UNIVERSITY OF ZIMBABWE

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ASSESSMENT OF THE IMPACT OF PIT LATRINES ON GROUNDWATER CONTAMINATION IN HOPLEY SETTLEMENT, HARARE, ZIMBABWE

BY

ALFONSE TAPERA NDOZIYA

M.SC. THESIS IN IWRM

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ALFONSE TAPERA NDOZIYA

MASTER OF SCIENCE THESIS IN INTEGRATED WATER RESOURCES MANAGEMENT

A thesis submitted in partial fulfilment of the requirements for the Master of Science Degree in Integrated Water Resources Management at the University of Zimbabwe

SUPERVISORS: Eng. Z. Hoko

Mr. W. Gumindoga

SEPTEMBER 2015

DECLARATION

I, Alfonse Tapera Ndoziya, declare that this research report is my own work. It is submitted for the Master of Science Degree in Integrated Water Resources Management (IWRM) at the University of Zimbabwe. It has not been submitted before for any other degree of examination at any other University. The findings, interpretations and conclusions expressed in this study neither reflect the views of the University of Zimbabwe, Department of Civil Engineering nor those of the individual members of the MSc Examination Committee, nor of their respective employers.

Signature: ___________________________________

Date: ________________

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LIST OF ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
AWWA	American Water Works Association
DN	Digital Numbers
DOSI	Diffuse Optical Spectroscopy and Imaging
EPA	Environmental Protection Agency
GWP	Global Water Partnership
IWRM	Integrated Water Resources Management
NWP	National Water Policy
QGIS	Quantum Geographical Information System
SAZ	Standards Association of Zimbabwe
SPSS	Statistical Package for Social Sciences
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
WHO	World Health Organization
ZESN	Zimbabwe Election Support Network

DEDICATION

To my Uncle Cosmos Chandisarewa and Aunt Winfreda Chandisarewa

ACKNOWLEDGEMENTS

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ABSTRACT

It is estimated that proximately 1.77 billion people around the world use some form of pit latrines as their primary means of sanitation. Most countries in sub-Saharan Africa failed to meet the Millennium Development Goals (MDG) target of improved sanitation by 2015. Only 66% of the world's population has access to improved sanitation far below the MDG target of 75% by year 2015. Hopley is a settlement in Harare that was established in 2005 and had an estimated population of 15 000 by 2012. Due to many reasons the responsible local authority (City of Harare) has failed to cope with Hopley's infrastructural development needs including that for water and sanitation. As a result many developments including Hopley Settlement have been occupied without adequate water and sanitation infrastructure. Many of the residence have resorted to shallow underground water mainly from wells and a few boreholes. Poor water and sanitation status is believed to have resulted in the 2008-2009 cholera outbreaks in Zimbabwe, which resulted in 4300 deaths. Therefore, this study sought to assess the impact of pit latrines on groundwater quality in Hopley Settlement. A supervised landuse classification of Landsat images was performed to determine landuse changes and pit latrine density in Hopley Settlement using Geographical Information Techniques (GIS) techniques. Grab sampling was performed for groundwater source quality during the period of February to April 2015 in four sampling campaigns from 11 sampling sites comprising of 3 boreholes and 8 wells. The parameters that were studied included Electrical Conductivity (EC), pH, turbidity, nitrates, chlorides, ammonia, Dissolved Oxygen (DO) and Faecal Coliforms (FC). Student t-test was performed using groundwater quality data of 44 groundwater samples from 11 sampling locations in Statistical Package for Social Sciences (SPSS) software (v 16) to determine groundwater suitability for drinking by comparing mean values of analysed groundwater parameters with guidelines/standards to check if there was any significant difference. The Inverse Distance Weighting (IDW) technique was used in a GIS environment to estimate the spatial distribution of the groundwater contaminants in the environment. Five disturbed soil samples in the vicinity of pit latrines and groundwater sources were collected at a depth of 1.5 m for permeability tests. Out of the 4 km^2 forming the study area, there was a 250 % growth in built up area from 1 km^2 in year 2000 to 3.5 km^2 in the year 2014. FC counts in groundwater sources increased with increase in pit latrine density, while nitrates, ammonia and chlorides showed a decrease in groundwater concentration. About 250 inhabitants of Hopley Settlement occupied a space of 0.014 km^2 translating to 4286 persons/km^2. There was an increase in the strength of the relationship between pit latrine density and groundwater contamination by faecal coliforms as the radius increased from 15 m to 100 m i.e. $r(42) = 0.425$, $p < 0.01$ to $r(42) = 0.624$, $p < 0.01$. Groundwater location W1 to the north in Hopley

Settlement had the highest pit latrine density of 79 pit latrines in 100 m radius of the groundwater source. Descriptive statistics of the analysed groundwater parameters showed mean values of 6.58 (pH), 574.89 μS/cm (EC), 5.23 NTU (turbidity), 3.70 mg/L (DO), 80.38 mg/L (nitrates), 0.54 mg/L (ammonia), 90.40 mg/L (chlorides) and 81.55 cfu/100 mL sample (FC). Student t-test showed that 84%, 50%, 14%, 34%, 9%, 34%, 64% and 0% of the 44 groundwater samples had FC, nitrates, ammonia, turbidity, Electrical Conductivity (EC), pH, dissolved oxygen and chlorides respectively exceeding the World Health Organization guideline value for drinking water.. Using Principal Component Analysis, nitrates, chlorides and EC were found as principal components contributing to groundwater contamination. Groundwater source locations that had mean FC counts >100 cfu/100 mL were generally located to the north and west in Hopley Settlement (i.e. groundwater source W1, W2, W6 were 240 cfu/100 mL, 153 cfu/100 mL and 155 cfu/100 mL respectively). The soil indicated low permeability coefficient values that ranged from 2.3×10^{-6} m/s to 8.0×10^{-7} m/s. The results showed that groundwater source locations to the north and west in Hopley Settlement had FC counts >100 cfu/100 mL indicating a high chance of pathogenic contamination. Based on pathogen survival time in soil, the results generally suggested that the low soil permeability coefficients allowed for the attenuation of pathogens in soil before reaching groundwater sources. There was also a significant positive relationship between groundwater level depth from the surface and groundwater pollution i.e. $r(18) = 0.764$, $p < 0.05$ (chlorides), $r(18) = 0.831$, $p < 0.05$ (EC) and $r(18) = 0.838$, $p < 0.05$ (turbidity); while DO showed an inverse relationship, $r(18) = -0.486$, $p < 0.05$. Nitrates, pH, ammonia and FC showed no relationship with water level depth from the ground surface. Nitrate levels posed a threat to human health. Raised and lined pit latrines and other low cost technologies should be considered to minimize the potential of groundwater pollution.

Keywords: Geographical Information Systems, Groundwater quality, Hopley Settlement, Landsat, pit latrine

CHAPTER 1
INTRODUCTION

1.1 Background

Over 1.1 billion people in the world do not use water from improved drinking water sources while 2.6 billion lack basic sanitation; and by the end of 2011, there was 2.5 billion people who still did not use an improved sanitation facilities that prevent human contact with human excreta (WHO/UNICEF, 2013). According to the Swedish Water House (SWH, 2007), urbanisation is accelerating worldwide and more than 692 million people in urban areas will live without basic sanitation and 240 million without improved sources of drinking water by 2015. In developing regions, the proportion living in cities and towns has raised from 1.4 billion in 1990 to 2.5 billion in 2010 (Jacobsen *et al.*, 2012). Migration from rural to urban areas has posed a major challenge to city planners in extending basic water and sanitation services to peri-urban areas (WHO/UNICEF, 2006). Many cities in developing regions dependent upon groundwater for a significant proportion of their water supply even in areas where the piped water supply is largely derived from surface waters (Morris *et al.*, 1994). Local Authorities cannot meet the demands of water supply and sewerage of expanding settlements in urban fringes, as a result groundwater has become a major source of drinking water and pit latrines as a means of disposing human excreta (Rosa and Clasen, 2010).

However, there is concern that pit latrine discharges of chemical and microbial contaminants to groundwater may negatively affect human health (Graham and Polizzotto, 2013). Contaminates from pit latrines can leach into groundwater sources (Dzwairo *et al*., 2006). Taylor *et al.* (2004) also concluded that chemical and microbial movement of contaminates from pit latrines contaminate groundwater, thereby threatening human health. Many water borne disease outbreaks are known to have been caused by the consumption of groundwater contaminated by pathogenic microorganisms (Powell *et al.*, 2003).

Inadequate safe drinking water and poor sanitation practices negatively affects human health (Fernández *et al.*, 2011). This is evident from both widespread detection of microbial pathogens in groundwater and outbreaks of waterborne diseases that derive from the consumption of sewage contaminated groundwater (Taylor *et al*., 2004). Poor solid waste management in urban areas has also affected groundwater quality (Tsinda *et al*., 2013). Microbial contamination of groundwater can occur as a result of inadequate sanitary completion of wells and boreholes, sitting of wells too close to onsite sanitation, leaking sewers, land based disposal of sewage sludge and the presence of pit latrines in the vicinity of the groundwater sources (BGS, 2002). The largest chemical concerns from excreta disposal in onsite sanitation systems are considered to be nitrate and chloride (BGS, 2002).

It is estimated that about 70% of the people in the SADC region rely on groundwater as their only source of drinking water (IGRAC, 2013). In sub-Saharan Africa, there was an 85% increase in urban population from 1990 to 2004 and the number of urban dwellers without either safe drinking water or basic sanitation doubled from 1990 to 2004 (WHO/UNICEF, 2006). Hand-dug wells and on-site sanitation are an increasingly common coping mechanisms for peri-urban households faced with problems of accessing reliable piped water supplies and sewerage systems (Cronin *et al.*, 2007). Peri-urban areas are often characterised by heavily compromised groundwater, contaminated with excess levels of nitrate, chloride and microbial pathogens (Xu and Usher, 2006).

Harare is the capital city of Zimbabwe and has the highest proportion of Zimbabwe's population that stood at 2,098,967 people and a population density of 2 406 people per square kilometre reported in the 2012 Zimbabwe census (ZIMSTAT, 2012). Harare City is facing water and sanitation challenges as a result of rapid urban population growth especially in the peri-urban areas (ZIMSTAT, 2012; WHO/UNICEF, 2014). According to Hove and Tirimboi (2011), Harare's service delivery on water and sanitation has been declining since 2005. According to WHO/UNICEF (2011) the peak of service deterioration was manifested in a cholera epidemic which gripped many parts of the county with about 191 000 reported cases and about 4 000 reported deaths for the period 2008-2009 (Fernández *et al.*, 2011). Nhapi (2009) suggests the problems of water and sanitation have been caused by rapid population growth, inadequate rehabilitation and maintenance of water and wastewater treatment plants, expensive technologies such as trickling filters and biological nutrient removal systems, and poor institutional framework. Hopley residents rely on untreated groundwater in the form of hand dugout wells and drilled boreholes for drinking water requirements (Zingoni *et al.*, 2005). Pit latrines are a common means of disposing of human excreta in Hopley Settlement. According to the Swedish Water House (SWH) (2007) efforts to prevent death from diarrhoea related deaths or to reduce the burden of waterborne diseases such as cholera and typhoid are doomed to fail unless people have access to safe drinking water and basic sanitation. There is strong evidence that access to improved sanitation and safe drinking water can reduce diarrhoea morbidity and mortality and soil transmitted helmiths (Albonico *et al.*, 2008; Cairncross *et al.*, 2010).

1.2 Problem statement

It has been shown by previous studies undertaken that improper disposal of human waste and excreta can lead to contamination of groundwater (Haruna *et al.*, 2005). The increasing use of both pit latrines and groundwater resources in peri urban areas has raised concern that pit latrines may contaminate groundwater through impacts associated with microbial and chemical transport, thereby threatening human health through drinking contaminated groundwater (Graham and Polizzotto, 2013). Human faeces contain a large number of microbes, including bacteria, *archaea*, *microbial eukarya*, viruses, and potentially *protozoa* and *helmiths* (Ley *et al.*, 2006; Ramakrishna, 2007).

The lack of adequate sanitation is a key contributing factor to the ongoing high rates of diarrhoeal diseases noted in developing countries (Graham and Polizzotto, 2013). The use of latrines in disposing excreta might be contributing to morbidity caused by groundwater contamination. Hopley Settlement clinic in Harare recorded a 21% increase in diarrhoeal cases in the period 2013 to 2014 (City of Harare, 2015). It is therefore vital that groundwater quality is regularly monitored and that appropriate action is taken to protect groundwater resources from pit latrines to minimize public health risks.

1.3 Justification

Previous studies on impacts of pit latrines on groundwater quality have demonstrated deterioration in groundwater quality (Graham and Polizzotto, 2013). According to BGS (2002), a number of recent case studies from developing countries have been published, but these are in general insufficiently detailed to provide definitive evidence for contaminant migration and behaviour. On-site sanitation systems may result in severe contamination of groundwater which could negate the anticipated health benefits (BGS, 2002). By analyzing water samples from installed boreholes in Epworth settlement in Zimbabwe, Zingoni *et al.* (2005) demonstrated that the highest nitrate concentrations in groundwater (20–30 mg/L) were associated with the highest population and pit latrine densities of the settlement. Nitrate is of health concern and WHO (2011) have set a Guideline Value of 50 mg/L as the safe level.

According to WHO (1997), the most significant risk to human health related to drinking-water quality is from microbiological contamination. Health protection thus demands that sources of microbiological contamination are located sufficiently far from drinking-water sources as to minimize or eliminate the health risk (WHO, 1997). Studies by Dzwairo *et al.* (2006) on impacts of pit latrines in groundwater quality in Marondera indicated that pit latrines were microbially impacting on groundwater. A study of groundwater quality in Epworth settlement of Zimbabwe found detectable total and faecal coliforms in more than two-thirds of study boreholes and existing domestic wells (Zingoni *et al.*, 2005). According to Amnesty International (2010) lack of access to safe water and sanitation exposes new babies to infections which can be life threatening. Improved access to safe drinking water and sanitation results in public health benefits (Mulenga *et al.*, 2004). Improved access to safe drinking water minimizes the incidence of waterborne diseases and the costs that the community incurs for health services. Therefore there was need to study the impact of pit latrines on groundwater quality (Chave *et al.*, 2006).

