© IWA Publishing 2016
329

Water Practice & Technology Vol 11 No 2
doi: 10.2166/wpt.2016.038

An analysis of ground water quality in a water stressed urban centre: a case of Gweru city, Zimbabwe

C. Mukanga, T. Chitata* and B. T. Mudereri

Midlands State University Faculty of Natural Resources and Agriculture, Bag 9055 Senga Road, Gweru, Zimbabwe

*Corresponding author. E-mail: chitatat@gmail.com

Abstract

Ground water quality conformance to the World Health Organisation standards for drinking water was carried out and inferred to the health risks associated with use of such quality of water. Water samples were collected thrice a month, from nine boreholes, over a period of twelve months and analysed for physical, chemical and biological parameters. Chemical parameters were tested using UV-Vis photometry. Physical parameters were measured using HI9829 waterproof portable logging multi-parameter meter and biological parameters were determined using the Minimal Media ONRG-MUG test and the Membrane Filtration Method (MF). Results shows that total hardness and Fe concentration were above limit in 78% and 56% of the sampled boreholes, respectively. pH, EC, Ca, Cl, Fl, Mn, Mg and Turbidity were within the acceptable WHO limits. Of the sampled boreholes, 67% were not conforming to the *Escherichia coli* loads recommended for drinking water. Parametric correlations showed strong and significant correlations between chlorides and fluorides ($r = 0.68$; $p < 0.05$), Nitrates and Sulphates ($r = 0.78$; $p < 0.05$). There is need to treat borehole water to eliminate *E. coli* and reduce nitrates and total hardness. Furthermore, analysis and monitoring systems to determine temporal variability and health risks, respectively, needs to be put in place.

Key words: borehole, ground water use, UV-Vis spectrophotometry, water scarcity, water quality

INTRODUCTION

Groundwater has emerged as a vital resource for domestic water supply, providing 25–40% of the world's drinking water (Margat & van der Gun 2013). In urban areas, a significant increase in groundwater use by 63.1% of the population has been reported between 1990 and 2010 (WHO & UNICEF 2014). The increase in ground water use mostly emanates from third world countries where outbreaks of water related diseases are prevalent (Gleick 2003; Sorenson *et al.* 2011; Bain *et al.* 2012; Onda *et al.* 2012). Lately, urban water utilities have resorted to groundwater exploration, development and use for two reasons. Firstly, there is need to cope with increasing population, rapid urbanisation, increasing affluence, accelerated rates of industrialisation, increasing per capita water demand (Rao *et al.* 2004). Secondly, the cost for drilling boreholes and wells is relatively affordable to the municipalities and private, in-situ self-supply residents (Rao *et al.* 2004; Foster *et al.* 2010).

Although ground water use has increased in urban areas, there are still challenges associated with its use as potable water. In urban environments, ground water is subject to temporal and spatial quality deterioration mainly due to pollution (Van Der Hoven *et al.* 2005; Schot & Pieber 2012). Ground water pollution is a subset of complex interactions between different legal or illegal land uses with rainfall, runoff and ground water recharge processes (Pionke & Urban 1985; Coulter *et al.* 2004; Lerner & Harris 2009).

Increasing population, serviced by old low capacity sanitation and reticulation facilities results in underground sewer burst which directly load faecal pathogens (eg *Escherichia coli*), pharmaceuticals, disinfectants, detergents and other persistent micro-pollutants to the ground water. Urban agriculture, landfills and waste tips may input high levels of nitrates or nitrite, ammonium, pesticides and sulphides through runoff, infiltration and seepage (Wakida & Lerner 2005). Industrial waste contributes heavy metals, poly-aromatic hydrocarbons among other pollutants.

Common health effects of groundwater pollution by heavy metals include high blood pressure, digestive problems, kidney damage and mental retardation from mercury and diarrhoea, nausea and death from Arsenic (Jarup 2003). Nitrates and nitrites, although their effects on human health is disputed (Addiscott 1996; Addiscott & Benjamin 2004; Addiscott 2005; Almasri 2007), it is strongly argued to cause infant methemoglobinemia and gastric cancer (Bruning-Fann & Kaneene 1993). These potential health risks can be fatal considering that physical, chemical and biological parameters are not usually tested for during acute water shortages. Furthermore, privately owned boreholes and wells are not mandatorily tested and most groundwater users regards groundwater to be pure.

The high level risk associated with groundwater use, is in a way, an indicator of information deficiency on the quality of the resource itself as well as lack of baseline data to base the development of a groundwater framework on. Therefore, this research may be a starting point towards informing local level policy makers about the groundwater quality and implications of its use as potable water. This may ultimately lead to the development of groundwater governance structures to control how groundwater is exploited and used. This status quo in Gweru city applies to all the other cities in Zimbabwe and most of countries in southern Africa. The correlations of groundwater parameters developed in this research may aid in identifying sustainable groundwater treatment options.

This research seeks to analyse the borehole water quality in Gweru city and assess the suitability of the water for domestic use using the World Health Organisation (WHO) guidelines for drinking water and analyse correlations between groundwater quality parameters.

SITE DESCRIPTION

Location and climate

The research was carried out in Gweru the fifth largest City in Zimbabwe, based on population. It is located at 19.4511 °S, 29.8302 °E and 285 km south-west of the Capital City Harare. The city covers about 26 113Ha of the Sanyati catchment. It is at an altitude of 1,420 above mean sea level. Gweru city lies in Natural Region IV and receives an average rainfall of 600 mm bordered by a minimum of 400 and a maximum of 850 mm (Mugandani *et al.* 2012). The area receives most of its rainfall in the tropical summer (October to March) with maximum average temperature of 28.3 °C and the winter is fairly cold with minimum average temperature of 8.7 °C (Vincent & Thomas 1960).

Soils and geology

The rocks consist of meta-sediments, felsic meta-volcanics, interbedded sediments, aeolian sands, grits sandstone, siltstone and Felsites rock formations (Figure 1). Most of the soils in the study area are related to the underlying rock. Two soil groups are common in the Gweru area, Regosols and Fersiallitic soils with the latter dominant. The former are deep sands with $<10\%$ silt and clay with very little to no reserves of weathered minerals (mainly Kalahari sands). Fersiallitic soils are mainly south of the city and have appreciable reserves of weatherable material, with moderately shallow to deep greyish brown sands or loamy sands over light reddish brown sandy loams formed on sandstones and quartzite of umkondo and to a lesser extent Permian formation (Nyamapfene 1991).

