Mabvuku, Tafara, Marlborough and Hatcliffe ponds, and all contribute towards pollution of Harare's water bodies (Staneva 1997). The Firle sewage treatment works uses partially treated wastewater for irrigation of the City of Harare farm and probably introduces *Salmonella* and other pathogens to the pastures (Gopo & Chingobe 1995).

Harare's water problems continue to worsen by the day, as Zimbabwe National Water Authority (ZINWA) dithers on the capital's water solutions and repairs of damaged water points, which have resulted in the loss of millions of litres of treated water since January 2007 (Anon, *New Zimbabwe*, 7 August 2007). The City of Harare Council centres were handling about 900 cases of diarrhoea per day and each of the city's 60 health centres were treating at least 15 cases of diarrhoea a day, with many more being treated by private doctors and government clinics and hospitals (T. Matope, *The Herald*, 20 August 2007; T. Sibanda, www.swafricaradio.com, 20 August 2007).

Operation Murambatsvina in 2005 resulted in poor sanitation and hygiene as the displaced people resorted to open bushes as toilets resulting in increased levels of faecal contamination in groundwater sources and increased incidences of gastrointestinal diseases. Most of the affected individuals moved to the semiformal areas (Hatcliffe extension and Epworth), thereby further straining the poor water sources resulting in endemic diseases in the areas as a result of failure of the water and wastewater systems (DS & ZLHR 2005).

The aim of this study was to investigate the effect of water quality in the upper Manyame catchment area so as to assess/predict the prevalence of gastrointestinal diseases in the study areas. The specific objectives of the survey were to:

1. Isolate and identify the faecal organisms in different potable water sources in Harare such as boreholes, shallow wells, taps, rivers and ground water.
2. Evaluate the prevalence of gastrointestinal diseases in the study locations.
3. Compare faecal contamination in different water sources.

MATERIALS AND METHODS

Study area

The sampled areas are located in the upper Manyame catchment area Harare (Figure 1). Samples in the study sites were collected in August 2007 and January 2008. Samples were collected from boreholes, bowsers (tanks), taps, rivers, wells and from Lake Chivero. All water samples were collected and preserved according to the standardized methods as described by Cheesbrough (1998) and SCA (2002).

Hatcliffe and Mabvuku-Tafara high-density suburbs were selected because of frequent sewage pipe bursts and the prolonged erratic supply of purified piped water in these areas. All these factors have created frequent outbreaks of gastrointestinal diseases such as cholera (T. Matope, *The Herald*, 20 August 2007; T. Sibanda, www.swafricaradio.com, 20 August 2007; G. Shamhu, *The Sunday Mail*, 5 August 2007; Sachiti, *The Sunday Mail*, 13 January 2008). The Manyame, Mukuvisi and Ruwa Rivers were used as indicators for the assessing the level of pollution entering the City of Harare water source, Lake Chivero. The rivers are heavily polluted or contaminated with sewage from the Chitungwiza Sewage treatment works and the Firle sewage plant (Staneva 1997).

All samples were tested for the presence of coliforms, streptococci, *Vibrio cholerae* and *Salmonella* sp. according to SCA (2000) and APHA/AWWA/WEF (1995). Positive tubes for the presumptive test for streptococci were subcultured in bile aesculin agar and incubated for 24 hours at 44 °C to test for faecal streptococci with the formation of a black/brown colour. The presence of *Salmonella* sp. was determined according to APHA/AWWA/WEF (1995), Cheesbrough (1998) and SCA (2006). Positive results for coliforms were used as indicators for the test of the presence of *V. cholerae*. Confirmatory tests for the vibrios were carried out according to Cheesbrough (1998).