1.4 Objectives

1.4.1 Main objective

The main objective was to assess the impact of pit latrines on groundwater quality in Hopley Settlement during the period of February to April 2015.

1.4.2 Specific objectives

The specific objectives were as follows:

(i) To determine pit latrine densities among the sampled groundwater sources in Hopley Settlement in 2015 using GIS and Remote sensing techniques;

(ii) To analyse groundwater samples from groundwater sources (wells and boreholes) for selected chemical and microbiological water quality parameters and assess suitability for drinking water;

(iii) To determine the spatial distribution of water quality parameters among the sampled groundwater sources in Hopley Settlement;

(iv) To assess the soil permeability in the vicinity of groundwater source location in order to explain the possibility of groundwater contamination from pit latrines.

CHAPTER 2
LITERATURE REVIEW

2.1 Global water and sanitation overview

According to British Geological Survey (BGS, 2002), the provision of water and sanitation facilities is important in reducing the incidence of waterborne diseases; and infant and maternal mortality rates. The WHO estimates that 2.1 million people die annually from diarrhoeal diseases (WHO, 2002). The peripheries of urban areas have been growing fast at a rate higher than urban services such as water and sanitation infrastructure development (McConville and Wittgrem, 2014). As a result hand dug out wells and onsite sanitation are common coping mechanisms for peri-urban households faced with problems of accessing reliable piped water supplies and sewage infrastructure (Cronin *et al.*, 2007).

2.1.1 Sanitation cover challenges

Graham and Polizzotto (2013) estimated that proximately 1.77 billion people around the world use some form of pit latrines as their primary means of sanitation. UNICEF/ WHO (2015) Joint Monitoring Program for water supply and sanitation established that the world has missed the MDG target for sanitation by almost 700 million people and that 2.4 billion people globally still lack improved sanitation facilities. According to WHO/UNICEF (2006), only 66% of the world’s population has access to improved sanitation far below the MDG target of 75% by the year 2015. Figure 1 shows that, globally, the number of people without improved sanitation decreased by 98 million between 1990 and 2004. WHO/UNICEF (2006) estimates that, the global MDG sanitation target will be missed by more than half a billion people if the trend of 1990-2004 continues up to 2015.

Table 1 shows the progress on MDG targets on water and sanitation in countries in the SADC region and the percentages of the population in each country with access to water and sanitation. Eight countries, that is, Angola, DR Congo, Lesotho, Madagascar, Mozambique, Tanzania, Zambia and Zimbabwe are off track for water MDG target and 12 countries (DR Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe) that are off track for sanitation MDG target. Zimbabwe is also off track on sanitation MDG target.

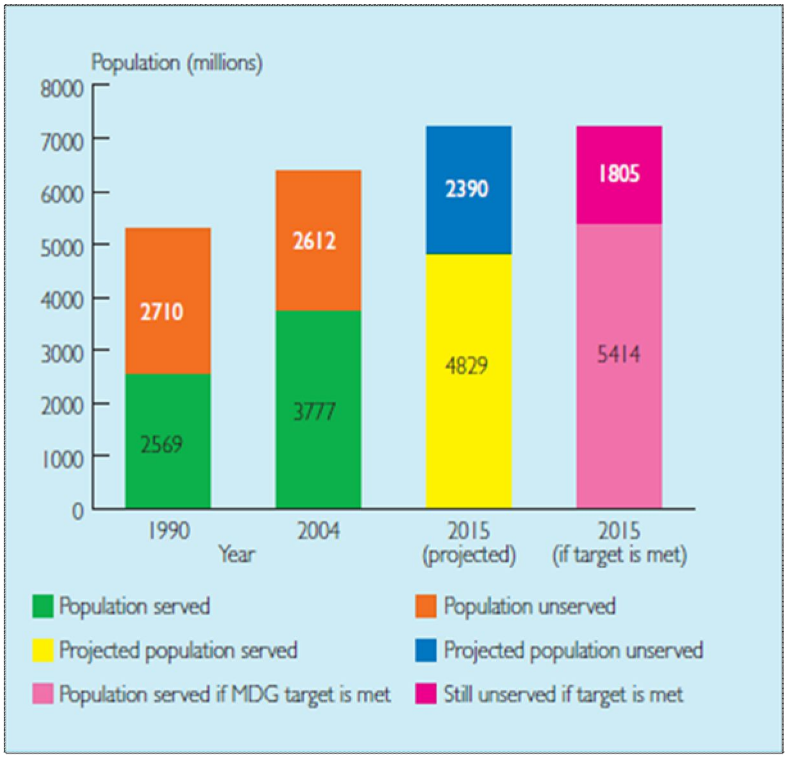


Fig. 1: World population served or not served with improved sanitation in 1990 and 2004 *(Adopted from: WHO/UNICEF, 2006*)

Table 1: Access to water and sanitation in the SADC Region Countries *(Adopted from: WHO/UNICEF, 2013*)

COUNTRY	MDG WATER TARGET	MDG SANITATION TARGET
Angola	Off-track, 53%	On-tack, 59%
Botswana	Near universal, 97%	On-track, 64%
DR Congo	Off-track, 46%	Off-track, 31%
Lesotho	Off-track,78%	Off-track, 26%
Madagascar	Off-track, 48%	Off-track, 14%
Malawi	On-track, 84%	Off-track, 53%
Mauritius	Universal, 100%	Off-track, 91%
Mozambique	Off-track, 47%	Off-track, 19%
Namibia	On-track, 93%	Off-track, 32%
Seychelles	Near universal, 96%	Near universal, 97%
South Africa	On-track, 91%	Off-track, 74%
Swaziland	On-track, 72%	Off-track, 57%
Tanzania	Off-track, 53%	Off-track, 12%
Zambia	Off-track, 64%	Off-track, 42%
Zimbabwe	Off-track, 80%	Off-track, 40%

2.1.2 Groundwater supply challenges

UNICEF/ WHO (2015) reported that 663 million people still lack improved drinking water sources especially those living in low-income, informal or illegal settlements. According to UNICEF/ WHO (2015), since 1990 the drinking water coverage in developing regions has increased by 17 percentage points to 87%. However, despite significant overall progress, 748 million people still did not have access to improved drinking water in 2012. About 325 million (43%) of these live in sub-Saharan Africa (UNICEF/ WHO, 2015).

Groundwater constitutes about 97% of all fresh water that is potentially available for human use (BGS, 2001). According to the International Groundwater Resources Assessment Centre (IGRAC) (2013), groundwater is developed for local systems to supplement urban supply in the rapidly growing peri-urban areas. For example in Angola, about 3.5 million out of the 18.5 million population (approximately 19%) rely exclusively on groundwater (IGRAC, 2013). In Zambia, in many low-cost areas the Water Supply and Sanitation (WSS) infrastructure is no longer functional and residents increasingly depend on open wells and pit latrines (IGRAC, 2013).

Figure 2 shows the World’s population with and without access to improved drinking water source between 1990 and 2004. Between 1990 and 2004 the number of people without an improved drinking water source decreased by 118 million people.

Figure 3 shows the overall groundwater dependency for domestic, irrigation and industrial use in the SADC Region categorised as low dependence, moderate dependence and high dependence. According to IGRAC (2013), in Zimbabwe, the overall groundwater resources are less compared to estimates of surface water resources. This is mainly because the greater part of Zimbabwe consists of ancient igneous rock formations where groundwater potential is comparatively low (Broderick, 2012).

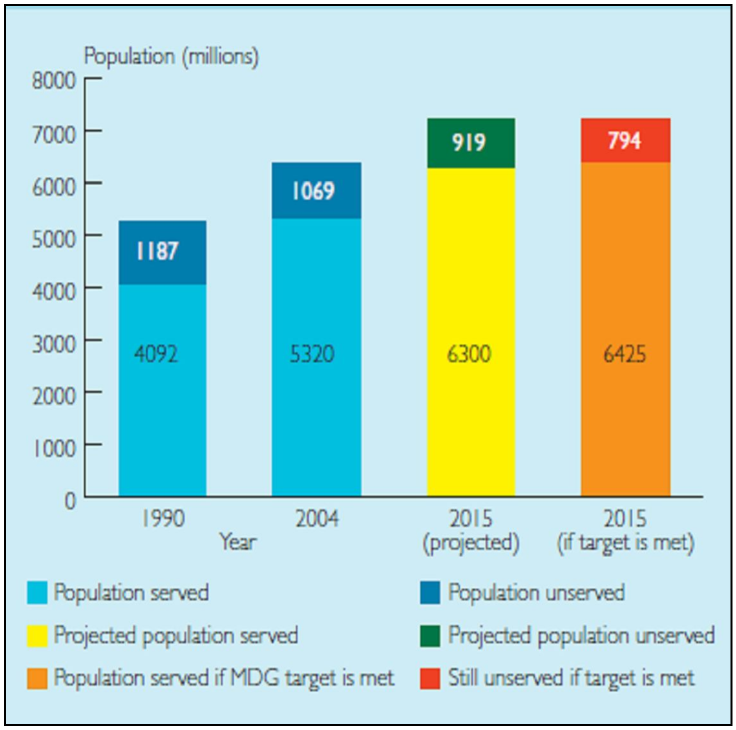


Fig. 2: Access to an improved drinking water source in between 1990 and 2004 *(Adopted from WHO/UNICEF, 2006)*

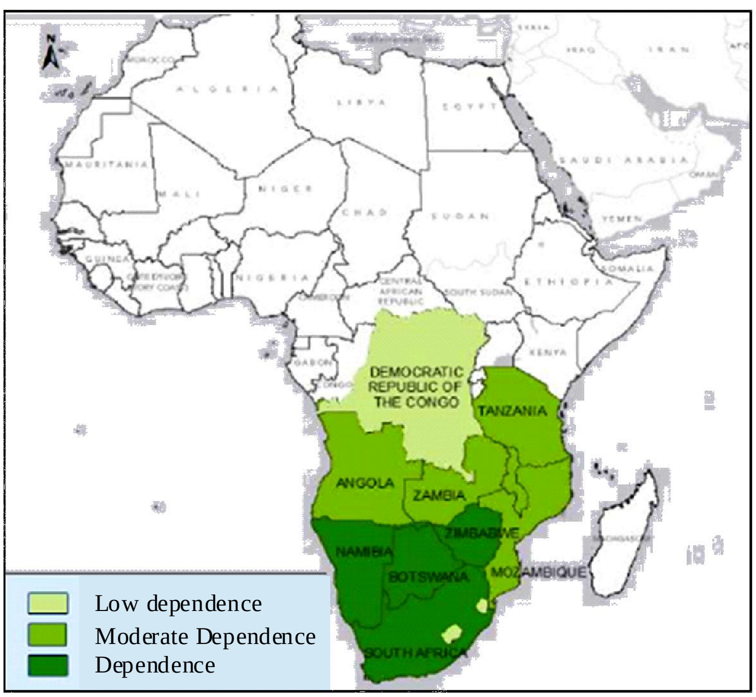


Fig. 3: Groundwater dependency in the SADC Region *(Adopted from IGRAC, 2013)*

2.2 Landuse activities associated with groundwater contamination

According to Graham and Polizzotto (2013), the interaction between groundwater contamination and factors related to sanitation facilities exist in concurrence with multiple contaminant sources. Land use has an influence on both groundwater quality and recharge rates. Therefore, consideration must be given not only to the present landuses, but also to historic and potential future landuses. McConville and Wittgrem (2014) further suggest that groundwater response to landuse impact is often gradual and delayed. Different land use practices leave distinctive signatures on the quality of groundwater (GWP, 2014). Landcover changes can affect the hydrologic makeup of the landscape. Highways, shopping centres, housing developments, industrial sites, businesses, agricultural operations, feedlots, waste disposal sites, sewer systems (to name a few) have the potential to directly or indirectly impact on the quantity and/or quality of both groundwater and surface waters. For example, intensive poultry production consumes a considerable amount of protein and other nitrogen containing substances in their diets, with 50% to 80% of the nitrogen being excreted (Arogo *et al.*, 2001). The improper disposal of poultry carcasses can thus contribute to groundwater quality problems, especially in areas prone to flooding or where there is a shallow water table (Maheshwari, 2013).

On-site sanitation systems dispose of human excreta, with or without treatment, on to the residents' plot. These systems include pit latrines and septic tanks with drainage fields (Cave and Kolsky, 1999; BGS, 2002). Common to all forms of on-site sanitation is the fact that decomposition is performed on site. The sludge can be fully decomposed within the pit or it may require to be periodically de-sludged and taken off-site for further treatment (BGS, 2002). Onsite wet systems also require soakaways to dispose of excess effluent, and this may increase risks from both pathogens and nitrate (BGS, 2001).

Therefore, applying protection in specific zones (Kibena *et al.*, 2014) improves groundwater quality than treating all of the land equally. It is therefore essential that local decision makers have access to tools that they can apply to land-use planning, zoning, and land acquisition, so as to effectively protect and sustain local ground water resources.

2.3 Factors affecting well and borehole water pollution by pit latrine contents

A contaminant is a substance that is present in an environmental medium in excess of natural background concentration (CCME, 2006). Causes of contamination range from improper disposal of household waste, industrial waste to over application of fertilizers (USGS, 2004). Site specific conditions such as soil properties, vegetation and topography affect contaminate transport, therefore pit latrine sludge can release bacteria and viruses into groundwater (USGS, 2004). Leachate from refuse dumps seeps through the soil and carries with it soluble chemicals.