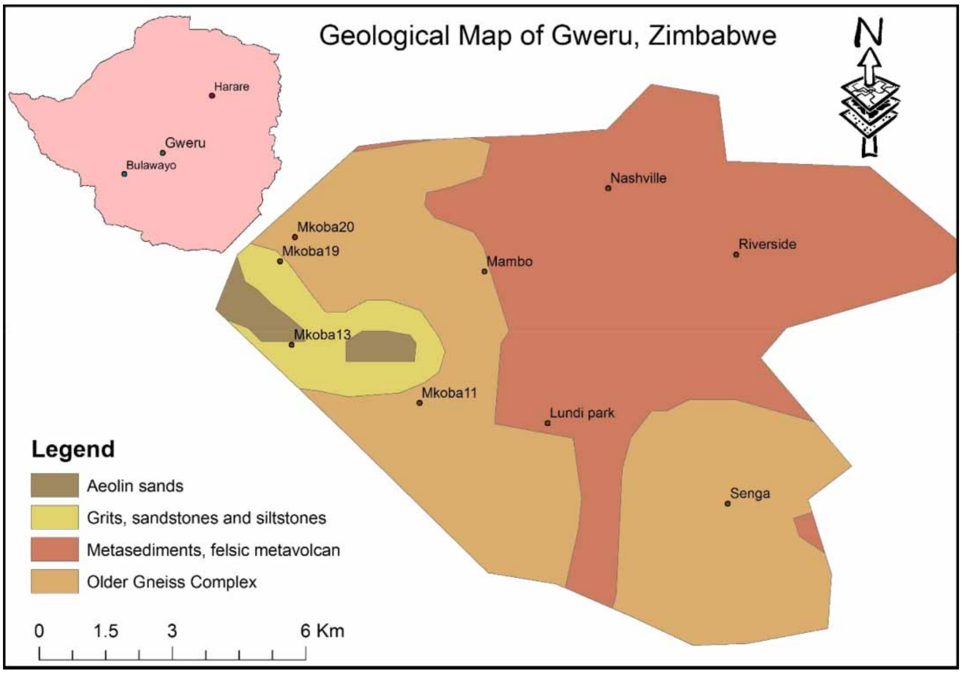

Figure 1 | Underlying rocks in different sampling locations.

Population

The city of Gweru, like most of the cities in Zimbabwe, is experiencing rapid increases in population (Table 1); the population growth rate for 2002–2012 was 1.0 (ZimStat 2012). The population is housed in around 41,149 households in low, medium and high density residential areas. The population increase has surpassed the capacity of potable and wastewater treatment plants.

Table 1 | Population increases for Gweru city and other major cities of Zimbabwe

	Population in census years			
City	**1982**	**1992**	**2002**	**2012**
Harare	656,011	1,189,103	1,435,784	1,468,767
Bulawayo	413,814	621,742	676,650	655,675
Mutare	69,621	131,367	170,466	188,245
Gweru	**78,918**	**128,037**	**140,806**	**158,233**
Masvingo	30,523	51,743	69,490	88,554

Source: ZimStat (2012).

Water reticulation system

Potable water in the city is supplied from three dams: Gwenoro (31.4×10^6 m^3), White Waters (4.9×10^6 m^3) and Amapongokwe (37.6×10^6 m^3). Gwenhoro dam used to supply 93% of the city's water demand in 2002 and the supply capacity reduced by 10% in 2012. This is attributed to the change in catchment land uses, reduced rainfall amounts and increased groundwater abstraction in the upstream of the catchment including the city. There has been a decrease in the peak water levels in Gwenhoro dam (Table 2) which resulted in the decommissioning of the dam in October 2013. This further worsened the water scarcity situation and residents resorted to ground water for portable water. The city also tried to implement water rationing to cope with increasing demand and diminishing supply.

Table 2 | Peak water levels for Gwenhoro and Whitewaters dams (2001–2013)

	Percentage full (%)												
Dam	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Gwenhoro	100	97	59	75	68	54	48	64	71	81	60	56	18
Whitewaters	100	99	61	89	97	93	92	88	96	99	100	98	97

Zimbabwe's economy has been on the downward trend for the past two decades and performance of the city's water utilities has not been spared by the economic crisis. The city failed to repair breakdowns and to acquire chemicals for water treatment. The water scarcity situation resulted in a Cholera outbreak from October 2009 and lasted into March 2010. The outbreak claimed at least at least 4,000 lives.

Ground water abstraction

In response to the 2009–2010 Cholera crisis, Non-Governmental Organisations (NGO), private property owners and the city council drilled at least 200 emergency boreholes. By the end of 2010 at least 400 public and private boreholes were serving the city residences. Each borehole in the high density suburbs services an average of 100 households and at most 20 households in the medium and low density suburbs. The boreholes were sunk to an average depth of 40 m.

METHODOLOGY

Ground water sampling and chemical analysis

A total of 324 samples were collected from 9 boreholes located in nine residential areas (Figure 2) over a period of 12 months. The water samples were collected three times a month on an 8–10 days interval. Before sampling the borehole outlet was disinfected and water from the borehole was flushed out first to minimise contamination from the pipes (Sundaram *et al.* 2010; APHA 2012). Water samples were collected in labelled (source name and date) 500 ml collecting bottles and immediately put in cooler boxes with ice for immediate transport to the laboratory for ground water quality analyses. Samples for biological parameter analysis were collected in autoclaved opaque glass bottles. Poly-ethylene bottles used in collecting samples for physical and chemical analysis were soaked in phosphate-free detergent for 24 hours before they were thoroughly rinsed with distilled water and 5% nitric acid. On the site, bottles were rinsed three times with the borehole water. All the samples were kept at approximately 4 °C prior to analysis and were analysed for total hardness, fluorides, chlorides, iron, nitrates, magnesium, manganese, calcium, sulphates, potassium, total and faecal coliforms in the National Institute of Health Research (NIHR) Water Quality Laboratory. Chemical parameters were tested for using UV-Vis photometry. Turbidity, pH and electrical conductivity (EC) were measured on site using an HI9829 waterproof portable logging multiparameter meter.