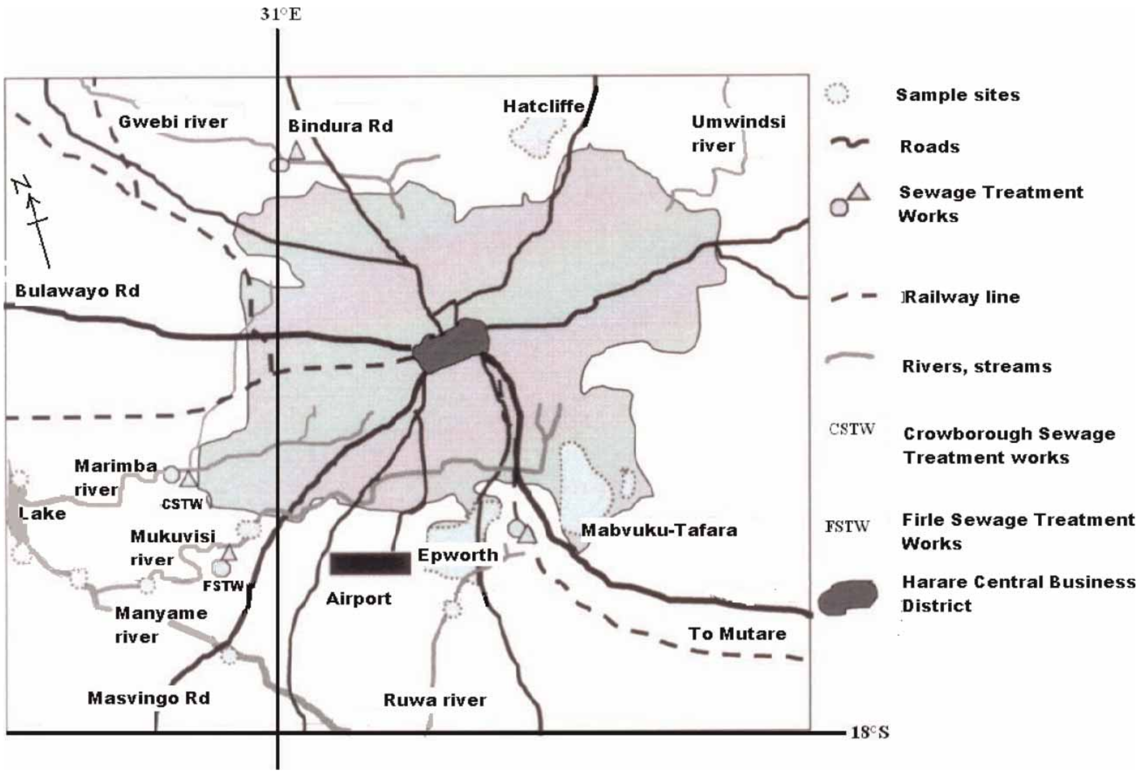

Figure 1 | City of Harare map showing the sampled areas in relation to other areas.

All water samples from the field were first observed under a light microscope at high power magnification before analytic techniques were employed for parasitological analysis. Samples of water (500 ml) were filtered using 2 μm absolute polypropylene filters for the concentration of oocysts, cysts, eggs and trophozoites at a flow rate of 1–5 litres / minute (WHO 2006). The trapped materials were then eluted by washing the filters in phosphate buffered saline with 5% detergent in Petri dishes (Grabb & Latchem 1967). Some of the resulting washings were further concentrated by standardized centrifugation methods (Grabb & Latchem 1967; WHO 2006). The resultant washings were then observed under a light microscope at high power and all parasites present were recorded. Sub-samples were stained with Lugol's iodine (wet mount) and eosin (Cheesbrough 1998) to identify helminth eggs, intestinal flagellates, ciliates and cysts (WHO 1991); the modified Ziehl–Neelsen reagent was used to stain and identify *Cryptosporidium parvum* and *Cyclospora cayetanensis* oocysts (WHO 1991; Cheesbrough 1998).

Two parameters, species richness and relative density, were determined at each site. Species richness refers to the total number of species recorded in a particular area (Magurran 1988). Relative density was defined as the number of parasites in the study area over the total number of organisms (both free-living and parasitic).

Analysis of faecal coliform and streptococci data was carried out using Minitab (Release 10.5 Xtra) and the data was noted to follow an ordinal rating that violates various ANOVA assumptions. Therefore, the non-parametric equivalent of a two-way ANOVA, the Kruskal–Wallis test for randomized blocks was used to test for the significant effect of faecal coliforms and streptococci on the water sources' water quality. SigmaPlot (Version 9.0) was used to plot the graphs. In all cases, a level of $p = 0.05$ was adopted as the minimum significance.