The zone of contribution (ZOC) or catchment area of a groundwater source influences the risk of contamination from any particular source (EPA, 2011). Soil texture affects movement of water through soil. Coarser soils have faster percolation. Soils with higher clay or organic matter content hold water and dissolved chemicals longer. Highly permeable soils allow dissolved chemicals to be carried along with water and are also likely to reach groundwater (Barnett and Ormiston, 2010). The shallower the depth to groundwater, or the water table, the less soil there is to act as a filter. Areas of high water tables are more susceptible to contamination. High rainfall and permeable soils will allow water to percolate to the groundwater within a few days. The permeability of the geologic layers between the soil and groundwater also affects the probability of groundwater contamination.

2.4 Microbial and chemical contaminants associated with pit latrines

According to WHO/UNICEF (2011), the unsafe disposal of excreta is the principal cause of the transmission of pathogens within the environment. Thus, an improvement in excreta management can provide significant reductions in diarrhoeal diseases. For example, UNICEF/WHO (2009) estimated that 2.5 billion cases of diarrhoea are reported among children under the age of 5 years and that more than half of these cases are in Africa and South Asia. The largest chemical concerns from excreta disposal in on-site sanitation systems include nitrate, chloride and ammonia (BGS, 2002).

2.4.1 Faecal coliforms

Drinking water quality is the composition of drinking water at the time of sampling (APHA/AWWA/WEF, 2005b). The most important contaminants from a public health perspective are faecal pathogens. Diarrhoeal infections are associated with overcrowded shelters with polluted water sources, inadequate sanitation and poor hygienic practices, among other issues. Microbial contamination of groundwater can occur as a result of inadequate sanitary completion of wells and boreholes, sitting of wells too close to onsite sanitation systems, leaking sewers, land based disposal of sewage sludge and the presence of pit latrines in the vicinity of groundwater sources. According to Graham and Polizzotto (2013), although the concentration for most faecal microorganisms declines after faeces have been excreted, the microorganisms may still impair groundwater quality. Studies that have assessed microbial contamination of groundwater sources installed test wells to measure the quality of water sampled down-gradient of pit latrines or collected core soil samples or both (Graham and Polizzotto, 2013). For example, in a study of a latrine placed in an alkaline alluvium soil, movement of total coliforms was limited to less than 7 m from the pit (Dyer, 1941). A relatively short transport distance was found in South Africa where high faecal coliform counts greater than 10 cfu/100 mL were detected 1 m from a pit latrine (Still and Nash, 2002). Dzwairo *et al.* (2006) found that faecal and total coliform contamination greatly reduced beyond 5 m from pit latrine. In another study, Banerjee (2011) found that the transportation of total and faecal coliforms increased during the monsoon period and in sandy soils. The author also noted that the maximum distance of bacteria to be 10 m from pit (Banerjee, 2011).

In contrast, a study in Zimbabwe found that groundwater contamination was higher in the dry season rather than in the wet season, with coliforms detected 20 m from the pit (Chidavaenzi *et al.*, 1997). A study of groundwater quality in an informal settlement of Epworth in Zimbabwe suggested that shallow wells and boreholes and incomplete lining of most latrines were contributing factors to high levels of groundwater contamination (Zingoni *et al.*, 2005). However, Graham and Polizzotto (2013) concluded that even in areas with high pit latrine densities, microbiological groundwater contamination may not necessarily be detected. Two other studies by (Ahmed *et al.*, 2002) and Howard *et al.* (2003) found no strong positive association between poor bacteriological water quality and sanitary surveys or proximity to latrines (Ahmed *et al.*, 2002; Howard *et al.*, 2003).

2.4.2 Nitrates

According to WHO (2011), high nitrate concentrations in water for drinking have been attributed to latrines through association and assumptions based on general proximity of the groundwater source to the pit latrine. However, pinpointing the actual sources of nitrate in groundwater has proved challenging. Nitrate may be derived from numerous potential sources in urban and rural environments, including latrines, plant debris, animal manure, garbage repositories, livestock pens, soil, and fertilizers (Howard *et al.*, 2003; Vinger *et al.*, 2012). Nitrate can also be formed and lost through natural soil processes (Jacks *et al.*, 1999). The highest nitrate concentrations in well water are expected to be found downstream of areas with high latrine use (Chidavaenzi *et al.*, 2000; Vinger *et al.*, 2012). Chidavaenzi *et al.* (2000) estimated that the nitrogen influence from pit latrines extend only 5 m from the latrine source. Chidavaenzi *et al.* (2000) and Zingoni *et al.* (2005) observed that groundwater nitrate concentrations near latrines were above local background levels, even if they remained below or near the WHO guideline. By analyzing water samples from installed boreholes in an Epworth settlement in Zimbabwe, Zingoni *et al.* (2005) demonstrated that the highest nitrate concentrations in groundwater (20-30 mg/L) were associated with the highest population and pit latrine densities within the settlement.

Nitrate is a health concern. Consequently, WHO (2011) has set a guideline value of less than 50 mg/L as the safe level of nitrate so as to reduce the likelihood of Methaemaglobinamenia in the population. Nitrate and chloride are generally stable, especially in aerobic environments; therefore contaminations are likely to build-up and persist in the long term. Studies have concluded that concentrations of nitrate in water from wells located near latrines are highly variable as evidenced by the detection of total or faecal coliforms without accompanying elevated nitrate concentrations (Howard *et al.*, 2003; Dzwairo *et al.*, 2006). However, other studies have reported nitrate concentrations >100 mg/L (Banks *et al.*, 2002) for similar setups. In Senegal and South Africa, groundwater nitrate concentrations have also been correlated with proximity to pollution sources, including pit latrines (Vinger *et al.*, 2012).

2.4.3 Chlorides

According to Graham and Polizzotto (2013), chloride has been the most commonly investigated in groundwater source contamination from latrines because of its high concentrations in excreta and its relative mobility in the subsurface. Chloride is also abundant in human wastes (the ratio of chloride to nitrate in human waste is approximately 1:2) According to BGS (2001) each person on average loses approximately 4 g of chloride per day through urination (90-95%), defecation (4-8%) and through sweating (2%). Chloride affects the acceptability of drinking water (WHO, 2011). Although there are no known health risks from chloride in drinking water, concentrations >250 mg/L may affect the taste and acceptability of water (WHO, 2011). In a study from Botswana, Lewis *et al.* (1980) found that the highest chloride concentrations occurred in soils closest to pit latrines. In Bangladesh, dissolved concentrations reached 400 mg/L at shallow depths, but then decreased with depth and distance from latrines (Ahmed *et al.*, 2002). Chloride is typically transported with minimal retention during groundwater flow, and concentrations frequently track with nitrate levels (Jacks *et al.*, 1999; Banks *et al.*, 2002) unless subsurface conditions promote nitrate reduction to nitrogen (Ahmed *et al.*, 2002).

Variable distributions of latrine contaminants resulting from pumping and seasonal fluctuations have been demonstrated by studies using chloride salts as tracers (Banerjee, 2011).

2.4.4 Ammonia

Ammonia, derived either directly from latrine waste or following denitrification of nitrate released from latrines, has not been reported to accumulate appreciably in groundwater near latrines (Graham and Polizzotto, 2013). For example, in a study of three pit latrines, Dzwairo *et al.* (2006) observed only one incidence of ammonium (NH_4^+) >1.5 mg/L at pH 7.0-7.4 in well water that had been microbiologically contaminated by latrines. In groundwater with latrine-derived nitrate concentrations that exceeded 500 mg/L, Lewis *et al.* (1980) found NH_4^+ at <0.2 mg/L in all wells but one, which had NH_4^+ at 3 mg/L. Similarly, NH_4^+ was below the South African National Standard (2 mg/L) in all water samples analyzed by (Vinger *et al.*, 2012). (Padmasiri *et al.*, 1992) reported that soil concentrations of NH_4^+ decreased substantially between 1 and 1.5 m from latrine pits. Ammonia tends to accumulate and persist under anaerobic conditions, and high concentrations are likely when the water table intersects the base of the latrine pit (Dzwairo *et al.*, 2006). In anaerobic environments ammonium is the stable form of nitrogen and it may represent a health hazard (BGS, 2001).

2.4.5 Turbidity

Latrines have also been associated with increased well water turbidity (Dzwairo *et al.*, 2006). Turbidity in excess of 5 NTU may be noticeable and objectionable to consumers (WHO, 1997). Higher turbidity levels are often associated with higher levels of disease causing microorganisms such as viruses, parasites and some bacteria. Higher levels of turbidity also can protect microorganisms from the effects of disinfection and stimulate growth of bacteria (WHO, 1997).

2.4.6 Dissolved oxygen

According to Morris *et al.* (1994), dissolved oxygen concentration should be considered a critical parameter in an investigation of groundwater contamination. Dissolved oxygen often controls the fate of dissolved organic contaminants by constraining the types and numbers of microorganisms present within a water source. In turn, bacteria can either decompose organic material present in water or produce organic contaminates as part of their metabolism (Morris *et al.*, 1994). Deletion of dissolved oxygen in water supplies can encourage the microbial reduction of nitrate to nitrite and sulphate to sulphide (WHO, 2008).

2.5 Soil characteristics and hydrogeology

The soil type and hydrogeology influence soil percolation rates and vulnerability of groundwater to nutrient contamination. Previous studies have established that the permeability of coarse grained soil is very greater than fine grained soil. If the soil has high permeability rainwater will soak into it easily. If the permeability is low, rainwater will tend to accumulate on the surface or flow across the surface if the surface is not level. When groundwater is found at shallow depths, pollutants from the surface are not filtered out before reaching the groundwater, and pollutants are difficult to remove, making the water unsuitable for drinking (EPU, 2012). Pujari *et al.* (2012) recommended that the construction of pit latrines be discouraged in rocky areas with shallow water tables.

Not all subsoil strata are equally effective in eliminating contaminants. Some contaminants will be attenuated as a result of biochemical degradation and/or chemical reaction, and the sorption to minerals as water infiltrating through the subsoil layers allows more time for constant attenuation processes. The survival time of the pathogen in the environment is a measure of how quickly the pathogen dies after it leaves the body (Cave and Kolsky, 1999). Bradley *et al.* (1980) suggested that survival time of the pathogen is the single property most indicative of faecal hazard, as a very persistent pathogen will create a risk to groundwater contamination.

Therefore, the assessment of siting and design requirements for on-site systems is typically achieved by a simple soil permeability test and an evaluation of soil structure and texture characteristics (Carroll *et al.*, 2006). Soil permeability determines the suitability for the soil for the pit latrine drain field. The liquid part of the waste in a pit latrine forms a hydraulic load that infiltrates into the soil. Where hydraulic loads are high and exceed natural attenuation potential in the sub-surface, this can lead to direct contamination of groundwater sources. Banks *et al.* (2002) suggests that pit latrines should be located no less than 15-30 m from groundwater abstraction points and should terminate no less than 1.5-2.0 m above the water table. In Zimbabwe, the southern part of Harare where Hopley Settlement is located is underlain by massive granite possessing semi-confined aquifers and the water table generally remains perched and high due to direct annual precipitation, presenting a significant pollution hazard (Broderick, 2012).

2.6 Methods of groundwater protection and management

Recognizing the increasing dependency on groundwater has resulted in regional strategic approaches to improve groundwater practices in Southern Africa such as the Groundwater Management Programme (GMP)(IGRAC, 2013). Groundwater sources can be protected by applying the principle of protection zones. The simplest form of zoning employs fixed distance methods where activities are excluded within a uniformly applied specified distance around abstraction points. Researchers have identified a range of latrine siting guidelines from the varying transport distances observed for microbiological and chemical contaminants originating from pit latrines. For example, in their comprehensive review about the risks for groundwater contamination by onsite sanitation sources, Lewis *et al.* (1982) noted that the “traditional” guideline of 15 m as a safe distance between wells and sanitation units may prevent groundwater contamination. On the basis of statistical associations between latrines and nitrate concentrations in water sources, Tandia *et al.* (1999) recommended distances of 20 m, 36 m, and 48 m for pits that are in use for <1 decade, 1-2 decades, and >2 decades, respectively. Banerjee (2011) concluded that, with the exception of fissured rock, the safe distance between a pit latrine and water source is 10 m. South Africa’s groundwater guidelines recommend that pit latrines are located at least 75 m from water sources (Still and Nash, 2002). Furthermore, 15 m is suggested as the safe lateral separation between pit latrines and the groundwater supply. This distance can be reduced if the well is not directly down gradient of the pit (Franceys *et al.*, 1992). However, in a more recent and conservative recommendation that seeks to account for a wide variety of contexts, WaterAid (2011) suggests that latrines and water sources should be at least 50 m apart. For disaster response situations, the Sphere Project (2011) has recommended 30 m as a minimum standard for the lateral distance between onsite sanitation systems and water sources, although this value could be adjusted based on the nature of subsurface features.

The British Geological Survey (BGS) guidelines provide a set of rules for determining the optimum horizontal separation between sanitation facilities and drinking-water sources for a variety of hydrogeological environments. These guidelines have been tested in Bangladesh (Ahmed *et al.*, 2002), Uganda (Howard *et al.*, 2003), and Argentina (Blarasin *et al.*, 2002) and have been advocated as sensible practice for aquifers for which data is limited and therefore do not otherwise lend themselves to conventional Environmental Health Perspectives vulnerability assessment (Ahmed *et al.*, 2002; Howard *et al.*, 2003). According to BGS (2001), risk assessments are defined for three scenarios, that is, localised microbial contamination, widespread microbial contamination and widespread nitrate contamination. For separation distances related to microbial quality, decisions are based on a time of travel estimation that includes hydraulic and pollutant loading as well as the attenuation potential and survival of microbes. Based on the BGS (2001), the setback distances approach uses a three-tier approach to risk shown in Table 2.