Coliform analysis

Total coliform, faecal coliforms and *E. coli* were tested for in the borehole water. The Minimal Media ONRG-MUG test was used to simultaneously detect total coliforms and *E. coli* load in sampled water. The presence and or absence of thermo-tolerant coliform (faecal coliform) populations was estimated using the Membrane Filtration Method (MF). The MF was carried out following USEPA Membrane Filtration Method 8047 (US-EPA 2012). A measured volume of water was filtered through a

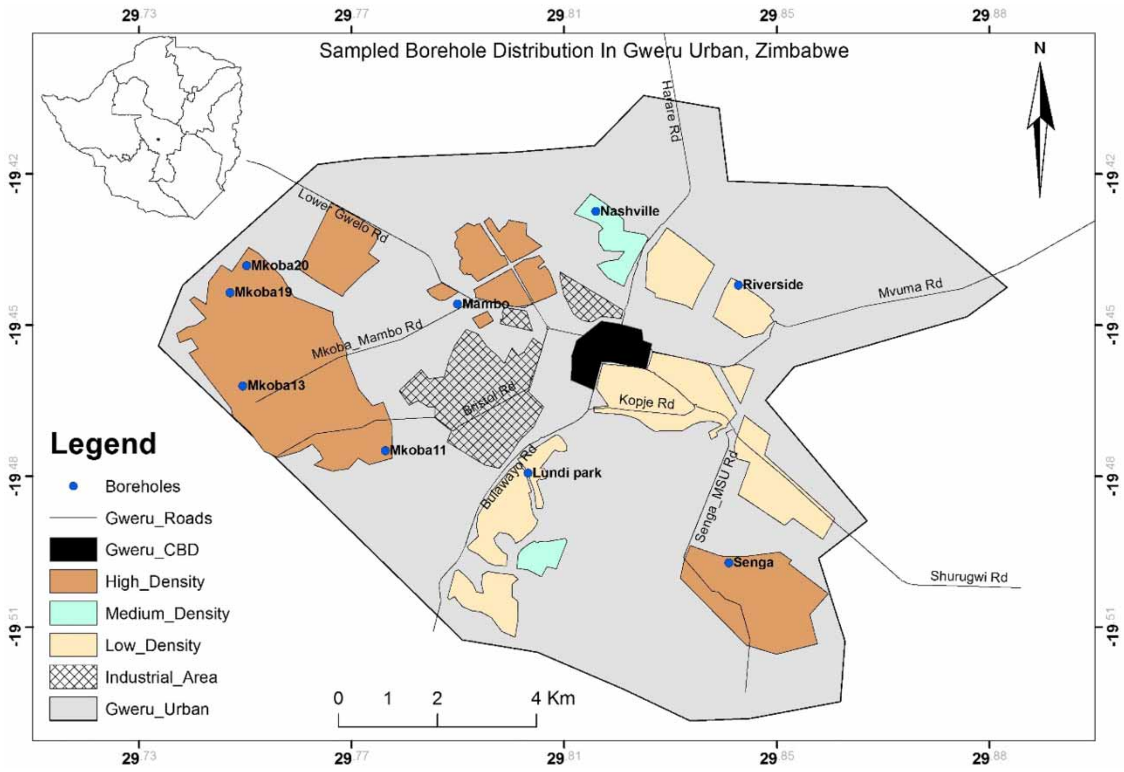

Figure 2 | Map of Gweru indicating residential areas and sampled boreholes.

membrane composed of cellulose esters. The pore size was such that the organisms to be enumerated are retained on or near the surface of the membrane, which was placed, face upwards, on differential medium selective for the indicator organism sought. Volumes were chosen so that the number of colonies to be counted on the membrane would lie between 10 and 100. Membranes were incubated for 14 hours and at 37 °C to determine total coliforms and separate membranes were incubated for 4 hours at 30 °C, and then for 14 hours at 44.5 °C. Shiny yellow colonies were counted. To calculate coliform number the following formula was used:

$$\text{Faecal Coliform Number} = \text{Coliform colonies counted}\,\text{ml}^{-1} \times 100 \tag{1}$$

Correlation between water quality parameters

A Pearson correlation test together with a two tailed significance test ($p = 0.05$) was carried out between water parameters. This was done to give preliminary options for ground water treatment and link the source and behaviour of the tested water parameters.

RESULTS

Turbidity, pH, electrical conductivity and total hardness

Turbidity values ranged from 0.013NTUs to 4.44NTUs. The highest turbidity value (4.44 NTUs) was recorded in Riverside residential area with the lowest (0.013 NTUs) recorded in Mkoba 11; a high density residential area. Borehole water pH ranged from 6.67 to 7.46 (Table 3). The lowest pH value was recorded in Mkoba 20 and the highest in Lundi Park residential area.

Table 3 | Summary of ground water physical parameters measured in Gweru urban district

Location of Borehole	pH	Mean ± SD	Turbidity (NTUs)	Mean ± SD	Conductivity (μScm^{-1})	Mean ± SD	Total hardness (mgl^{-1})	Mean ± SD
Senga	7.46	7.46 ± 0.32	0.097	0.097 ± 0.001	209	209 ± 91	575	575 ± 155
Mambo	7.11	7.11 ± 0.11	1.250	1.25 ± 0.1	336	336 ± 103	381	381 ± 87
Mkoba 13	6.99	6.99 ± 0.23	0.647	0.647 ± 0.03	249	249 ± 97	325	325 ± 77
Mkoba 19	6.67	6.67 ± 0.28	2.017	2.017 ± 0.4	116	116 ± 23	222	222 ± 38
Mkoba 20	7.06	7.06 ± 0.08	2.283	2.283 ± 0.03	152	152 ± 19	228	228 ± 56
Mkoba 11	7.61	7.61 ± 0.41	0.013	0.013 ± 0.002	64.3	64.3 ± 0.9	106	106 ± 14
Lundi Park	7.00	7 ± 0.13	0.043	0.043 ± 0.01	268	268 ± 88	261	261 ± 63
Nashville	6.84	6.84 ± 0.26	0.040	0.04 ± 0.004	218	218 ± 72	498	498 ± 146
Riverside	7.21	7.21 ± 0.28	4.440	4.44 ± 0.77	56.6	56.6 ± 13	114	114 ± 33
WHO limits	6.5–9.2		5		1,380		200	

EC ranged from 56 to 336 μS cm^{-1}. The maximum and minimum EC values were recorded in Mambo (336 μS cm^{-1}) and Riverside (56.6 μS cm^{-1}), respectively. Total hardness ranged from 106 to 575 mgl^{-1}. Borehole water in Mkoba 11 and Riverside was classified as moderately hard (75–150 mg l^{-1}), while in Mkoba 19, 20 and Lundi Park was found to be hard water with total hardness ranges of 150–300 mg l^{-1} and very hard water was found in Senga, Mambo, Mkoba 13 and Nashville boreholes (Table 4). Only 22% of the boreholes were within the WHO limit of water hardness. All the boreholes had water turbidity, pH and EC values within the WHO acceptable range.