RESULTS

The total faecal coliforms and faecal streptococci were high for the entire duration of the study in August 2007 and January 2008 (Figures 4–8). The counts varied with the water sources: the highest counts were observed in the rivers and lake that supply water to the City of Harare and wells that are used for domestic purposes, for both the total faecal coliforms and faecal streptococci in all sites, except in Hatcliffe Extension (Figure 2 and 3). The Mukuvisi River had an average 1,100+ most probable number (MPN) per 100 ml total faecal coliforms and faecal streptococci, upstream and downstream (Pension Farm). The figures for Mukuvisi River were similar to those of Manyame River. The borehole water (Hatcliffe Urban and Mabvuku-Tafara), bowser water (Hatcliffe Urban), burst pipe (Epworth) and tap water (Hatcliffe Extension), had a value 0 MPN counts per 100 ml for both total faecal coliforms and faecal streptococci which was quite low compared to all water sources in the sites sampled (Figure 4). *E. coli* was identified from all the sites; *Salmonella* was also identified in all sites except Epworth and Pension Farm; *V. cholerae* was identified in all sites except Hatcliffe Urban, Manyame River (Skyline) and Pension Farm (Table 1) and (Figures 5–8).

Table 1 below shows microorganisms and parasites found in the different study sites. Wells, rivers and lake had the greatest incidence of occurrence for most of the organisms. *Cryptosporidium* oocysts were the most common form of protozoan in domestic water sources; springs, taps and wells. *E. histolytica* cysts (wells and springs) and *Giardia lamblia* cysts (wells and bowser) were the second most common. Among other parasites, *Cyclospora* cysts, hookworm eggs, *Rhabditis* spp. and *Strongyloides* spp. were only found in wells, and *Ascaris*

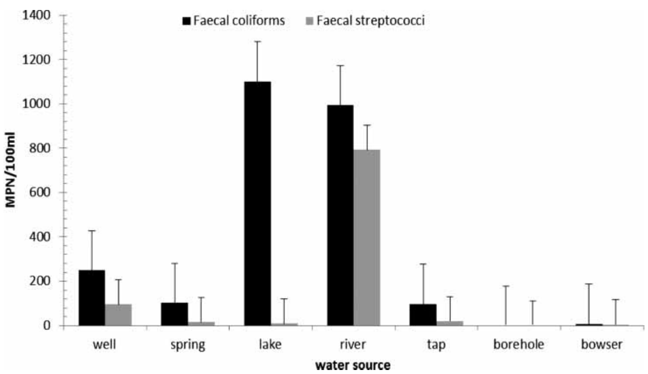

Figure 2 | Abundance of faecal coliforms and streptococci in sampled water sources. Error bars represent the standard errors.

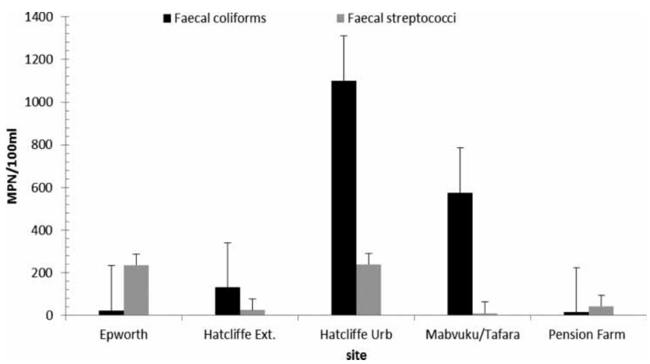

Figure 4 | Variation of faecal coliforms and streptococci in well water for the sampled sites. Error bars represent the standard errors.