Table 2: Levels of pathogen risk in relation to travel time *(Adopted from BGS, 2001)*

LEVEL OF RISK	COMMENTS
Significant risk	Travel time under 25 day (breakthrough of both viral and bacterial pathogens in significant numbers possible)
Low risk	Travel time over 25 days (primarily related to the potential for viral break through) but under 50 days
Very low risk	Travel time over 50 days (unlikely to have significant breakthrough of any pathogens, although low risk of viral breakthrough remains)

A new systematic review of literature, commissioned by the Joint Monitoring Program (JMP), identified 345 studies with drinking water quality data and has been used to estimate global exposure to faecal contamination in drinking water (WHO/UNICEF, 2014). The study estimates that 1.8 billion people globally use a source of drinking water that is contaminated by faecal material. Of these, 1.1 billion people drink water that is of at least “moderate” risk (>10 faecal indicator bacteria per 100 mL sample). Data from nationally randomized studies suggest that 10% of improved sources may be “high” risk, containing at least 100 faecal indicator bacteria per 100 mL water sample. According to WHO/UNICEF (2014), drinking water safety can be ensured only when water supply systems are designed, constructed and managed in a way that minimizes and addresses risks that could cause contamination. The monitoring of water safety should, therefore, include both water quality testing and risk management measures. Pujari *et al.* (2012) advised that groundwater sources in areas served by on-site sanitation systems should be monitored by responsible agencies; and that monitoring should include nitrate, chloride, and faecal coliforms.

Technological upgrades to pit latrines may substantially reduce microbial and chemical threats to groundwater quality. Latrine liners can minimize seepage of pit contents to groundwater and raised latrines may help minimize groundwater contamination by increasing vertical separation and promoting the aerobic digestion of waste (Dillon, 1997; Dzwairo *et al.*, 2006). Urine diverting toilets, painted ventilation tubes, and chemical amendments to latrines can minimize nitrate formation and release to groundwater (Jacks *et al.*, 1999). Dillon (1997) and Endale *et al*. (2012) suggested that composting toilets and ecological sanitation technologies may reduce microbial risks and minimize chemical leaking from pit latrines. One effective way of protecting groundwater sources from contamination by pathogenic microorganisms leaked into aquifer systems is by delineating well head protection areas around a drinking source. This strategy relies upon the effective natural attenuation of sewage derived microorganisms by soils over set back distances (Taylor *et al*., 2004). While natural processes may assist in reducing pollution, most biological contaminants can travel through soils and aquifers until they either enter a water well or are discharged into streams (Corapcioglu and Haridas, 1985).

Overall, the threats to groundwater quality from onsite sanitation can be mitigated through technology design, risk assessment, development of protection zones, and monitoring (Lawrence *et al.*, 2001; Robins *et al.*, 2007). It can be concluded that urban local authorities need to adopt a comprehensive housing development approach through the provision of decent homes as a key factor in expanding access to water and sanitation (WHO/UNICEF, 2013). Dzwairo *et al.* (2006) highlighted specific recommendations for minimizing latrine effects on groundwater quality, and these included the need to analyze critical parameters such as depth of the infiltration layer and direction of groundwater flow; the need to develop alternative sanitation options, such as raised or lined pit latrines, to minimize groundwater impacts; and the application of an integrated approach, involving geotechnology and hydrogeology, to solve sanitation problems. Pujari *et al.* (2012) recommended that latrines be discouraged in rocky areas with shallow water tables. They also suggested that systematic lithological and hydrogeological mapping be conducted and that parameters such as the depth of the water table, soil characteristics, and rock strata be considered prior to installing latrines.

CHAPTER 3
STUDY AREA

3.1 Description of Study Area

The peri-urban Settlement of Hopley was selected as the study case because of the water supply and sanitation challenges that are facing residents of the Settlement. The predominant source of drinking water is from groundwater sources (wells and boreholes). Pit latrines are used as the predominant form of disposing human excreta and this has posed a great chance of pit latrine contents contaminating groundwater source locations, thereby posing a health risk to consumers. Hopley Settlement was established in 2005 as a result of the Zimbabwean Government initiative to do away with informal settlements and illegal buildings in urban areas (ZESN, 2008; Nhapi, 2009; Amnesty International, 2010). The residents at Hopley Farm are evictees which were drawn from different areas which included Hatcliffe Extension, Porta Farm and Mbare (Nyama, 2013).

Figure 1 shows the location of Hopley Settlement in Harare. Hopley Settlement is located south of Harare's Central Business District and has a population of about 15,000 people (ZIMSTAT, 2012). The study area occupies an area of about 4 km^2. Each of the housing unit in Hopley Settlement occupies an area of about 250 m^2. Hopley Settlement is predominantly residential and is surrounded by Waterfalls residential, Irvin's Chickens Poultry Farm, Derbyshire Farm, Boka Tobacco Sales Floor, Stoneridge Residential, Granville "Mbudzi" Cemetery and SouthView Park Residential area. The City of Harare is yet to incorporate most of the farms that house these settlements, therefore they are inadequately prepared for urban development (Chirisa *et al.*, 2014). The majority of housing in Hopley Settlement constitutes temporary to semi permanent shacks that range from plastic shacks to unplanned structures built with 'green' bricks (Nyama, 2013). A few houses have been built using approved plans and a large part of these structures were constructed by the then Ministry of Local Government and Urban Development (Nyama, 2013).

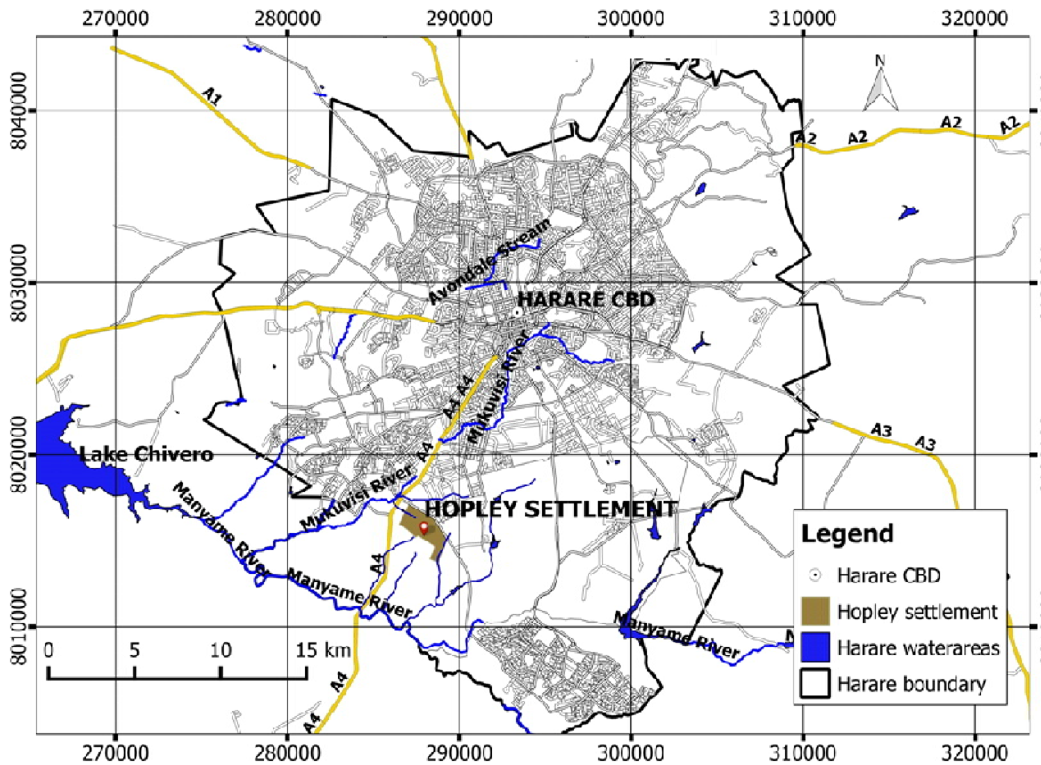


Fig. 4: Location of Hopley Settlement in Harare, Zimbabwe

3.2 Background on water supply and sanitation

3.2.1 Water supply

Infrastructural water service facilities on water and sanitation in Hopley Settlement were developed by organisations like UNICEF on a communal basis (boreholes and stand-pipes) (Nyama, 2013). In addition to these facilities, most of the residents also have wells since taped water supplies on individual household level are absent. The peri-urban settlement experiences irregular water supplies to the Harare municipal water stand pipes (Nyatsanza and Chaminuka, 2013). The communal boreholes and stand pipes cannot meet the water demands of the residents; hence the use of wells as a source of drinking water. As a result, the main sources of drinking water in Hopley Settlement are open wells and boreholes. Nhapi (2009) noted that the problems of water and sanitation in Harare have been caused by rapid population growth, inadequate rehabilitation and maintenance of water and wastewater treatment plants, expensive technologies such as trickling filters and biological nutrient removal systems, and poor institutional framework. Moyo (1997) reported that Harare

Sewerage Systems were overloaded and the reticulation systems were so old such that sewage blockages were quite common especially in high density areas.

3.2.2 Sanitation

The peri-urban settlers of Hopley in Harare have built structures on un-serviced land; hence, development is taking place without adequate water and sanitation support infrastructure (Chirisa *et al.*, 2014). Nyatsanza and Chaminuka (2013) reported that some of the most common sanitation practices in peri-urban areas are open defecation within the settlement. The predominant forms of sanitation are pit latrines which are used throughout the settlement. Latrines in the peri-urban areas of Harare are often poorly designed and maintained and may not be used by all family members (McGuigan, 1996). The stands in Hopley Settlement are small to accommodate pit latrines on each at every household. UNICEF has also supported the Hopley community with the construction of EcoSan toilets and more than half the residents have these units on their plots. The handling and final disposal of EcoSan toilets contents has often posed a great challenge to the residents who have opted the use of pit latrines. Some households rely on septic tanks that are often poorly maintained or undersized (Nyatsanza and Chaminuka, 2013).

3.3 Population

Harare has the highest proportion of Zimbabwe’s population that stood at 2,098,967 people in year 2012 (ZIMSTAT, 2012). A population density of 2,406 people per square kilometre was reported in 2012 according to the Zimbabwe census (ZIMSTAT, 2012). Harare’s growth rate was 1.0% from 2002 to 2012; and there was an increase in the number of households from 490,000 to 530,000 households during the same period. In 2012 Hopley settlement had a population of about 15,000 people (ZIMSTAT, 2012).

3.4 Climate

According to ClimaTemps.com (2015), Harare receives a total annual precipitation average of about 805 mm. There are three main seasons: normally; a warm, wet season from November to March/April; a cool, dry season from May to August (corresponding to winter in the Southern Hemisphere); and a hot, dry season in September/October. In summer, Harare has high average temperatures of ground 26^{o}C and average low temperatures of 16^{o}C. During the winter time records indicate temperatures of upto 22^{o}C and low average temperatures of 13^{o}C.

3.5 Soil and geology

The Harare geology map obtained from the Geological Survey Office in Harare; showed that Hopley Settlement is underlain with coarse grained granite rock. According to Broderick (2012), the area is underlain by granite rock and has a semi confined aquifer. There was no historical data on groundwater quality for Hopley Settlement. Figure 5 shows Harare geology map and the location of Hopley Settlement. Figure 5 shows that most of Hopley Settlement is underlay with coarse grained granite rock.

3.6 Landuse and socio-economic activities

In Zimbabwe, Hopley Settlement sanitation infrastructure for disposing human excreta comprised of pit latrines. Poor refuse management by the City of Harare has resulted in indiscriminate dumping of refuse onto open spaces in Hopley Settlement. Appendix 1 shows photos of pit latrines, open wells and refuse dumps found in Hopley Settlement. Figure 6 shows the location of pit latrines in Hopley Settlement. There are more than 4 300 pit latrines and most of the pits in the settlement were not lined with concrete.

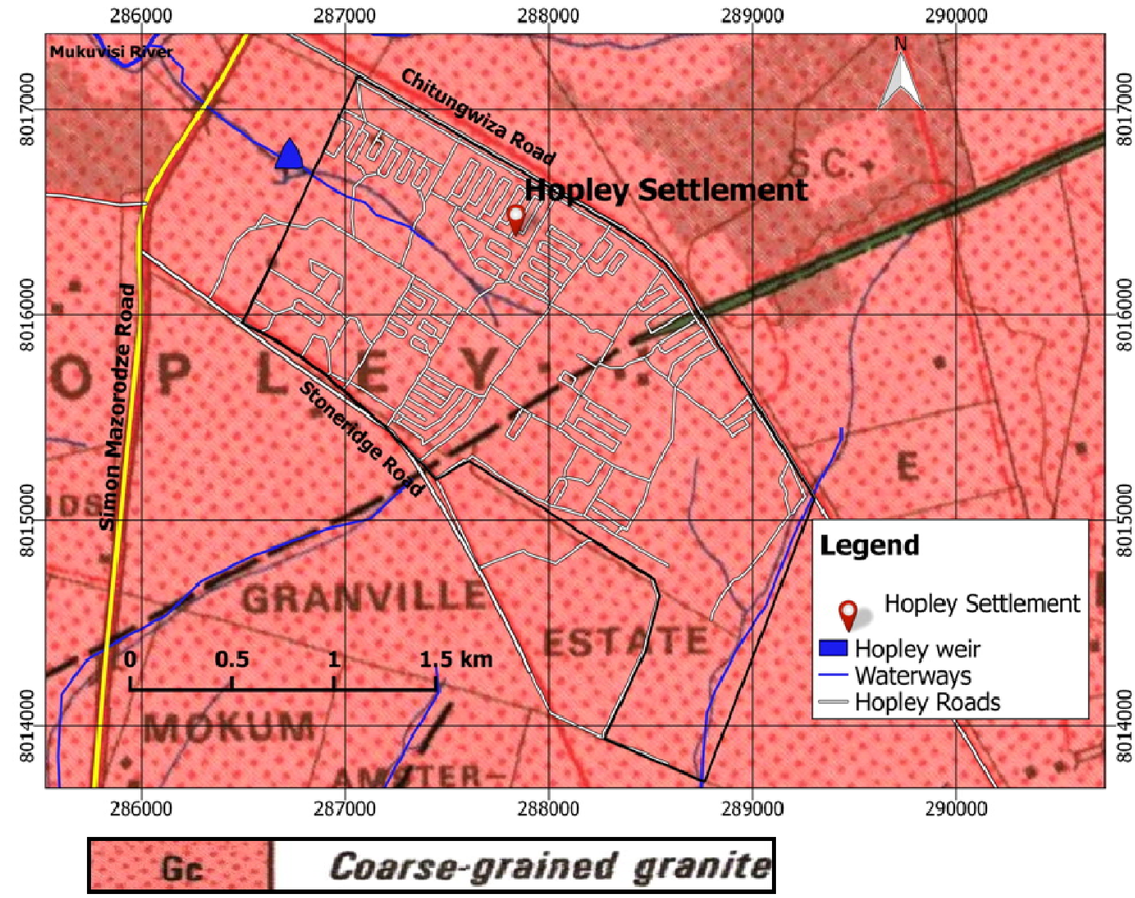


Fig. 5: Hopley Settlement geology map *(Adopted from Harare Geology map by Baldock J.W, 1983-86)*