Chemical parameters

Manganese, Sulphates, Potassium, Fluorides, Chlorides, calcium and Magnesium concentrations in all borehole locations were within the WHO limits. Only Iron concentrations were out of the recommended WHO limit in Mambo, Mkoba 20, Mkoba 19, Senga and Mkoba 13. Nitrates concentration ranged between 1.85 and 11 mg l^{-1} the WHO limits were surpassed in Mkoba 13 (Table 5).

Biological parameters

Total coliform load ranged from 14 CFU 100 ml^{-1} to 167 CFU 100 ml^{-1} and *E. coli* load ranged from 0 to 23 CFU 100 ml^{-1}. The highest faecal coliform load of 80 CFU 100 ml^{-1} was recorded in Riverside and no *E. coli* was recorded in Nashville (Table 7). The risk posed by faecal coliform load in borehole water was low in 56% of the boreholes. Thirty-three percent of the boreholes were on intermediate risk and only 1 borehole (11%) was at no risk (Table 6). A substantial 67% of the boreholes were not conforming to the WHO standards of 0 *E. coli* in potable water.

Correlations between ground water parameters

Total hardness had a strong and significant correlation with turbidity, Calcium, Chlorides, Magnesium and conductivity (Table 8). Conductivity was significantly correlated to Fluoride, Calcium and magnesium. Chlorides were significantly correlated to Fluorides ($r = 0.68$), Iron was correlated to Calcium and Chlorides, Nitrates were significantly correlated to Sulphates ($r = 0.78$).

DISCUSSION

Total water hardness above recommended limits is stated as a major etiological factor causing cardiovascular disorders, diabetes, reproductive failure, neural diseases, and renal dysfunction (Subba Rao 2006; Sengupta 2013). In Gweru, seventy-eight percent of surveyed boreholes had hard or very hard water which is a health risk to the consumers. In addition, hard water use in bathing and washing requires higher volumes of soap to lather compared to soft water (World Health Organization 2011). The source of water hardness are naturally occurring rocks, felsites and porphyries; rich in magnesium, calcium, sodium and potassium. The metal ions Mg^{2+} and Ca^{2+} weathered from the rocks are responsible for water hardness. The ions concentrations were significantly high and correlated to water hardness (Table 8). These findings reinstate the notion that of the 1 in 8 people who lack safe drinking water a substantial percentage consume hard water (WHO & UNICEF 2012).

Table 4 | Ground water total hardness classes in Gweru City

Total hardness	Class	Borehole Location
0–75	Soft	None
75–150	Moderately hard	Mkoba11, Riverside
150–300	Hard	Mkoba19, 20 and Lundi Park
>300	Very hard	Senga, Mambo, Mkoba 13 and Nashville

To reduce the risk associated with hard water, users should consider boiling the water as a primary precaution to get rid of temporary hardness. For secondary treatment options, there is need to further understand the nature of hardness; whether it is temporary or permanent hardness.

The iron guidelines provided for by WHO are not based on the health risk but on the aesthetics of drinking water. Higher concentrations, as recorded in 56% of the sampled boreholes, are responsible for bad taste, discolouring of water, bad smell, corrosivity (World Health Organization 2011). High concentrations of Iron could be related to the geomorphology and geology of the area; felsites rocks rich in iron especially the mafic rocks which can be fine grained thus high solubility and concentrations in ground water. Although there are high concentrations of iron in the drinking water the pH level recorded is relatively high (Table 3), suggestive of the presence of the non-ferrous form ($Fe3^{+}$). Non-ferrous form is not bioavailable and is not easily absorbed in the gastrointestinal (GI) tract (Hallberg & Hulthén 2000; Hurrell & Egli 2010; Merrill *et al.* 2010; Merrill *et al.* 2012). However, low absorbance is not a cushion to the unknown effects of high iron concentrations because there is a potion that will be added by the dietary food, increasing the daily intake of Iron. In addition, once the non-ferrous form is in the acidic digestive system it can be reduced to the ferrous iron (Aster 2007).

The city council should consider reducing the iron concentrations using the following methods: First, an inexpensive biosand filtration at house hold or at borehole catchment level; this method is reported by Karakochuk *et al.* (2015) and Murphy *et al.* (2010) to successfully remove 98–99% and 99% of iron from groundwater, respectively. Second, water storage prior to use, that is, giving water settling time so as to increase likelihood of Fe^{2+} conversion to Fe^{3+} (Murphy *et al.* 2010).

Nitrates concentrations higher than the recommended limits cause infant methemoglobinemia (Bruning-Fann & Kaneene 1993). Only one borehole did not conform to the WHO limits and is located in one of the oldest high density suburbs in the city. Sewer leakages in the area is likely to be responsible for high nitrates levels recorded. The sewer system has outlived its design lifespan and is servicing more people than its design capacity. The borehole water is susceptible to nitrate loads associated with underground and aboveground seepage of waste water into the ground water.

Table 5 | Summary of ground water chemical parameters

(a)

Borehole Location	Manganese (mg l^{-1})	Mean ± SD	Iron (mg l^{-1})	Mean ± SD	Nitrates (mg l^{-1})	Mean ± SD	Sulphates (mg l^{-1})	Mean ± SD
Senga	0.03	0.03 ± 0.001	0.65	0.65 ± 0.25	4.17	4.17 ± 2.3	2.32	2.32 ± 0.3
Mambo	0.02	0.02 ± 0.001	0.77	0.77 ± 0.32	1.85	1.85 ± 0.63	4.37	4.37 ± 0.8
Mkoba 13	0.00	0.00 ± 0.000	0.61	0.61 ± 0.13	11.00	11.0 ± 3.6	19.33	19.33 ± 3.9
Mkoba 19	0.01	0.01 ± 0.0001	0.41	0.41 ± 0.11	7.04	7.04 ± 2.9	1.33	1.33 ± 0.12
Mkoba 20	0.00	–	0.54	0.54 ± 0.13	2.53	2.53 ± 0.8	0.03	0.03 ± 0.01
Mkoba 11	0.00	–	0.14	0.14 ± 0.03	2.54	2.54 ± 0.93	0.33	0.33 ± 0.03
Lundi Park	0.03	0.03 ± 0.002	0.27	0.27 ± 0.02	2.97	2.97 ± 0.89	3.00	3.00 ± 0.34
Nashville	0.00	–	0.00	–	4.54	4.54 ± 1.64	0.00	–
Riverside	0.00	–	0.17	0.17 ± 0.01	2.05	2.05 ± 0.77	0.02	0.02 ± 0.01
WHO limit	0.1		0.3		10		400	