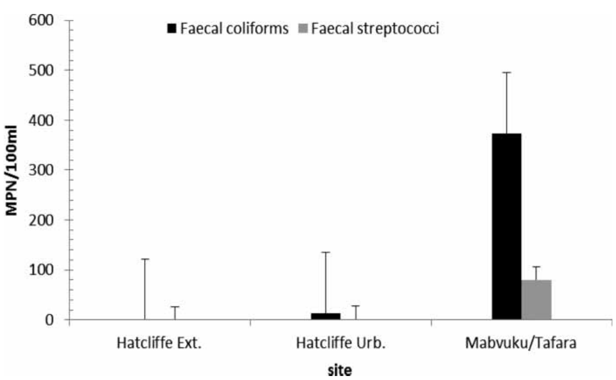

Figure 3 | Variation of faecal coliforms and streptococci in the sampled sites for tap water. Error bars represent the standard errors.

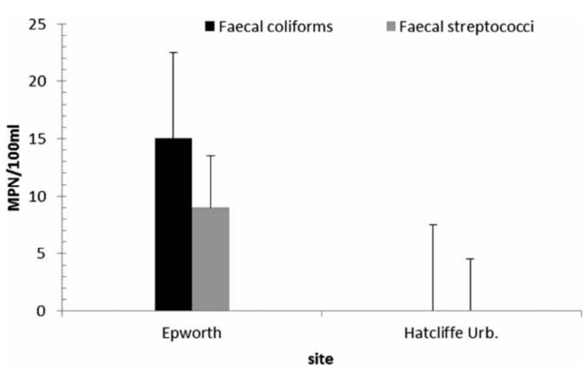

Figure 5 | Variation of faecal coliforms and streptococci in bowser water for sampled sites. Error bars represent the standard errors.

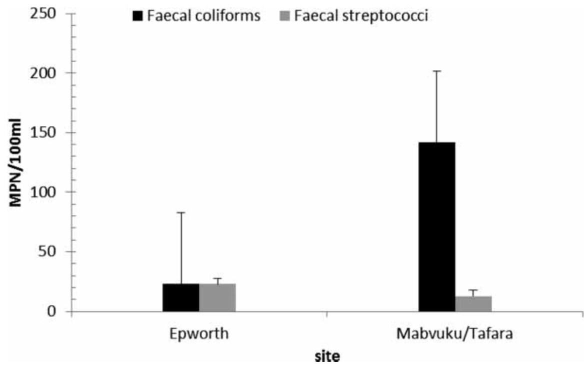

Figure 6 | Variation for faecal coliforms and streptococci in spring water for sampled sites. Error bars represent the standard errors.

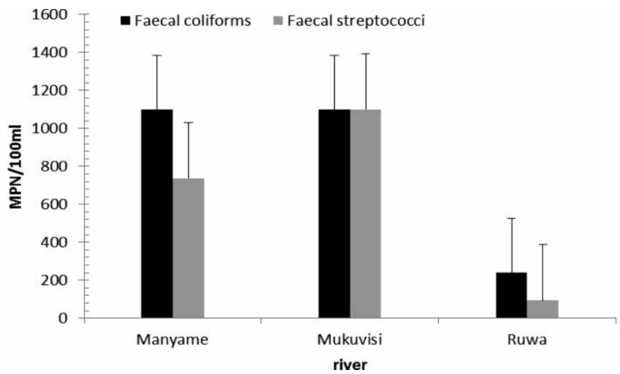

Figure 7 | Variation of faecal coliforms and streptococci for rivers in the sampled areas. Error bars represent the standard errors.

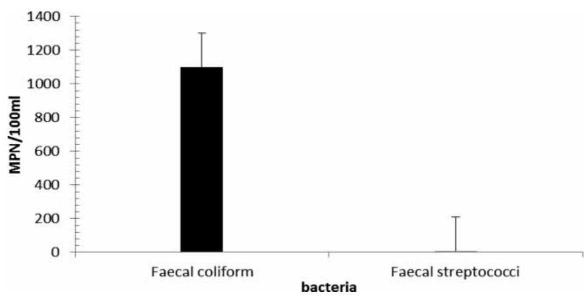

Figure 8 | Variation of faecal coliforms and streptococci in lake water. Error bars represent the standard errors.

lumbricoides, *E. histolytica* trophozoites, *Isospora belli* cysts, *Schistosoma mansoni* eggs and *Taenia* spp. eggs were identified only in the rivers and lake. The most parasites were identified in water sources found in Hatcliffe Urban and Mabvuku/Tafara with Hatcliffe Extension recording the fewest. In the rivers and lake that supply the City of Harare with water; *Taenia* spp. eggs, hookworm eggs, *E. histolytica* cysts and trophozoites were the most common parasites. Most parasites identified were common in the rivers and lake and were found in at least two different sites with the exception of *Rhabditis* spp. and *Strongyloides* spp., which were only identified in the wells. Most of the parasites were common in Lake Chivero, and Manyame and Mukuvisi Rivers with the Ruwa River having only *G. lamblia* cysts detected.