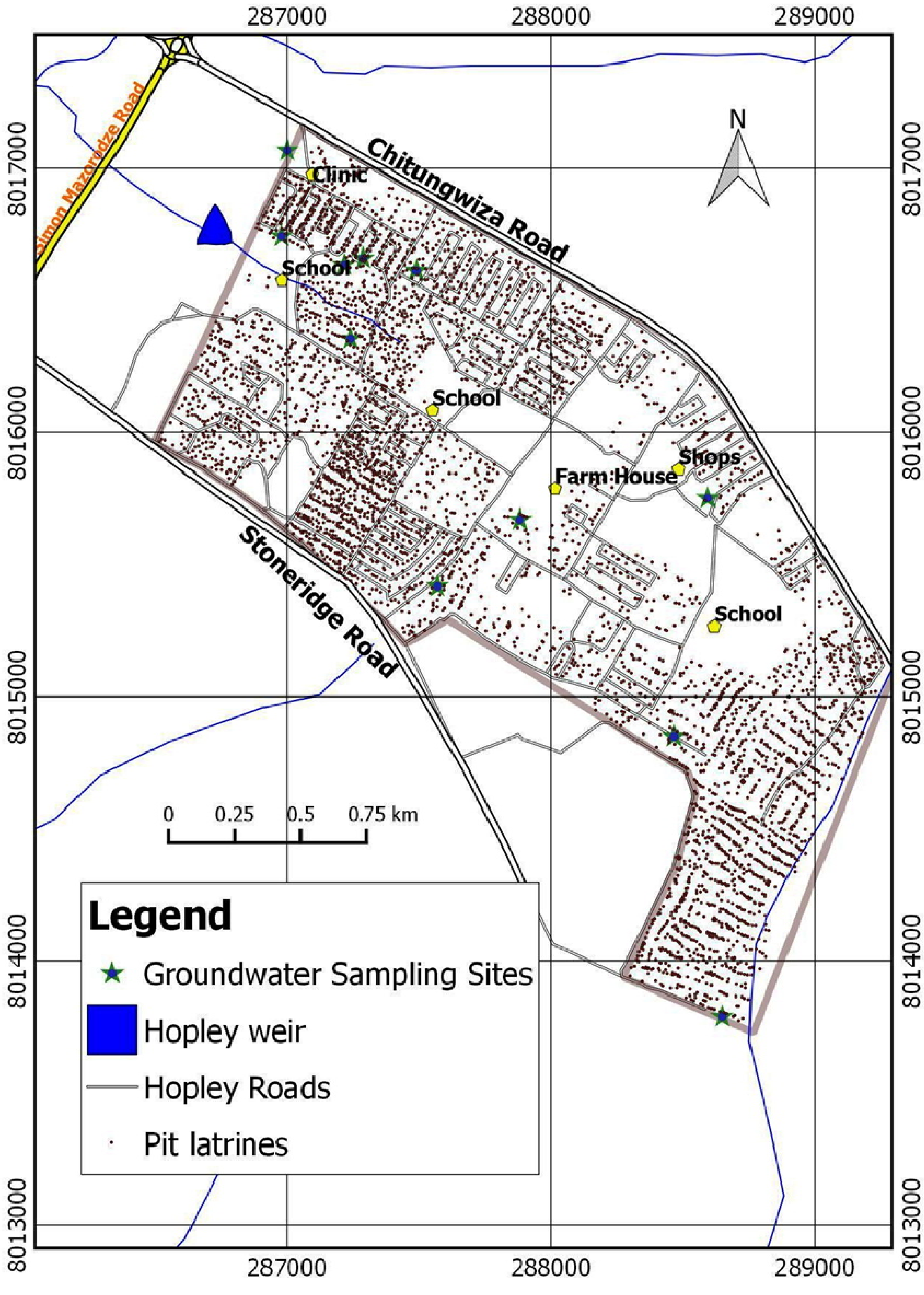


Fig. 6: Location of Pit latrines in Hopley Settlement

CHAPTER 4
MATERIALS AND METHODS

4.1 Study design

4.1.1 Selection of study site

Harare City is facing water and sanitation challenges as a result of rapid urban population growth especially in the peri-urban areas (ZIMSTAT, 2012; WHO/UNICEF, 2014). Hopley Settlement is one of the peri-urban settlements of Harare that is faced with water and sanitation challenges. Harare City has not been able to cope with the water and sanitation infrastructural development in these peri-urban settlements. As a result, people have resorted to the use of groundwater for drinking water requirements and pit latrines for disposing human excreta (Nhapi, 2009; Graham and Polizzotto, 2013). There is high utilization of unimproved pit latrines in the settlement for disposal of human excreta, thereby threatening groundwater contamination by pit latrine contents. Erratic refuse collection has resulted in the indiscriminate disposal of domestic solid waste on to open spaces adjacent to groundwater sources. Wastewater from bathrooms is carried through open drains forming stagnant puddles of waste water.

4.1.2 Selection of sampling sites/areas

Groundwater sampling was carried out to determine whether groundwater parameters were at concentrations permissible in drinking water. Groundwater samples of both wells and boreholes were selected based on representativeness of anthropogenic activities and hydrogeological conditions in Hopley Settlement. They were also based on groundwater sources with high risk of contamination from pit latrines. The location of the wells and boreholes was determined using a Geographical Positioning System (GPS) and coordinates georeferenced to the Universal Transverse Mercator Zone 36 south projections based on the WGS84 datum.

Figure 7 shows the location of the selected groundwater sampling sites in Hopley Settlement. A total of 11 sampling sites were selected and these included 8 open wells (W1, W2, W3, W4, W5, W6, W7 and W8) and 3 boreholes (B1, B2 and B3) shown in Figure 2. Sampling sites were selected throughout the Hopley Settlement. All sampling sites were located down gradient of pit latrines.

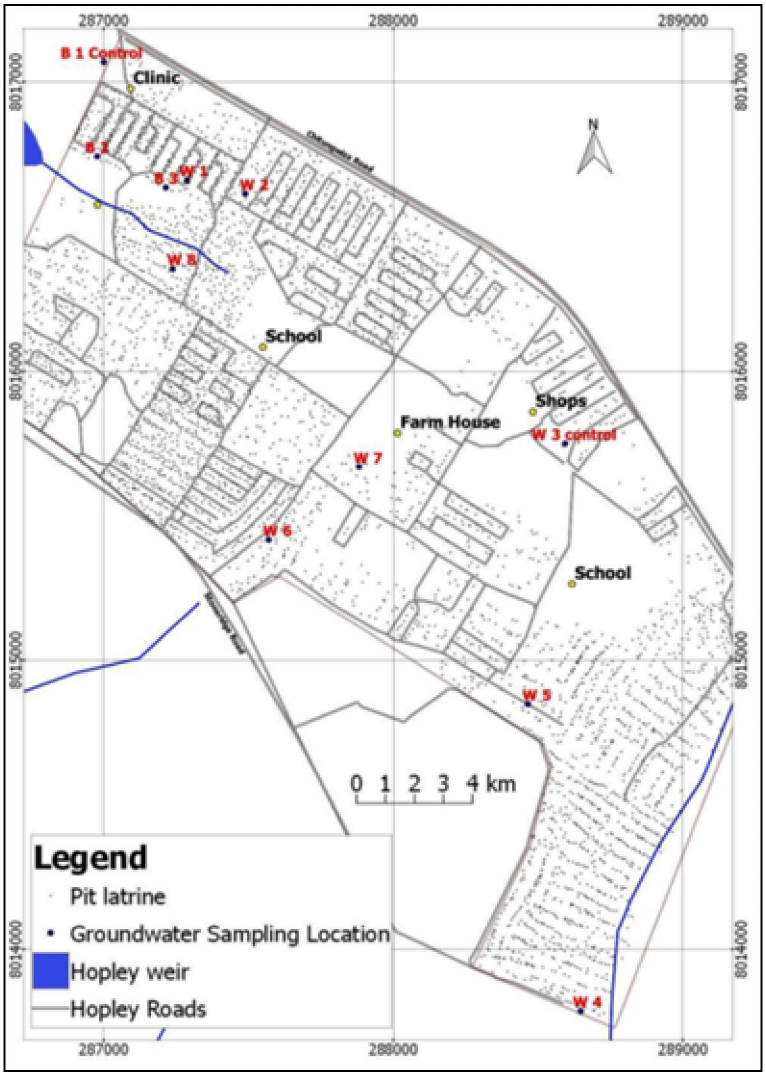


Fig. 7: Location of groundwater sampling points in Hopley Settlement

Table 3 shows the nearest distance of each sampling location from a latrine.

Table 3: Groundwater sampling sites and distances from pit latrine

Groundwater Sampling Site	B1	B2	B3	W1	W2	W3	W4	W5	W6	W7	W8
Distance from nearest Pit Latrine (m)	40	28	13	3.5	13	25	15	10	10	13	15

Pit latrine contents form a hydraulic load and the contents can travel through the soil thereby posing risk to groundwater contamination (BGS, 2002). Studies have shown a relationship between the distance from the pit latrine and the groundwater contamination (Caldwell and Parr, 1937; Caldwell, 1938; Dzwairo *et al.*, 2006; WaterAid, 2011). High pit latrine densities have also been associated with groundwater contamination (Graham and Polizzotto, 2013).

4.1.3 Selection of parameters to be analyzed

Water quality parameters selected in this study included pH, turbidity, dissolved oxygen, chlorides, nitrates, electrical conductivity, ammonia and chlorides. The selected parameters are of importance in groundwater monitoring in settlements using onsite sanitation for disposing human excreta (Howard *et al.*, 2003). For example, studies have indicated that chloride, nitrate and faecal coliforms are parameters closely associated with groundwater contamination by onsite sanitation systems (Pujari *et al.*, 2012). Dzwairo *et al.* (2006) and Hoko (2005) have demonstrated in their studies of groundwater quality that turbidity, dissolved oxygen, pH and electrical conductivity are problematic with regards to onsite sanitation.

Chloride has been the most commonly investigated chemical indicator of groundwater contamination from latrines because of its high concentrations in excreta and its relative mobility in the subsurface (Graham and Polizzotto, 2013). Chlorides are abundant in human wastes (the ratio of chloride to nitrogen in human faeces is approximately 1:2) (BGS, 2002). Chlorides increase the electrical conductivity of water. Chloride concentration in excess of about 250 mg/L can give rise to detectable taste (WHO, 2011). The WHO (2011) drinking water guideline permissible concentration of chlorides in drinking water is recommended at less than 300 mg/L, while SAZ (1997) drinking water standards recommends permissible concentrations of less than 250 mg/L.

Nitrate is relatively non-toxic. However upon ingestion, it is partially converted by bacteria in the mouth to nitrite. Nitrites react with haemoglobin, the oxygen carrying constituent of red blood cells, to produce methaemoglobin which cannot transport oxygen (BGS, 2002).

Electrical conductivity is affected by the presence of dissolved ions such as nitrates and chlorides in water which generally affects the taste (Hoko, 2008). Nitrate has been the most widely investigated chemical contaminant derived from pit latrines because of high concentrations of nitrogen in human excreta, its ability to react with human blood negatively affecting human health, and its use as an indicator of faecal contamination (Graham and Polizzotto, 2013). The WHO (2011) drinking water guidelines recommends a concentration of less than or equal to 50 mg/L in drinking water, and SAZ (1997) drinking water standards recommends concentrations of less than or equal to 10 mg/L.

Ammonia is naturally produced in the intestinal tract and is very soluble in water. The odour threshold is 1.5 mg/L in water. High localized concentrations of ammonia inhibit nitrogen transformation by microbial processes. The WHO drinking water guidelines recommends concentrations of less than 0.2 mg/L ammonia in drinking water.

The WHO drinking water guidelines suggests that the appearance of water with turbidity less than 5 NTU is usually acceptable to consumers. The consumption of highly turbid water may constitute a health risk as excessive turbidity can protect pathogenic microorganisms and can also stimulate the growth of bacteria (Hoko, 2005).

According to WHO (2011), dissolved oxygen in drinking water has no direct impact on health. Dissolved oxygen often controls the fate of dissolved organic contaminants by constraining the types and numbers of microorganisms present within a water source. The SAZ (1997) drinking water standards recommend dissolved oxygen concentrations of above 5 mg/L in drinking water.

However, the WHO drinking water guideline does not specify the guideline value for electrical conductivity but does stipulate the one for Total Dissolved Solid (TDS), which is a 1000 mg/L. There is generally a correlation by TDS and EC, and when a correlation factor of 0.725 is applied the limit for EC becomes approximate 1380 μS/cm (Hoko, 2005). Electrical Conductivity depends on the presence of ions, on their total concentration, mobility and temperature of measurement. Higher value of conductivity shows higher concentration of dissolved ions (Choudhary *et al.*, 2011).

Hydrogen Ion concentration (pH) indicates the intensity of acidic or basic character at a given temperature. Measurement of pH is one of the most important and most frequently used tests in determining water quality. Low pH tends to make water corrosive while high pH will result in taste complains (Hoko, 2005). The recommended level of pH in drinking water is 6.5 to 8.5.