(b)

Borehole Location	Potassium (mg l^{-1})	Mean ± SD	Fluorides (mg l^{-1})	Mean ± SD	Chlorides (mg l^{-1})	Mean ± SD	Calcium (mg l^{-1})	Mean ± SD	Magnesium (mg l^{-1})	Mean ± SD
Senga	2.47	2.47 ± 0.81	0.21	0.21 ± 0.08	0.44	0.44 ± 0.13	151	151 ± 23	41.00	41.00 ± 8.2
Mambo	1.53	1.53 ± 0.33	1.42	1.42 ± 0.39	2.30	2.30 ± 0.73	171	171 ± 53	31.33	31.33 ± 13
Mkoba 13	1.80	1.80 ± 0.26	0.35	0.35 ± 0.11	1.32	1.32 ± 0.38	131	131 ± 18	15.00	15.00 ± 5.8
Mkoba 19	3.00	3.00 ± 0.43	0.20	0.20 ± 0.13	1.76	1.76 ± 0.68	128	128 ± 36	17.00	17.00 ± 10
Mkoba 20	2.45	2.45 ± 0.75	0.13	0.13 ± 0.09	0.29	0.29 ± 0.18	108	108 ± 27	15.67	15.67 ± 5.4
Mkoba 11	2.14	2.14 ± 0.18	0.20	0.20 ± 0.15	0.79	0.79 ± 0.29	25	25 ± 13	9.33	9.33 ± 4.31
Lundi Park	4.10	4.10 ± 0.83	0.55	0.55 ± 0.21	0.50	0.50 ± 0.17	129	129 ± 19	20.33	20.33 ± 11
Nashville	1.77	1.77 ± 0.11	0.29	0.29 ± 0.10	0.22	0.22 ± 0.09	133	133 ± 42	42.33	42.33 ± 14
Riverside	1.85	1.85 ± 0.34	0.27	0.27 ± 0.18	0.10	0.10 ± 0.02	35	35 ± 12	12.67	12.67 ± 3.6
WHO limit	–		1.5		250		200		150	

Table 6 | Water quality risk assessment for faecal coliform load

Faecal coliform load	Risk Ranking	Location of Boreholes	Proportion of Boreholes (%)
0	No risk	Nashvile	11
1–10	Low	Mambo, Mkoba 13, Mkoba 19, Mkoba 11, Lundi Park	56
10–100	Intermediate	Senga, Mkoba 20, Riverside	33
100–1,000	High	None	0
>1,000	Very high	None	0

Table 7 | Total coliform, faecal coliform and *E. coli* load in borehole water

Borehole Location	Total coliform load (CFU 100 ml$^{-1)}$	Faecal coliform load (CFU 100 ml^{-1})	*E-coli* load (CFU 100 ml^{-1})
Senga	88	73	8
Mambo	34	10	2
Mkoba 13	16	7	6
Mkoba 19	14	9	3
Mkoba 20	81	68	14
Mkoba 11	14	10	0
Lundi Park	24	4	0
Nashville	15	0	0
Riverside	167	80	23

In addition, complex interactions of aquifers and groundwater movement may be responsible for import of nitrates from agricultural lands in neighbouring areas (Wakida & Lerner 2005). For example, Mkoba 13 is surrounded by areas under intensive urban agriculture. The residence practice rain fed agriculture on open stands that are yet to be built on or areas left for strategic reasons by the municipality. The average area under agriculture per urban farmer is 0.5 ha (Rakodi 1995). Of the urban farmers in surrounding areas, 65% are reported to over apply fertilisers to maximise yields (Sammie *et al.* 2014).

The fluoride concentrations in all the sampled boreholes were within the WHO limits. However, the concentrations were below 0.5 mgl^{-1} which is reportedly the minimum required to protect people from dental problems (Ozsvath 2009). Generally, intake of 0.5–1.0 mgl^{-1} is considered beneficial to human health; in the production and maintenance of health bones (Ayoob & Gupta 2006; Chilton *et al.* 2006; Mohapatra *et al.* 2009). In South Africa, the South Africa Dental Association recommends consumption of water with fluoride concentration in the range of 0.7–1.5 mgl^{-1} to reduce level of tooth decay (SADA 2014). Concentrations of <0.5 mgl^{-1} increases the risk of dental caries (Ozsvath 2009). In Gweru urban, only 22% of the boreholes had fluoride concentrations above the lower safe limit. This is risky given that Zimbabwe like other African countries has not set low and high empirically tested threshold levels on which the extremes of fluoride concentrations can be a problem or cause dental fluorosis (NRC 2006).

Ground water, in most cases, contains high concentrations of fluoride which causes dental and skeletal fluorosis with such cases recorded in China (Guo *et al.* 2007; Gao *et al.* 2013), Sri Lanka and Ethiopia (Rango *et al.* 2012) among others. In this study, the low concentration of fluorides can be attributed to two factors. First, the neutral to alkaline pH of the water which prevent dissolution of fluorides (Subba Rao 2006). Second, high calcium content which may lead to formation of CaF_2 (Subba Rao & John Devadas 2003). This is supported by the significant correlation between calcium and fluoride ($p = 0.015$).