Coliforms, *E. coli* and streptococci were the most common bacteria amongst the different domestic water sources: bowser, springs, taps and wells. In the domestic water sources, *Salmonella paratyphi* A and *V. cholerae* were only identified in the wells. Most of the bacterial species were identified in Epworth and Mabvuku/Tafara water sources with Mabvuku/Tafara recording the only *S. typhi* in tap water to be found in the domestic water sources. *Salmonella typhimurium* was only identified in the Manyame River with all the other bacterial species (*E. coli, S. paratyphi* A, *S. typhi*, streptococci and *V. cholerae*) being identified in most of the rivers and lake (Table 1).

Intestinal protozoan parasites were found in relatively high densities of between 16.67 and 90.9% in all water sources. Rivers, lake and wells showed the greatest diversity of 10, 5 and 6 species and relative density of 90.9, 83.4 and 61.67% respectively for the protozoan parasitic organisms. *Cryptosporidium* from groundwater sources was identified in boreholes (relative density (rd) = 0%), wells (rd = 8.3%) and springs (rd = 41.7%) and further identified in tap water (rd = 6.23%) and the Mukuvisi River downstream (rd = 8.3%). *E. histolytica, Cyclospora, I. belli, Trichuris trichiura* and *G. lamblia* were identified in all water sources, with densities ranging of 1–16.67%. Non-protozoan organisms; hookworm and *A. lumbricoides* eggs, *Strongyloides* spp., *Rhabditis* spp., *Taenia* spp. eggs and *S. mansoni* were identified at densities of 28.32% for each species named.

The greatest diversity of parasitic species was observed amongst the major rivers that flow into Lake Chivero (Table 2). Of the rivers that flow into Lake Chivero, Mukuvisi River had a species richness of 10, giving a 90.9% relative density and Manyame River with a relative density of 43% of the species parasites. High relative densities of 33.33 and 37.5% were noted in Hatcliffe Urban and

Table 1 | The microbial pathogens and parasitic organisms identified in the different sources of the study sites

Species	Hatcliffe Extension	Hatcliffe Urban	Mabvuku Tafara	Epworth	Pension Farm	Mukuvisi River	Manyame River	Ruwa River	Lake Chivero
Microorganisms									
E. coli	W	W, T	W, T, S	W, S	W, B	U, D	Sk, C	E	M, K
S. paratyphi A	W	W				D			
S. typhi			T				Sk,C		
S. typhimurium						U		E	M
Streptococci	W	W, T	W, T, S	W, T, S	W, B	U, D	Sk, C	E	M, K
V. cholerae	W		W	W		U, D	Sk, C		M, K
Parasites									
A. lumbricoides						U	C		
Cryptosporidium oocysts		W	T, S	T, S	W	D			
Cyclospora cysts						U, D			
E. histolytica cysts		W	W, S	W		D	C		K
E. histolytica trophozoites						U, D	Sk		M
G. lamblia cysts		W	W		B	U, D		E	M, K
Hookworm eggs		W				U, D	C		M
I. belli cysts						D			
Rhabditis spp.	W		W						
S. mansoni eggs						D	C		
Strongyloides spp.		W							
Taenia spp. eggs						D	Sk, C		M

W: well, T: tap, S: spring, B: bowser, Sk: Skyline, C: confluence with the Mukuvisi River, U: upstream, D: downstream, E: Epworth, M: mouth, K: Kuimba Shiri.