The hydrogeological factors such as depth to water table, nature of soil matrix, and lateral separation between the onsite sanitation and the groundwater source are the key parameters affecting groundwater pollution. Assessment of siting and design requirements for onsite systems is typically achieved by a simple soil permeability test and an evaluation of soil structure and texture characteristics (Carroll *et al.*, 2006). Permeability (or hydraulic conductivity) refers to the ease with which water can flow through a soil.

4.2 Data collection methods

4.2.1 Methods of sampling and frequency

Table 4 shows the methods of sampling and frequency. Discrete grab water samples were collected from 8 wells and 3 boreholes for on-site measurements and laboratory analysis. The sampled groundwater locations were B1, B2, B3, W1, W2, W3, W4, W5, W6, W7 and W8. A total of 4 water sampling campaigns was carried out. The water samples were collected over the period February 2015 to April 2015. Discrete grab samples were taken at selected location, depth and time (APHA/AWWA/WEF, 2005b). The samples represented the composition of its place of collection. Grab samples were collected at suitable intervals and analysed separately in order to document the extent, frequency and duration of variations in water quality with time (Keith *et al.*, 1996). A resistivity meter was used to measure the water level depth from the ground surface at each sampling campaign.

Five soil samples from sampling points SB1, SB3, SW2, SW5 and SW6 were collected in April 2015 using the Backhoe Sampling Method prescribed in Science and Ecosystem Support Division Operating Procedure (U.S. Environmental Protection Agency) for collecting soil samples for soil permeability analysis (Simmons, 2014). The soil sampling sites selected were representative of the soil subsurface strata at each selected location. The depth levels of pit the latrines and groundwater sources were obtained from interviews of key informant of Hopley Settlement.

Table 4: Methods of sampling and frequency

SAMPLING POINTS	PARAMETER	SAMPLING METHOD	FREQUENCY	NUMBER OF SAMPLES
a) 8 Wells	Nitrates, Chlorides, Ammonia, Faecal Coliforms	GRAB sampling	Once per two weeks	32
b) 3 Boreholes	Nitrates, Chlorides, Ammonia, Faecal Coliforms	GRAB sampling	Once per two weeks	12
c) 5 Soil Sites	Permeability	Disturbed soil sample at 1.5 m depth	Once	5

4.2.2 Water sample collection

The methods prescribed by APHA/AWWA/WEF (2005) Standard Methods for Examination of Water and Wastewater were used for collection of water samples. Water samples were collected from the selected wells and boreholes of Hopley Settlement. A water sample was collected in a 1 litre acid rinsed and sterilized plastic bottles for chemical and microbial analysis respectively. The samples were stored and transported to the laboratory in a cooler box and water samples were analyzed within 24 hours. During water sample collection, records of environmental situation within the vicinity of the wells and boreholes, that included solid waste dumping and the presence of grey water, were carried out at each sampling campaign.

Well and Borehole sampling: A sample was taken with the sampling bottle held in a clamp on the end of a rope. Water samples were taken at a depth of about half a meter below the surface to avoid contamination that may be on the surface or in the settled material at the bottom. Boreholes were first flushed by having about 10 strokes discharging water (Hoko, 2008). The water sample was then collected.

4.2.3 Onsite field measurement

These included measurement of pH, electrical conductivity, turbidity and dissolved oxygen using electrode probe field meters. Calibrated electrode field meters were used to measure pH, turbidity, dissolved oxygen and electrical conductivity. Table 5 shows the instruments used on onsite measurements. Turbidity was read off a calibrated HACH 2100N turbidity meter against distilled water set at zero.

Table 5: Devices used on onsite field measurements

Parameter	**pH**	**Electrical conductivity**	**Turbidity**	**Dissolved oxygen**
Measurement Instrument	pH ion meter pMx 3000	WTW Cond. 340i test kit	HACH 2100N turbidity kit	OXI 340i/set

4.2.4 Laboratory water quality analysis

Microbiological: Faecal coliforms were determined using the membrane filtration technique method 9222D according to Standard Methods for Water and Wastewater Examination (APHA/AWWA/WEF, 2005b) with membrane lauyrl sulphate broth (MLSB) culture media. A 10 mL water sample of was filtered through a 47-50 mm diameter membrane filters with a pore diameter of 0.45 µm. The prepared culture media was then incubated at 44^oC for 24 hours. Faecal coliforms were identified as yellow colonies.

Chlorides: Chlorides were analyzed by the method of Silver Nitrate Titration standard method 4500-CH-D using a 50 mL water sample (APHA/AWWA/WEF, 2005b). A 1 mL potassium chromate indicator was added to the water sample and then titrated with silver nitrate solution until a brick red end point was reached. Calculation per sample was based on the volume of the sample (mL) and the volume of $AgNO_3$ (mL) was used. The amount of chlorides in a groundwater sample was calculated by using Equation (1) prescribed by EPA-600/4-79-020, USEPA.

$$Cl^- = \frac{(mlofAgNO_3 - blank) \ * NormalityAgN0_3 * 35.45}{mLofSample} \ mg/L$$

Equation 1

Where:

Blank = 0.1

Normality = 0.1N $AgNO_3$

Nitrates: The ultraviolet spectrophotometric screening standard method 4500-NO_3^-B was used to measure nitrates in water sample (APHA/AWWA/WEF, 2005b). A 50 mL water sample was added 1 mL HCl solution and mixed thoroughly to prevent interference from hydroxide or carbonate concentrations upto 1000 mg $CaCO_3$/L. Preparation of standard curves was done by preparing NO_3^- calibration standards in the range of 0 to 7 mg NO_3^- N/L by diluting to 50 mL measure. Absorbance or transmittance was read against distilled water set at zero absorbance or 100% transmittance. Wavelength of 220 nm was used to obtain NO_3^- reading and a wavelength of 275 nm was used to determine interference due to dissolved organic matter. Using the corrected sample absorbance, the sample concentrations were obtained directly from the standard curve.

Ammonia: The Photometric method standard method 4500-NH_3 - A at wavelength of 630 nm - 660 nm was used to measure ammonia (APHA/AWWA/WEF, 2005b). A 10 mL water sample was used. The reagents were provided in the form of tablets. The test was carried out by adding one of each tablet to a sample of the water. Ammonia reacts with alkaline salicylate in the presence of chlorine to form a blue-green indophenol complex. The intensity of the colour produced in the test was proportional to the ammonia concentration. The resulting indophenol blue was detected by colorimetry in a flow cell. Photometric measurement was made between the wavelengths of 630 and 660 nm (APHA/AWWA/WEF, 2005a).

4.2.5 Landuse and pit latrine density assessment

Supervised classification was performed using Quantum GIS (QGIS) software to create classified thematic maps showing changes in landcover/landuse. Landsat TM and Landsat OLI images were obtained from the US Geological Survey website for the years 2000, 2005, 2009 and 2014. The landcover classification was based on spectral signatures calculated with the original image DN, the TOA reflectance image and corrected reflectance image in order to identify the different landuses (Chander and Markham, 2003). Table 7 shows the acquired Landsat images for the year 2000, 2005, 2009 and 2014. The year 2000 image was acquired to assess the landcover prior to the establishment of Hopley settlement which was established in 2005. The trend in landcover was assessed for the period 2000 to 2014. The false colour composites were used in the classification process because of their ability to enhance image interpretation that ultimately facilitates differentiation of land cover types, such as grass, woodland, cropped area and bare surfaces which are critical for assessing changes in land cover (Kibena *et al.*, 2014; Chander and Markham, 2003). Spectral angle mapping was used as the classification algorithm as outlined by Chander and Markham (2003).

Table 6: Landuse classification scheme

LANDUSE/COVER	DESCRIPTION
Built-up	Residential, commercial and services, industrial, transportation, communication and utilities, construction sites, and solid waste landfills.
Vegetation	All wooded areas, riverine vegetation, shrubs and bushes, grass cover, golf courses, parks, cultivated land or land being prepared for raising crops, fallow, land under irrigation, bare exposed areas and transitional areas.
Water	Rivers and reservoirs.

Table 7: Acquired remotely sensed Landsat images

Sensor	Date of Acquisition	Spatial Resolution (m)	Bands Used	Cloud Cover (%)
Landsat 7 ETM	2000-09-30	30	4,3,2	0
Landsat 5 TM	2005-09-13	30	4,3,2	0
Landsat_5 TM	2009-11-18	30	4,3,2	18
LANDSAT_8 OLI	2014-09-29	30	5,4,3	0.03

The location of all 4 300 pit latrines in Hopley Settlement was identified using GPS device and additional information from Google earth images of the settlement. Based on the available data, a local pit latrine density was calculated for each sampling point on a circular neighboured in radius of 15 m, 30 m, 50 m and 100 m in a GIS environment. This generated a map showing different pit latrine density estimates for each sampled groundwater location. The radius was based on previous studies and existing guidance for siting wells relative to pit latrines detailed below.

From the findings of other early researchers, a general guideline rule of 15 m between a pit privy and a well became widely accepted (BGS, 2002). In South Africa, DWAF (1997) developed a framework for selecting separation distances using contaminant risk assessment based on presence of existing latrines within 50 m located up-gradient of the well. Banks *et al*. (2002) suggested setback distances of 15 m to 30 m as the minimum standard lateral distance between on-site sanitation and water sources during disaster response. Wright *et al*. (2013) also suggested separation distances of up to 100 m between a groundwater source and pit latrines. From this the setback distance ranges from 15 m to 100 m.

4.2.6 Validation of landcover classification

The user and producer accuracy were used to assess the reliability of the land cover classification. The producer's accuracy refers to the probability that a certain landcover of an area on the ground was classified as such, while the user's accuracy refers to the probability that a pixel labelled as a certain landcover class in the map was really that class (Foody, 2002). According to Chander and Markham (2003), classification accuracy is considered good when the classified landcover for each class (i.e. vegetation or built up areas) is greater than 80%. The classification results were also compared to additional ground truth information on images obtained from a 2015 Google Earth satellite image.

4.2.7 Soil permeability analysis

The falling head test was performed for soil permeability using a calibrated manometer tube and a permeater. The soil permeability (*K)* of the soil sample was calculated following ASTM D 2434 - Standard Test Method for measurement of hydraulic conductivity of saturated porous material (ASTM, 2003). A compacted soil sample mould was allowed to soak for 24 hours to saturate completely. The manometer tube was filled with water and level drops to h_1, h_2, h_3 noted and the time recorded. The permeability coefficient (*K*) was calculated as follows:

$$K - \frac{aL}{At} In \left(\frac{h_0}{h_1}\right)$$

Equation 2

Where;

a = area of cross section of nanometer tube (mm^2)

L = length of soil sample (mm)

A = area of cross section of soil sample (mm^2)

t = time taken for water level to fall from h_0 to h_1 (minutes)

h_0 = initial height of water

h_1 = final height of water = $h_0 - \Delta h$

The permeability coefficient (*K*) was used to estimate travel time for the contaminant to reach the groundwater source.

According to Carroll *et al.* (2006), assessment of siting and design requirements for on-site systems can be achieved by soil permeability tests and an evaluation of soil structure and texture properties. Soil permeability was used to determine the suitability of the pit latrine distance from the groundwater source. Permeability was carried out from five selected soil sampling sites, that is, SB1, SB3, SW2, SW5 and SW6. Soil samples were collected at a depth of 1.5 m, which was the reported average depth for most of the pit latrines in Hopley settlement. Groundwater sources down gradient of pit latrines of the selected soil sampling sites included B1, B3, W2, W5 and W6. The permeability coefficient (*K*) was used to estimate travel time for the contaminant to reach the groundwater source. Also, the relationship between permeability coefficient (*K*) and groundwater parameters was determined using SPSS software application. The results of permeability were compared to previous studies on lateral separation distances emanating of pit latrines in relation to the groundwater sources.

4.3 Methods of Data Analysis and Interpretation

4.3.1 Landuse changes and pit latrine densities amoung sampled groundwater sources

A visualised output of classified landsat images was created using QGIS supervised classification. A classification report gave a report on percentage changes in landuse/cover i.e. vegetation or built-up areas. The population data was obtained from Zimbabwe National Statistical Agency for the year 2002 and 2012 census (ZIMSTAT, 2012). Pearson's correlation coefficient was used to establish the linkages between landcover changes and the key drivers to landuse changes such as population changes.

Pit latrine densities among the sampled groundwater sources were calculated using Geographic Information System (GIS). The pit latrine density was calculated for each sampled groundwater source within a radius of 15 m, 30 m, 50 m and 100 m to give maps. Pearson's correlation coefficients were calculated between pit latrine density and groundwater parameters.

4.3.2 Groundwater suitability for drinking water requirements

Groundwater data was analysed using the descriptive statistics analysis tool in Statistical Package for Social Sciences (SPSS) software version 16. Data of the groundwater parameters was presented as mean values, maximum and minimum values. Student t-test was used in SPSS software version 16.0 to determine whether the concentrations of parameters measured in groundwater were at levels permissible to drinking water requirements by comparing the mean levels of the analysed groundwater parameters with WHO drinking water guidelines and SAZ standards.

Singh and Kumar (2011) suggest the use of student t-test statistical method to analyse groundwater quality. The student t-test was used in SPSS to determine groundwater quality suitability for drinking water requirements by comparing the mean values of the analysed groundwater parameters with WHO drinking water guidelines and SAZ standards to show if there is any significant difference. The null (H_o) and the alternative hypotheses (H_1) were defined in the student t-test analysis between groundwater quality parameters amoung sampled sites and drinking water guidelines/standards assuming equal variances stated as follows:

$$H_o;\ \mu_{parameter} = \mu_{standard/guideline}$$

$$H_1;\ \mu_{parameter} \neq \mu_{standard/guideline}$$

The water parameter was considered a continuous variable while drinking water standards/guidelines were considered categorical variable with 2 levels (i.e. unacceptable/acceptable) coded 0 and 1. An alpha (α) of 0.05 with a two tailed test with 42 degree of freedom (df) was used. Degree of freedom was calculated as follows:

$df = (n_1 - 1) + (n_2 - 1)$;

Where $n_1 = 22$ and $n_2 = 22$

The t table was used to look up for a 2-tailed test with (df) of 42 and α of 0.05 at 95% confidence interval. The critical value (r) was read from the r-table. A critical value of 1.682 was found. Thus, decision rule for this two tailed test was: If (t) is less than −1.682 or greater than 1.682, reject the null hypotheses. The test statistic (t) was calculated using SPSS software.