Table 8 | Correlation between measured borehole water parameters

Correlations		Mn	pH	Con	TotHar	K	Fl	Cl	Ca	Fe	SO_4	Mg	NO_3	TC	FC	Turbidity
Manganese	Pearson Correlation	1														
	Sig. (2-tailed)															
pH	Pearson Correlation	−0.005	1													
	Sig. (2-tailed)	0.981														
Conductivity	Pearson Correlation	0.342	−0.241	1												
	Sig. (2-tailed)	0.081	0.226													
Total hardness	Pearson Correlation	0.269	−0.086	0.642	1											
	Sig. (2-tailed)	0.175	0.668	0.000												
Potassium	Pearson Correlation	0.377	−0.232	0.023	−0.149	1										
	Sig. (2-tailed)	0.052	0.245	0.911	0.459											
Fluoride	Pearson Correlation	0.206	−0.059	0.708	0.192	−0.194	1									
	Sig. (2-tailed)	0.302	0.770	0.000	0.337	0.333										
Chloride	Pearson Correlation	0.122	−0.234	0.425	0.029	−0.160	0.653	1								
	Sig. (2-tailed)	0.546	0.241	0.027	0.887	0.427	0.000									
Calcium	Pearson Correlation	0.347	−0.436	0.824	0.731	0.091	0.464	0.425	1							
	Sig. (2-tailed)	0.076	0.023	0.000	0.000	0.652	0.015	0.027								
Iron	Pearson Correlation	0.292	0.004	0.525	0.327	−0.093	0.452	0.572	0.589	1						
	Sig. (2-tailed)	0.140	0.986	0.005	0.096	0.644	0.018	0.002	0.001							
Sulphate	Pearson Correlation	−0.006	−0.134	0.436	0.143	−0.177	0.159	0.371	0.302	0.437	1					
	Sig. (2-tailed)	0.977	0.504	0.023	0.477	0.377	0.430	0.057	0.126	0.023						
Magnesium	Pearson Correlation	0.252	0.106	0.579	0.864	−0.231	0.296	−0.198	0.498	0.100	−0.067	1				
	Sig. (2-tailed)	0.205	0.600	0.002	0.000	0.247	0.134	0.323	0.008	0.621	0.740					
Nitrate	Pearson Correlation	−0.106	−0.415	0.143	0.174	0.002	−0.234	0.268	0.288	0.206	0.780	−0.196	1			
	Sig. (2-tailed)	0.600	0.031	0.478	0.385	0.994	0.240	0.176	0.146	0.303	0.000	0.327				
Total coliforms	Pearson Correlation	−0.072	0.262	−0.247	−0.145	−0.318	0.090	−0.139	−0.305	0.025	−0.121	0.027	−0.317	1		
	Sig. (2-tailed)	0.721	0.186	0.214	0.472	0.106	0.655	0.488	0.121	0.903	0.547	0.895	0.107			
Faecal coliforms	Pearson Correlation	0.189	0.415	−0.161	0.147	0.034	−0.267	−0.379	0.025	0.259	−0.194	0.201	−0.259	0.362	1	
	Sig. (2-tailed)	0.346	0.031	0.423	0.465	0.866	0.179	0.052	0.901	0.193	0.333	0.314	0.192	0.063		
Turbidity	Pearson Correlation	−0.189	−0.150	−0.480	−0.518	−0.174	−0.079	−0.086	−0.371	−0.003	−0.212	−0.444	−0.197	0.682	0.160	1
	Sig. (2-tailed)	0.346	0.454	0.011	0.006	0.385	0.696	0.670	0.057	0.990	0.288	0.020	0.325	0.000	0.425	1

Presents of coliform bacteria in water is used as an indicator of the general microbial conditions of the water and sub-groups may indicate the risks associated with use of such water. The risk posed to the Gweru residents by using ground water for portable purposes ranges from low to intermediate risk (Table 6). Most research done on water quality in Africa highlights the presence of coliform bacteria Total coliform bacteria indicates 'All facultative anaerobic, gram-negative, non-spore-forming, oxidase-negative, rod-shaped bacteria that ferment lactose to acid and gas within 48 h at 35 °C or members of *Enterobacteriaceae* which are β-galactosidase positive' (APHA 2012). They are common in the environment and are not explicitly harmful. Their presence however in drinking water indicates the probable occurrence of other pathogenic microbes (Cabral & Marques 2006). Faecal coliform is a subgroup of total coliform which is a thermo-tolerant bacteria that can grow at temperatures around 42 °C (Leclerc *et al.* 2001; APHA 2012).This subgroup is important in that most of the diseases causing bacteria e.g. *vibrio cholerea* and *salmonella* are spread in water contaminated with faecal matter (Grabow 1996).

Sixty-seven percent of the boreholes indicated presents of *E. coli*, which is consistently found in faeces of human beings and other animal (Tallon *et al.* 2005). *E. coli* is a subset of the thermotolerant coliforms with the enzyme β-glucuronidase and produce indole from tryptophan (Tallon *et al.* 2005). *E. coli* presents in sampled boreholes in Gweru is associated with pollution by sewage leaking into the groundwater. In addition, residents do their laundry including children nappies within 20 meter radius of the borehole. Safe laundry infrastructure was not included in the designs for ground water supply and can be a contributing factor to *E. coli* loads in the water. Although the presence of *E. coli* indicates faecal contamination and health risk, not all strains of *E. coli* cause diseases or pose a health risk, most *E. coli* are commensal bacteria of the GI tract (Salyers & Whitt 2002).

CONCLUSION

The research advances the need to carry out ground water quality tests in urban areas as a way of minimising the health risk associated use of groundwater. It was noted that 80% of the tested water quality parameters were within WHO guidelines for drinking water. Only Iron, nitrates, total hardness and *E. coli* load were above recommended limits set by WHO. Unless treated, it is very risky and not recommended for residents in Senga, Mkoba 20, Mambo, Mkoba 19, Riverside and Mkoba 13 to use borehole water for potable uses. It is therefore recommended that the city or households chlorinates the borehole water to reduce the health risk associated with *E. coli*. There exist strong and significant correlations between some water quality parameters, however, there are other parameters that were significantly correlated but with a weak correlation which suggest the possibility of their correlations to be strong if the analysis was carried out on short time/seasonal intervals.

Future research need to focus on heavy metal concentrations, temporal variability of ground water quality and seasonal correlations of water quality parameters.

REFERENCES

Addiscott, T. M. 1996 Fertilizers and nitrate leaching. *Issues in Environmental Science Technology* **5**, 1–26.

Addiscott, T. M. 2005 Nitrate in Fresh Water and Nitrous Oxide in the Atmosphere. In: *Nitrate, Agriculture and Environment* (pp. 110–126).

Addiscott, T. M. & Benjamin, N. 2004 Nitrate and human health. *Soil Use and Management* **20** (2), 98–104. http://doi.org/10.1111/j.1475-2743.2004.tb00344.x.