Table 2 | Incidence of parasitic organisms identified for all the study sites

Site	Species richness	Relative density (%)
Hatcliffe Extension	1	16.67
Hatcliffe Urban	6	33.33
Mabvuku/Tafara	5	17.86
Epworth	3	37.50
Lake Chivero	5	83.40
Manyame River (Skyline)	2	20.00
Manyame River (after Mukuvisi River confluence)	5	66.67
Mukuvisi River (upstream)	5	85.71
Mukuvisi River (downstream)	9	90.90
Ruwa River	1	20.00

Epworth respectively while low relative densities of parasites were observed in Hatcliffe Extension with 16.67% and Mabvuku-Tafara with 17.86%. High amounts of the parasites were found in rivers, wells and springs while no parasites were observed in boreholes and bowser (Table 2).

Clinical data shows the suspected cases of diarrhoeal and cholera cases in the study areas (Table 3). The August values show low incidences of the diseases compared to January. The semiformal areas show the highest incidences of the diseases for both months and also the highest number of deaths from the diseases. Pension Farm has the lowest number of cases and deaths from the enteric diseases.

Faecal coliform levels had a significant effect on the water sources' water quality with $p < 0.05$ in all cases except in for the borehole with $p < 0.05$ (Table 4). The level of faecal coliforms had significant effect on the water quality for lake, river, spring, well, tap and bowser on each site. Total faecal coliforms had a significant effect on the water sources' water quality with $p = 0.018$ whilst total faecal streptococci had no effect ($p = 0.513$).

Table 3 | Suspected diarrhoeal and cholera cases for August 2007 and January 2008 in the study sites. Statistical records obtained from the Central Statistical Office, Harare

	Suspected diarrhoeal cases		Suspected cholera cases		Total diarrhoeal deaths		Total cholera deaths	
Site	August 2007	January 2008	August 2007	January 2008	August 2007	January 2008	August 2007	January 2008
Hatcliffe Extension	57	74	4	9	11	15	2	4
Hatcliffe Urban	21	33	2	6	5	7	0	1
Mabvuku/Tafara	46	53	3	11	7	5	1	3
Epworth	67	82	9	7	13	17	3	3
Pension Farm	9	11	0	1	2	1	0	0
Total	200	253	18	34	38	45	6	11

Table 4 | Kruskal–Wallis test for coliform variation between water sources amongst the study sites

Water source	*p*-value
Borehole	1.000
Bowser	0.041
Lake	0.005
River	0.013
Spring	0.035
Tap	0.042
Well	0.017

DISCUSSION

The microbiological results indicate faecal coliform and streptococci contamination, as well as *E. coli*, *V. cholerae* and *Salmonella* contamination for all the study sites. The high levels of faecal contamination within the rivers, lake and wells can be attributed to the current discharge of partially treated sewage, sewage runoffs draining into them and their close proximity to Blair toilets (personal observations). Microbial results also show that there is no faecal contamination within any of the boreholes sampled but other groundwater sources, i.e. springs and shallow wells were considerably contaminated, with a greater degree of contamination within the latter. Groundwater in boreholes is generally of good quality due to the relatively slow subsurface movement of water compared to surface water sources like rivers (Zvidzai *et al.* 2007). It was found in the study that, the deeper the borehole or well and the better protected it was, the lower the risk of contamination, as shown by Butler *et al.* (1954), Baars (1957) and Ziebell *et al.* (1975) who noted that no faecal microorganisms are found below 1.3 m depth due to the different factors that hinder bacterial movement. Shallow wells and springs in Epworth and Hatcliffe Extension served more people than in Pension Farm, resulting in a higher demand on the former, with consequential higher microbiological contamination levels due to their frequent use. WHO guidelines value of 0 MPN/100 ml was not met in nearly all of the faecal coliform results obtained for the water sources.

The results obtained for groundwater sources located within a 12-m radius of the Blair toilets in Hatcliffe Extension and Epworth indicate the area that Blair toilets can. Beyond 12 m the faecal coliforms were greatly reduced, as noted also by Dzwairo *et al.* (2006) in Marondera district of Zimbabwe where they found a decrease of faecal contamination with distance. This could imply that the coliform and streptococci effect is decreasing with an increase in the distance from the Blair toilets and also with depth, which tend to suppress microbial growth, movement and contamination (Samukange 2006); these findings also agree with Lewis *et al.* (1980) who found diminished bacterial loads with distance from the source of contaminant. Lewis *et al.* (1980) noted that the bacteria are virtually absent at a distance of 15 m from the Blair toilet (Cave & Kolsky 1999).