4.3.3 Determination of principal water quality parameters

Principal component analysis (PCA) has been used successfully to detect major water quality processes. For example, Moyo (2013) used PCA in a study that analysed the chemical and microbiological quality of ground water from boreholes and shallow wells in Zimbabwe. In this study Principle component analysis (PCA) was used to reduce the complexity of the data sets and to ascribe concentration variations to significant processes leading to groundwater source contamination. The fundamental goal of PCA is to find a set of uncorrelated linear combinations that is able to explain most of the variance of the original multivariate data (Jolliffe, 1986). A number of “stopping rules” were proposed to determine when to stop adding factors (Gorsuch, 1983 ; Bryant and Yarnold, 1995).

The data was tested for suitability for principal component analysis through the correlation matrix and Bartlett’s Test of sphericity. In the correlation matrix, the sum of the correlations among items must have a sum of the correlation coefficients greater than or equal to 0.3 ($r \geq 0.3$) and the Bartlett’s Test of sphericity should be statistically significant at $p < 0.05$; and Kaiser-Meyer Olkin (KMO) value (dimension reduction factor) should be 0.6 or greater in order to consider the data suitable for PCA. Any correlation coefficients less than 0.3 and Bartlett’s test above 0.05 were not used. The decision on the number of components to extract was determined by the total Eigenvalue, Kaiser Criterion of the Eigenvalue scree plot, component matrix, rotated four factor solution and the component correlation matrix.

Decision on how many components to select was based on components with total Eigenvalue of greater than one and the explained cumulative percentage variance. The Kaiser criterion of the Eigenvalue of the scree plot was also used to decide the cut-off point. Components above the elbow or break of the line graph were retained because they explained much of the variance than the values of the remaining components. Values above 0.4 in the component matrix had the strongest relationship. A rotated four factor solution was presented in a pattern matrix table and values above 0.3 with three or more items loading were retained. Rotation of the two factor solution was carried out to determine the suitability of the two components solution explained in the total variance table. A component correlation matrix showed the strength of the relationship between the two factors and the decision rule was that values above 0.3 showed a strong relationship.

4.3.2 Spatial distribution of groundwater parameters

The Inverse Distance Weighting (IDW) technique was used in a GIS environment to estimate the spatial distribution of the groundwater contaminants in the environment. The sampled groundwater locations were weighted during interpolation such that the influence of one point relative to another decline with distance from the groundwater source. A weighting coefficient ($p = 2$) was used to control the drop off as the distance increased (Mitas and Mitasova, 1999).

4.3.5 Linkages between groundwater parameters

A Pearson Correlation Analysis was used to determine the degree of association between two variables, whether there was a positive or negative linear relationship. A critical value was determined for a 95% confidence interval from the sample size, n, and the Pearson Correlation Coefficient, r. The proportion of the variance in water quality was explained by the square of Pearson Correlation Coefficient. The relationship between the groundwater parameters was explained as strong as the r^2 value reached 1.0. Pearson’s correlation coefficients were also calculated between pit latrine density within radius of 15 m, 30 m, 50 m and 100 m; and groundwater contamination.

4.3.6 Relationship between soil characteristics and groundwater contamination

Pearson’s bivarient correlation analysis was also used to determine the relationship between soil permeability and depth of the groundwater level from the surface and extracted principal parameters contributing to groundwater contamination to identify if there was any significant relationship. Groundwater sources showing magnitude to groundwater contamination by faecal coliforms were mapped based on WHO drinking water guidelines was carried out by interpolation of faecal coliform data from water quality analysis of sampled groundwater sources. A visualised output map was created in QGIS software and the map showed areas with various degrees of risk to faecal coliform groundwater pollution.

CHAPTER 5
RESULTS AND DISCUSSION

5.1 Determination of pit latrine densities

5.1.1 Landuse and landcover assessment

Figure 8 shows the classified images and the landcover changes for the year 2000, 2005, 2009 and 2014. The total classified area for each thematic map was 4.0 km^2. Vegetation included grass, woodlands, shrubs and bushes based on Chander and Markham (2003).

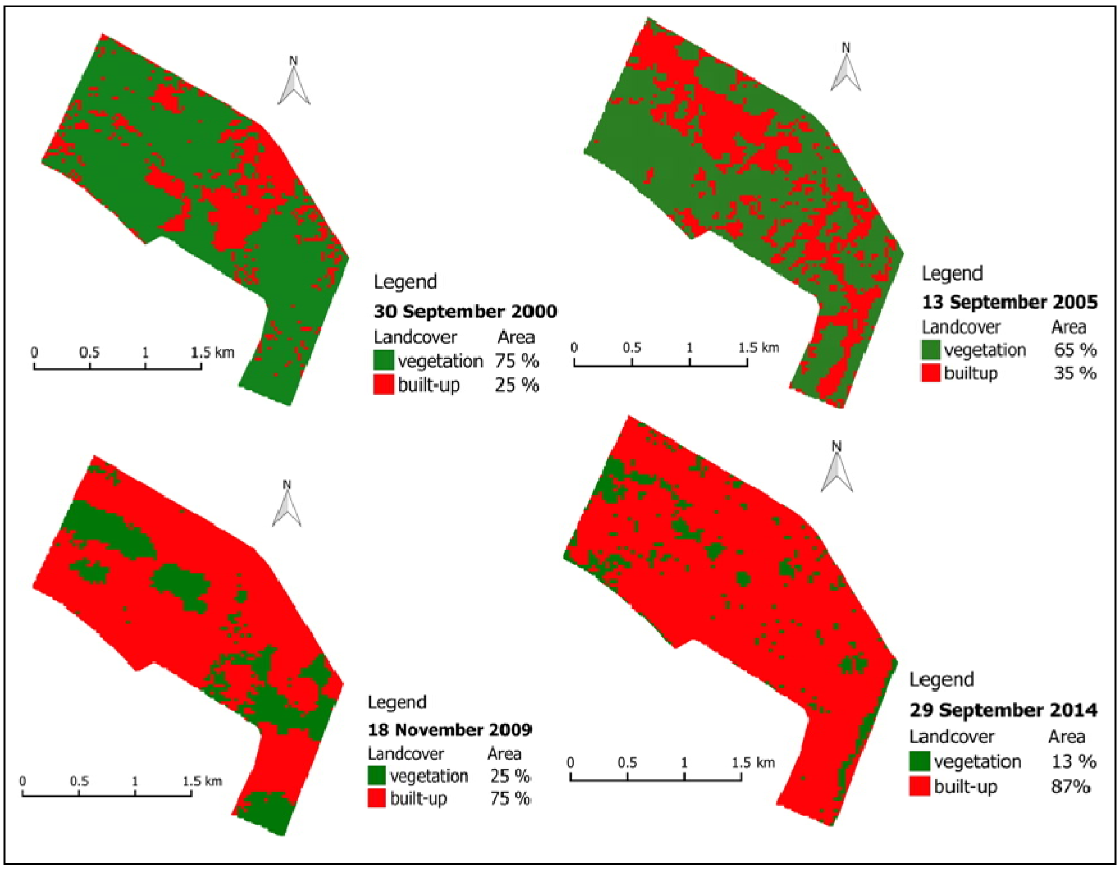


Fig. 8: Classified processed images of year 2000, 2005, 2009 and 2014

The built up area increased from 1 km^2 in 2000 to 3.5 km^2 in 2014. There was a decline in vegetation and an increase in built up areas during the period of year 2000 to 2014 showing a 250% increase in built up areas. Vegetation cover decreased from 3 km^2 in 2000 to 0.5 km^2 in 2014 (see Figure 9).

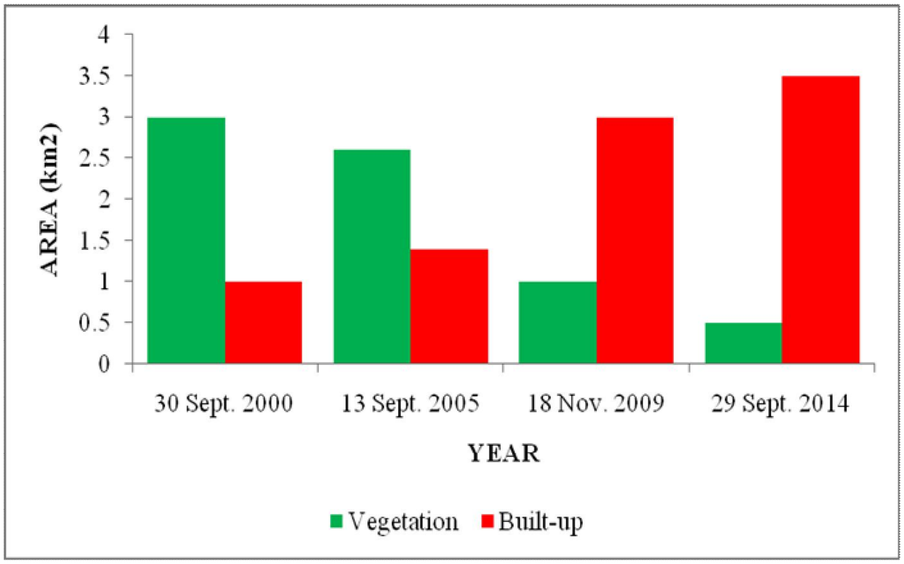


Fig. 9 Landcover trends in Hopley Settlement

According to Wright *et al*. (2013), where population density is 150-250 inhabitants per hectare (0.01 km^2), ongoing groundwater monitoring should take place for possible contamination. In September 2014, the total classified built up area was 3.5 km^2, which meant that 250 inhabitants of Hopley Settlement occupied a space of 0.014 km^2 translating to a density of 4286 people/km^2 that suggested risk of groundwater contamination by pit latrines.

5.1.2 Pit latrine densities assessment

Figure 10 and 11 shows Hopley Settlement pit latrine densities within a circular setback neighboured of radius 15 m, 30 m, 50 m and 100 m of each groundwater source location. Table 1 shows results of the number of pit latrines in each radius of the groundwater source location. There was a general increase in the number of pit latrines as the distance from the groundwater source location increased from 15 m to 100 m. The pit latrine density ranged from 0 pit latrines in a 15 m radius to 79 pit latrines in 100 m radius. Groundwater location W1 had the highest pit latrine density of 79 pit latrines in 100 m radius. There was an increase in the number of pit latrines from the groundwater source and groundwater source contamination by faecal coliforms i.e. $r(42) = 0.425$, $p<0.01$ to $r(42) = 0.654$, $p<0.01$ while groundwater nitrate, ammonia and chloride concentration decreased as the distance of the pit latrines from the groundwater source increased from 15 m to 100 m. The results suggest that an increase in pit latrine density such as at groundwater source locations W1, W2 and W8 exposed groundwater sources to faecal coliform contamination.