Almasri, M. N. 2007 Nitrate contamination of groundwater: a conceptual management framework. *Environmental Impact Assessment Review* **27** (3), 220–242. http://doi.org/10.1016/j.eiar.2006.11.002.

APHA 2012 *Standard Methods for the Examination of Water and Wastewater*. *American Water Works Association/American Public Works Association/Water Environment Federation*.

Aster, J. C. 2007 The hematopoietic and lympoid system. In: *Robbins Basic Pathology*, 8th edn. (Kumar, V., Abbas, A. K., Fausto, A. & Mitchell, R., eds). Sauders Elsevier, Philadelphia.

Ayoob, S. & Gupta, A. K. 2006 *Fluoride in Drinking Water: A Review on the Status and Stress Effects*. *Critical Reviews in Environmental Science and Technology* (Vol. 36). http://doi.org/10.1080/10643380600678112.

Bain, R., Gundry, S., Wright, J., Yang, H., Pedley, S. & Bartram, J. 2012 Accounting for water quality in monitoring access to safe drinking-water as part of the Millennium Development Goals: lessons from five countries. *Bulletin of the World Health Organization*. **90**, 228A–235A. http://doi.org/10.2471/BLT.11.094284.

Bruning-Fann, C. S. & Kaneene, J. B. 1993 The effects of nitrate, nitrite and N-nitroso compounds on human health: a review. *Veterinary and Human Toxicology* **35** (6), 521–538.

Cabral, J. P. & Marques, C. 2006 Faecal coliform bacteria in Febros River (northwest Portugal): temporal variation, correlation with water parameters, and species identification. *Environmental Monitoring and Assessment* **118** (1–3), 21–36. http://doi.org/10.1007/s10661-006-0771-8.

Chilton, J., Dahi, E., Lennon, M. & Jackson, P. 2006 *Fluoride in Drinking-water*. *World Health* (Vol. 408). http://doi.org/10.1007/BF01783490.

Coulter, C. B., Kolka, R. K. & Thompson, J. A. 2004 Water quality in agricultural, urban, and mixed land use watersheds[1]. *Journal of the American Water Resources Association* **40** (6), 1593–1601. http://doi.org/10.1111/j.1752-1688.2004.tb01608.x.

Foster, S., Hirata, R., Misra, S. & Garduno, H. 2010 Urban Groundwater Use Policy-Balancing the Benefits and Risks in Developing Nations. *GW-MATE Strategic Overview Series*. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Urban+Groundwater+Use+Policy+balancing+the+benefits+and+risks+in+developing+nations#1.

Gao, X. B., Zhang, F. C., Wang, C. & Wang, Y. X. 2013 "Coexistence of High Fluoride Fresh and Saline Groundwaters in the Yuncheng Basin, Northern China." *Procedia Earth and Planetary Science* **7**, 280–83. doi:10.1016/j.proeps.2013.03.052.

Gleick, P. H. 2003 The human right to water. *Water Nepal*. **9-10** (1–2), 115–149. http://doi.org/10.3126/wn.v10i1.97.

Grabow, W. O. K. 1996 Waterborne diseases: Update on water quality assessment and control. *Water SA* **22** (2), 193–202.

Guo, Q., Yanxin, W., Teng, M. & Rui, M. 2007 Geochemical Processes Controlling the Elevated Fluoride Concentrations in Groundwaters of the Taiyuan Basin, Northern China. *Journal of Geochemical Exploration* **93** (1), 1–12. doi:10.1016/j.gexplo.2006.07.001.

Hallberg, L. & Hulthén, L. 2000 Prediction of dietary iron absorption: an algorithm for calculating absorption and bioavailability of dietary iron. *The American Journal of Clinical Nutrition* **71** (5), 1147–1160. Retrieved from http://ajcn.nutrition.org/content/71/5/1147.long.

Hurrell, R. & Egli, I. 2010 Iron bioavailability and dietary reference values 1–4. *The American Journal of Clinical Nutrition* **91** (Suppl.), 1461s–1467s. http://doi.org/10.3945/ajcn.2010.28674F.Am.

Jarup, L. 2003 Hazards of heavy metal contamination. *British Medical Bulletin* **68** (1), 167–182. http://doi.org/10.1093/bmb/ldg032.

Karakochuk, C. D., Murphy, H. M., Whitfield, K. C., Barr, S. I., Vercauteren, S. M., Talukder, A., Porter, K., Kroeun, H., Eath, M., McLean, J. & Green, T. J. 2015 Elevated levels of iron in groundwater in Prey Veng province in Cambodia: a possible factor contributing to high iron stores in women. *Journal of Water and Health* **13** (2), 575–586. http://doi.org/10.2166/wh.2014.297.

Leclerc, H., Mossel, D. A., Edberg, S. C. & Struijk, C. B. 2001 Advances in the bacteriology of the coliform group: their suitability as markers of microbial water safety. *Annual Review of Microbiology* **55**, 201–234. http://doi.org/10.1146/annurev.micro.55.1.201.

Lerner, D. N. & Harris, B. 2009 The relationship between land use and groundwater resources and quality. *Land Use Policy* **26** (SUPPL. 1). S265–S273. http://doi.org/10.1016/j.landusepol.2009.09.005.

Margat, J. & van der Gun, J. 2013 *Groundwater around the World : A Geographic Synopsis*. *CRC Press/Balkema*.

Merrill, R. D., Labrique, A. B., Shamim, A. A., Schulze, K., Christian, P., Merrill, R. K. & West Jr., K. P. 2010 Elevated and variable groundwater iron in rural northwestern Bangladesh. *Journal of Water and Health* **8** (4), 818–825. http://doi.org/10.2166/wh.2010.144.

Merrill, R. D., Shamim, A. A., Ali, H., Jahan, N., Labrique, A. B., Christian, P. & West, K. P. J. 2012 Groundwater iron assessment and consumption by women in rural northwestern Bangladesh. *International Journal for Vitamin and Nutrition Research. Internationale Zeitschrift Fur Vitamin- Und Ernahrungsforschung. Journal International de Vitaminologie et de Nutrition* **82** (1), 5–14. http://doi.org/10.1024/0300-9831/a000089.

Mohapatra, M., Anand, S., Mishra, B. K., Giles, D. E. & Singh, P. 2009 Review of fluoride removal from drinking water. *Journal of Environmental Management* **91** (1), 67–77. http://doi.org/10.1016/j.jenvman.2009.08.015.