Tap water stored in containers showed high levels of faecal coliform and streptococci, *E. coli* and *S. typhi* in all sites with the exception of Hatcliffe Extension and Epworth that had running tap water. The stored water acted as a reservoir for microorganisms and studies have suggested that increased faecal contamination of stored water may be a result of continuous growth of bacterial already present in the water (Black *et al.* 1982). The main cause of contamination of stored water could be attributed to mechanical means during water handling, usually through regular use of a dipper such as a plastic/metal bowl or a gourd as was indicated by Pinfold (1990) who found that a dipper was the main stored water contaminant in households. Hands that are in regular contact with the local surroundings could also be a potential conduit for transferring microorganisms from water either via a dipper or through direct contact with water (Feachem *et al.* 1978; Attair *et al.* 1982). This can also be said to be true for springs and shallow wells contamination where faecal coliforms and streptococci, *E. coli, V. cholerae, S. typhi* and *paratyphi A*, were identified and the main contaminant could be dippers which are used to collect water amongst the two water sources. The springs and wells are also prone to contamination from surface run-off as they are not properly protected.

In semiformal areas (Hatcliffe Extension and Epworth), there is risk of gastrointestinal disease outbreak due to the high numbers of faecal coliform and streptococci, *E. coli, Salmonella* and *V. cholerae* which can be related to the clinical data shown in Table 2, recording that the cases have been increasing over the months. This could be attributed to poor sanitation and lack of piped water for some households resulting in the use of unprotected wells (Gandidzanwa 2003). The presence of *E. coli*, faecal coliform and streptococci, *Salmonella and V. cholerae* is indicative of faecal contamination in the water sources and could be a result of effluent contamination from Blair toilets and surface run-offs from burst sewage pipes and poor hygiene.

The faecal coliform levels had a significant effect on the water sources' water quality for the rivers ($p = 0.013$), lake ($p = 0.005$), bowser ($p = 0.041$), spring ($p = 0.035$), tap ($p = 0.042$) and well ($p = 0.017$) whilst they was no significant effect on the water quality for borehole ($p = 1$), suggesting that the water was not of good quality in all sources' except for the boreholes. Total faecal coliform had a significant impact on the sources' water quality as shown by a $p = 0.018$ whilst total faecal streptococci had no impact ($p = 0.513$). This means that different water sources' water quality in the study sites are heavily impacted by the faecal coliforms whilst faecal streptococci had no impact at all statistically.

Parasitological results show shallow wells had the highest species richness (five species) posing a greater risk to human health as it is the people's main source of domestic water. The semi-formal settlements, Hatcliffe Extension and Epworth had the fewest protozoan parasites (zero and two species respectively), compared to the formal settlements Hatcliffe Urban and Mabvuku-Tafara (three species each). Rivers had the highest protozoan parasites species diversity with an average 60% for each of the six protozoan parasites namely, Cryptosporidium, Entamoeba, Giardia, Cyclospora, Trichuris trichiura and Isospora. The wastewaters that discharge into the rivers act as sources of protozoan parasites in surface waters as indicated by Sykora *et al.* (1991) who studied the occurrence of *Giardia* and *Cryptosporidium* in wastewaters and sludge of 11 cities in the USA (EPA 2001a, b). The Firle Sewage Works proved to be the heaviest polluter of the Mukuvisi River downstream as shown by a lower species density of 85.71% of parasites upstream and 90.9% downstream after the sewage works and ultimately polluting Lake Chivero, thus posing a potential health hazard to the city of Harare as some of the protozoan parasites *Cryptosporidium* and *Cyclospora* oocysts can withstand normal water disinfection processes.