Mugandani, R., Wuta, M., Makarau, A., Chipindu, B., Gweru, S. R. & Pleasant, M. 2012 Re-classification of the agro-ecological regions of Zimbabwe in conformity with climate variability and change. *African Crop Science Journal* **20** (S2), 361–369.

Murphy, H. M., McBean, E. A. & Farahbakhsh, K. 2010 A critical evaluation of two point-of-use water treatment technologies: can they provide water that meets WHO drinking water guidelines? *Journal of Water and Health* **8** (4), 611–630. http://doi.org/10.2166/wh.2010.156.

NRC 2006 Fluoride in drink water: a scientific review of EPA's standards. *The National Academies Press* **531**. 85–106. Retrieved from http://www.actionpa.org/fluoride/nrc/NRC-2006.pdf.

Nyamapfene, K. W. 1991 *The Soils of Zimbabwe*. Harare: Nehanda Publishers. Retrieved from http://books.google.com.et/books/about/The_Soils_of_Zimbabwe.html?id=AO1HAAAAYAAJ&pgis=1.

Onda, K., LoBuglio, J. & Bartram, J. 2012 Global access to safe water: accounting for water quality and the resulting impact on MDG progress. *International Journal of Environmental Research and Public Health*. **9** (3), 880–894. http://doi.org/10.3390/ijerph9030880.

Ozsvath, D. L. 2009 Fluoride and environmental health: a review. *Reviews in Environmental Science and Biotechnology* **8** (1), 59–79. http://doi.org/10.1007/s11157-008-9136-9.

Pionke, H. B. & Urban, J. B. 1985 Effect of agricultural land use on ground-water quality in a small Pennsylvania watershed. *Ground Water* **23** (1), 68–80. http://doi.org/10.1111/j.1745-6584.1985.tb02781.x.

Rakodi, C. 1995 The household strategies of the urban poor: coping with poverty and recession in Gweru, Zimbabwe. *Habitat International* **19** (4), 447–471. http://doi.org/10.1016/0197-3975(95)00039-I.

Rango, T., Kravchenko, J., Atlaw, B., McCornick, P. G., Jeuland, M., Merola, B. & Vengosh, A. 2012 Groundwater quality and its health impact: an assessment of dental fluorosis in rural inhabitants of the Main Ethiopian Rift. *Environment International* **43** (1), 37–47. http://doi.org/10.1016/j.envint.2012.03.002.

Rao, S. V. N., Bhallamudi, S. M., Thandaveswara, B. S. & Mishra, G. C. 2004 Conjunctive use of surface and groundwater for coastal and deltaic systems. *Journal of Water Resources Planning and Management*. **130** (3), 255–267. http://doi.org/10.1061/(ASCE)0733-9496(2004).

SADA 2014 SADA Endorses fluoridation. *South African Dental Journal* **69** (1), 4.

Salyers, A. A. & Whitt, D. D. 2002 *Bacterial Pathogenesis: A Molecular Approach*, 2nd edn. ASM Press, Washington, DC.

Sammie, B., Chitata, T., Chagonda, I., Zirebwa, F. & Gwazane, M. 2014 Dynamics of maize production practices in urban open field agriculture in Zimbabwe. *International Journal of Agronomy and Agricultural Research* **5** (2), 164–170.

Schot, P. P. & Pieber, S. M. 2012 Spatial and temporal variations in shallow wetland groundwater quality. *Journal of Hydrology*, **422–423**, 43–52. http://doi.org/10.1016/j.jhydrol.2011.12.023.

Sengupta, P. 2013 Potential Health Impacts of Hard Water. *International Journal of Preventive Medicine* **4** (8), 866–875.

Sorenson, S. B., Morssink, C. & Campos, P. A. 2011 Safe access to safe water in low income countries: water fetching in current times. *Social Science and Medicine* **72**, 1522–1526. http://doi.org/10.1016/j.socscimed.2011.03.010.

Subba Rao, N. 2006 Seasonal variation of groundwater quality in a part of Guntur District, Andhra Pradesh, India. *Environmental Geology* **49** (3), 413–429. http://doi.org/10.1007/s00254-005-0089-9.

Subba Rao, N. & John Devadas, D. 2003 Fluoride incidence in groundwater in an area of Peninsular India. *Environmental Geology* **45** (2), 243–251. http://doi.org/10.1007/s00254-003-0873-3.

Sundaram, B., Feitz, J. A., Caritat, D. P., APlazinska, A., Brodie, S. R., Coram, J., Ransley, T. & Geosicence Australia 2010 *Groundweater Sampling and Analysis-A Field Guide*.

Tallon, P., Magajna, B., Lofranco, C. & Kam, T. L. 2005 Microbial indicators of faecal contamination in water: a current perspective. *Water, Air, and Soil Pollution* **166** (1–4), 139–166. http://doi.org/10.1007/s11270-005-7905-4.

US-EPA 2012 *Coliforms – Total, Fecal and E-Coli (No. DOC316.53.001224). Filtration*. USA.

Van Der Hoven, S. J., Solomon, D. K. & Moline, G. R. 2005 Natural spatial and temporal variations in groundwater chemistry in fractured, sedimentary rocks: Scale and implications for solute transport. *Applied Geochemistry* **20** (5), 861–873. http://doi.org/10.1016/j.apgeochem.2004.11.013.

Vincent, V. & Thomas, R. G. 1960 *An Agricultural Survey of Southern Rhodesia: Part I: Agro-ecological Survey*. Government Printers, Salisbury.

Wakida, F. T. & Lerner, D. N. 2005 Non-agricultural sources of groundwater nitrate: a review and case study. *Water Research*. **39** (1), 3–16. http://doi.org/10.1016/j.watres.2004.07.026.

World Health Organization 2011 Hardness in Drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality. *World Health Organization*.

WHO and UNICEF 2012 *Progress on drinking water and sanitation, 2012 update. Update*. Retrieved from http://www.wssinfo.org/fileadmin/user_upload/resources/JMP-report-2012-en.pdf.

WHO and UNICEF 2014 *Progress on sanitation and drinking-water - 2014 update. … Monitoring Programme for water supply and sanitation*…. http://doi.org/978.92.4.150724.0.

ZimStat 2012. Zimbabwe National Census 2012 Report, Government of Zimbabwe, Harare. http://www.zimstat.co.zw/sites/default/files/img/National_Report.pdf.