Groundwater sources in Mabvuku/Tafara and Epworth; springs (rd = 41.7%) and shallow wells (rd = 8.3%), had the highest levels of *Cryptosporidium* oocysts. This result contradicts studies which suggested that *Cryptosporidium* oocysts are found less frequently in groundwater than in surface water because the wells in the EPA study were very different in that they are typically true groundwater, not groundwater under the influence of surface water or directly impacted by surface inputs (EPA 2001a). The results obtained in the investigation are supported by Hancock *et al.* (1998) who showed that between 9.5 and 22% of groundwater samples tested positive for *Cryptosporidium*. Besides the large numbers of protozoan parasites, other types of parasites such as hookworm eggs, *A. lumbricoides, Strongyloides* eggs, *Rhabditis*, tapeworm eggs (*Taenia* spp.) and *S. mansoni* eggs were observed at densities of 28.32%. These parasites were mostly found in rivers suggesting that they were of faecal origin. The presence of these parasites could pose risks of serious gastrointestinal diseases as already shown by the clinical data (see Tables 1 and 3).

The data from Tables 1 and 2 could be used to explain the high incidences of diarrhoeal and cholera cases in the study areas as shown in Table 3. Cholera cases relate with the study findings, which show the presence of *V. cholerae* bacteria in all sites except for Hatcliffe Urban and Pension Farm (Table 1). The high increase in cases of diarrhoea and cholera in January could be attributed to the on-set of the summer rains that further disseminate the microbial pathogens and protozoa causing more disease outbreaks. There have been reports on the outbreak of diarrhoea and cholera in Epworth, Hatcliffe and Mabvuku-Tafara (Shamhu G, *The Herald*, March 3, 2008; Anon, *The Herald*, March 2, 2008 and Sachiti R, *The Sunday Mail*, January 13, 2008).

For most of the microbial microorganisms and protozoan parasites that cause diarrhoeal diseases such as dysentery, cholera, paratyphoid and typhoid fever, the clinical data will have been helpful as it will have enabled us to explain our findings properly. This failure to access data for the different diseases can be attributed to no comprehensive assessment of Zimbabwe's health system since 2006, making it difficult to assess its true state. Thus, the disease surveillance and early warning system, which depends on a weekly epidemiological system, has been compromised in terms of timeliness and completeness of data, which is only around 30% (UN 2008). Another challenge facing Zimbabwe is that the overall health service has been steadily declining for the last ten years, wracked by critical shortages of essential drugs and skilled personnel. The staffing and financial limitations are impacting on Zimbabwe's ability to produce a national health profile. Universal access to basic health services is compromised due to deteriorating infrastructure, staffing and financial resources (UN 2008; WHO 2008).

CONCLUSIONS

In conclusion, water quality for all water sources and major rivers was poor as indicated by the presence of at least one microbial and parasitic microorganisms, with very few exceptions of the boreholes and bowser. Groundwater sources (springs and wells) which are mostly used for domestic purposes posed a greater health risk as most of the microbial pathogens and parasites were identified in them. The conclusion that can be drawn from this study and early studies is that at least 2 m is required groundwater source depth and a distance of at least 15 m from Blair toilets to prevent contamination of any underlying groundwater. Despite the shortcomings, clinical data matched with the findings from the study that the water quality, hygiene and sanitation play a pivotal role in determining the incidences of diseases.

Reactivating primary health care services should be addressed as a matter of emergency. Zimbabwean health facilities face a massive gap estimated at 70% in 2008 in required medicines due to reduced local manufacturing capacity, which has been weakened by a lack of foreign currency; this is despite support received from different partners through UNICEF's procurement systems (UN 2008). We recommend that ZINWA should repair water and sewerage reticulation systems, as well as rehabilitate and upgrade the sewage treatment facilities to prevent overloads and overspills into the rivers. The Harare City Council must also play its part in ensuring that they improve the collection of garbage to prevent contamination of groundwater sources and spread of diseases such as cholera as people tend to throw away their garbage in the open. ZINWA must ensure they provide sewerage and water supply systems to all households in semiformal areas and ensure that all areas receive piped water. Financial resources must be directed towards installing more boreholes so that residents can obtain safe drinking water. Laws must be put in place and enforced that promote a safe and clean environment.

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