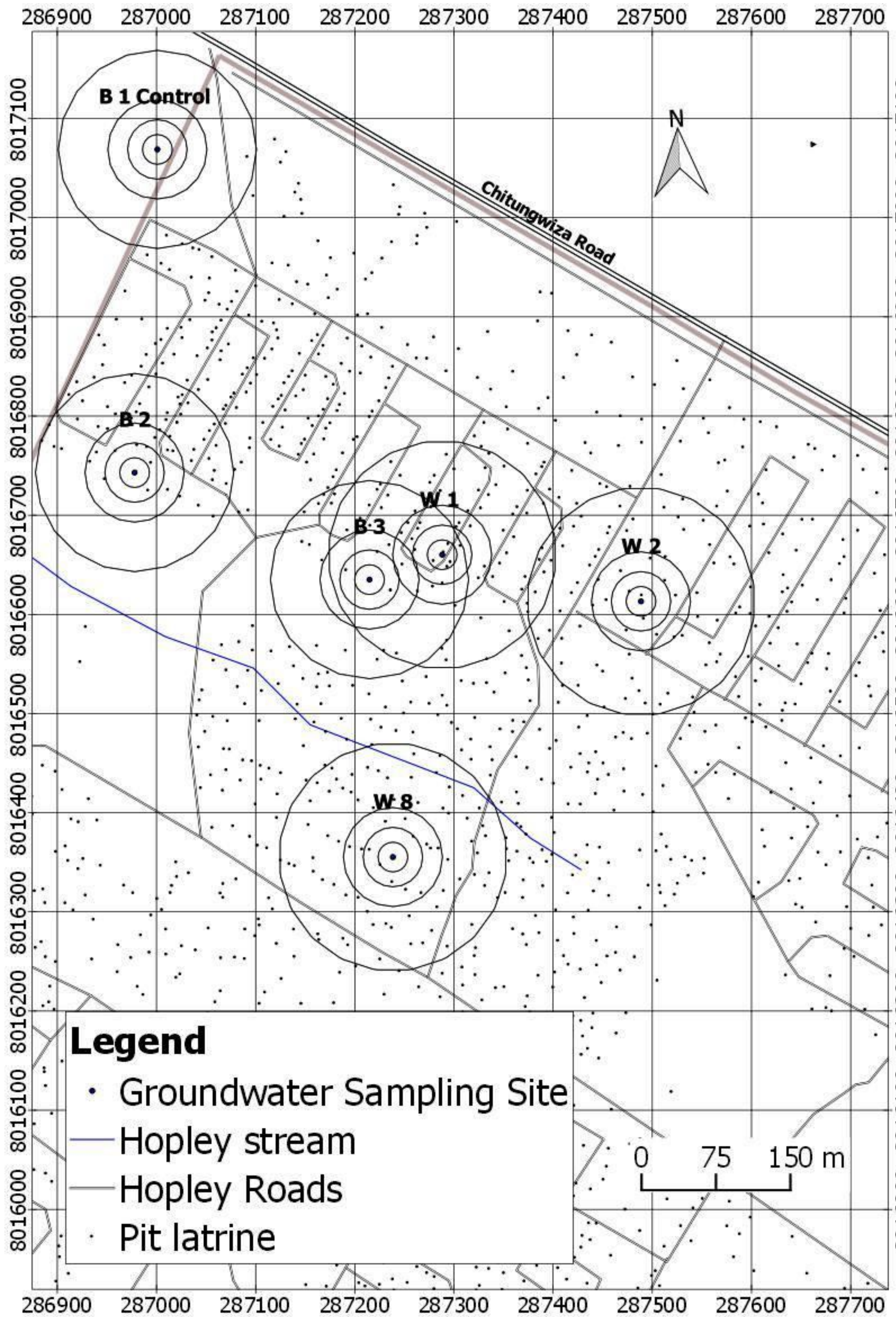


Fig. 10: Pit latrine densities in Hopley Settlement

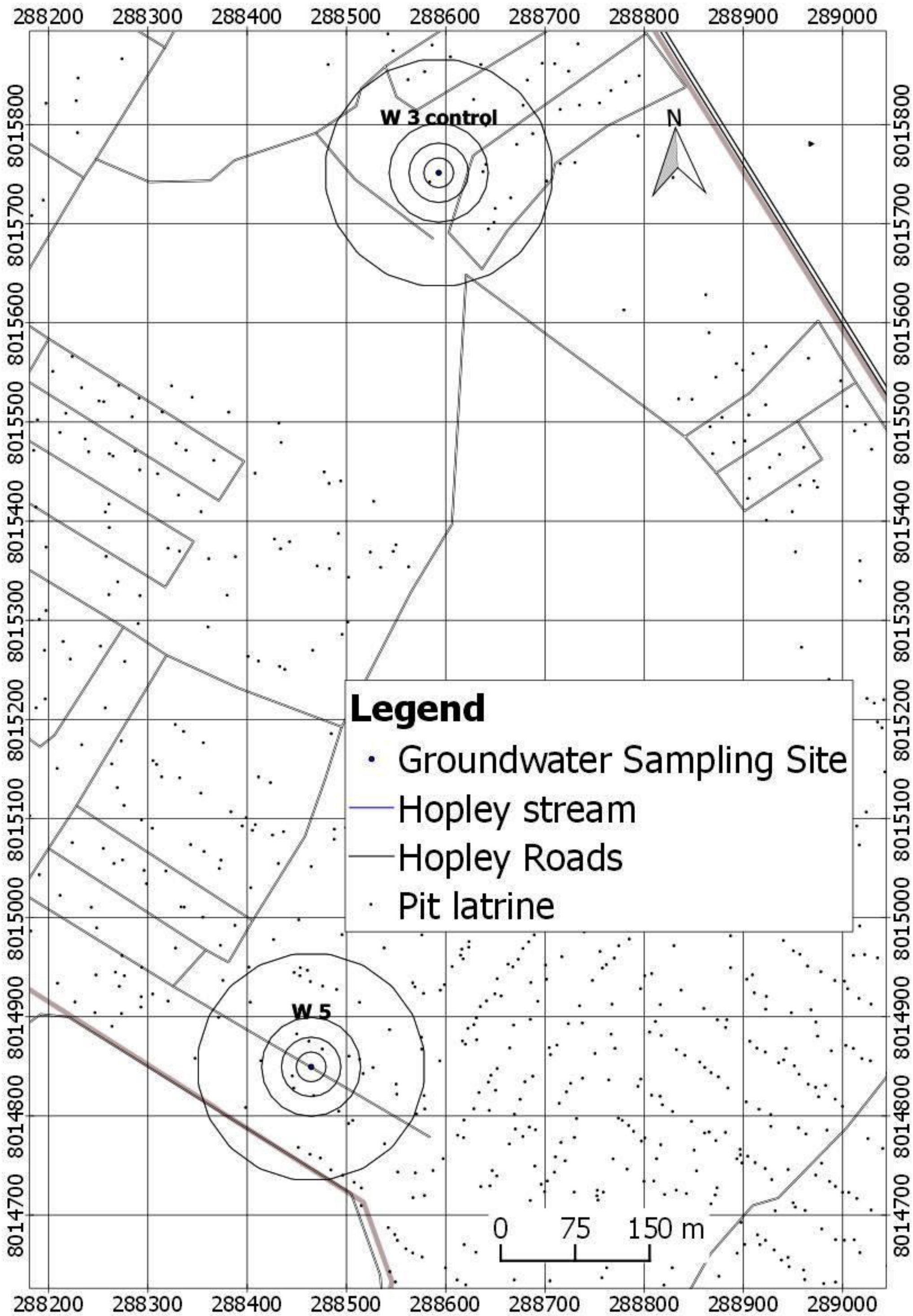


Fig. 11: Pit latrine densities in Hopley Settlement

Table 8 shows results of the number of pit latrines in a radius of 15 m, 30 m, 50 m and 100 m among the sampled groundwater sources.

Table 8: Pit latrine densities among sampled groundwater sources

SAMPLING POINT	NUMBER OF PIT LATRINES			
	15 m radius ($707\ m^2$)	30 m radius ($2,827\ m^2$)	50 m radius ($7,854\ m^2$)	100 m radius ($31,416\ m^2$)
B1	0	0	0	3
B2	0	5	13	52
B3	0	3	5	45
W1	5	8	21	79
W2	1	3	13	73
W3	1	1	3	15
W4	0	3	6	27
W5	0	5	7	35
W6	0	4	9	57
W7	0	4	8	20
W8	0	4	13	77

5.2 Determination of groundwater suitability for drinking water requirements

5.2.1 Groundwater quality

The results of the descriptive statistics analysis performed using SPSS software (v 16) for the data from the selected groundwater parameters is presented as values of mean, minimum and maximum, standard error, median, skewness and standard deviation (Table 9). The results were compared to WHO (2011) drinking water guidelines and Standards Association of Zimbabwe (SAZ) (1997) drinking water standards shown in Appendix 2. Table 9 shows a summary of the results for the water quality parameters obtained from descriptive statistics. Individual groundwater field measurements and laboratory analysis results are shown in Appendix 4 and Appendix 5 respectively.

Table 9: Summary of water quality analysis results

	pH	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Faecal Coliforms (cfu/100 mL sample)	Nitrates (mg/L)	Electrical Conductivity (µs/cm)	Ammonia (mg/L)	Chlorides (mg/L Cl^-)	Number of samples
Minimum	5.30	0.38	2.00	0	9.25	219.00	0	9.93	44
Mean	6.58	5.23	3.70	82	80.38	574.89	0.54	90.40	44
Maximum	7.20	34.80	6.04	450	324.66	1726.00	10.00	290.69	44
Std. error	0.07	1.33	0.15	0.29	13.34	63.38	0.29	11.73	44
Median	6.70	1.86	3.49	16.50	51.44	339.00	0.05	53.16	44
Skewness	− 0.99	2.64	0.54	1.65	1.82	1.40	4.47	1.36	44
Std. Deviation	0.43	8.83	0.99	88.48	88.48	420.44	1.93	77.80	44
WHO (2011)	6.5-8.5	< 5	**	0	50	<1380	< 0.2	< 300	44
SAZ 560: (1997)	6.5-8.5	< 1	> 5	0	10	< 300	**	< 250	44

** Value not specified

The mean pH of 6.7 in groundwater sources was acceptable in drinking water. Turbidity had a mean level of 5.23 NTU that was greater than the permissible level of 1 NTU and 5 NTU in terms of SAZ drinking water standards and WHO drinking water guideline value respectively. Dissolved oxygen had a mean concentration of 3.7 mg/L less than the permissible concentration of greater than 5 mg/L recommended by WHO drinking water guidelines. The results showed a mean faecal coliform count of 82 cfu/100 mL that was greater than the permissible count of 0 cfu/100 mL in drinking water. Nitrates had a mean concentration of 80 mg/L that was greater than the permissible concentration of less than 10 mg/L and 50 mg/L in terms of SAZ standards and WHO drinking water guidelines respectively threatening the health of consumers. The mean EC value of 575 µS/cm was permissible in drinking water according to WHO drinking water guidelines, while the same value was unacceptable according to SAZ Drinking Water Standards. The mean ammonia concentration of 0.54 mg/L was above the recommended value of 0.2 mg/L according to WHO Drinking Water Guidelines. Only chlorides showed groundwater mean concentration of 90.4 mg/L that was permissible in drinking water. The results showed that three (i.e. pH, chlorides and EC) out of the eight selected parameters had mean values that were acceptable in drinking water according to either the WHO Drinking Water Guidelines or SAZ Drinking Water Standards.

5.2.2 Spatial distribution of selected groundwater parameters

Figure 12 shows the spatial distribution maps for the selected groundwater parameters data among the groundwater locations sampled in Hopley Settlement that were made using GIS techniques. The colour schemes assigned were to reflect the different bands or levels in SAZ Drinking Water Standards and WHO Drinking Water Guidelines. The blue colour was for SAZ (1997) acceptable drinking water standards. The orange colour was for WHO (2011) acceptable guideline values. The red colour represented unacceptable levels. In general SAZ standards are generally stricter than the WHO Guidelines.

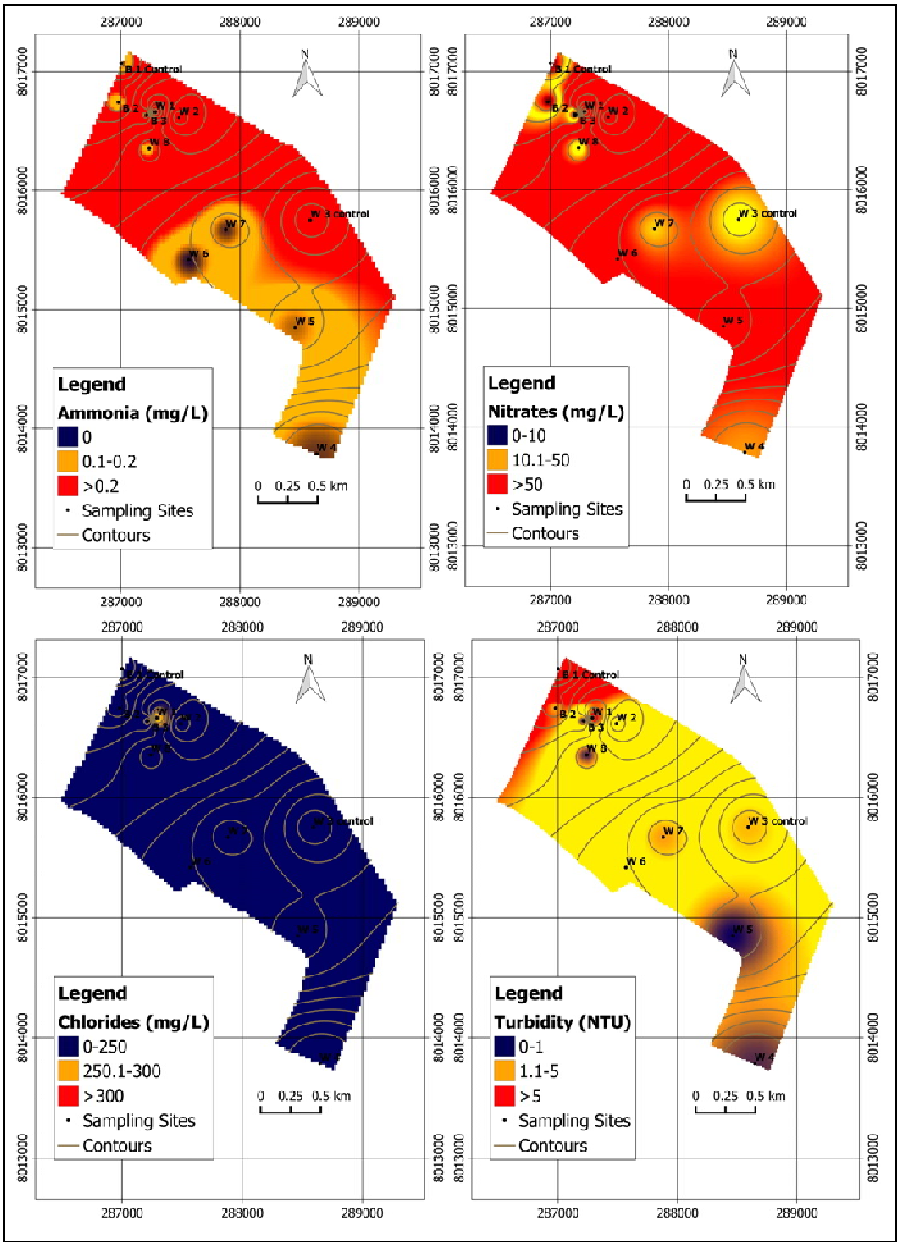


Fig. 12: Spatial distribution groundwater parameters among sampling locations for period Feb - April 2015

The area to the north in Hopley Settlement showed an earlier reduction in vegetation from year 2000 to 2014 (see Figure 8). The area to the north in Hopley Settlement was also associated with the highest pit latrine densities plus high groundwater contaminant levels of ammonia, nitrates, chlorides and turbidity.

Ammonia: The results showed that groundwater locations B1, B2, W4, W5, W6, W7 and W8 had ammonia concentrations that were at recommended levels in drinking water in terms of SAZ and WHO Drinking Water Standards and Guidelines respectively. Groundwater source locations in the north and east of Hopley Settlement were the most affected. Groundwater source locations in the north and east of Hopley Settlement (i.e. groundwater source W1, W2 and W3 had mean concentrations of 4.70 mg/L, 0.46 mg/L and 0.34 mg/L respectively) had ammonia levels that exceeded the recommended levels in drinking water in terms of both SAZ Drinking Water Standards and WHO Drinking Water Guidelines. The close proximity of the nearest pit latrine to the groundwater source W1 (3 m) seemed to explain the elevated ammonia concentration in W1. The results showed that groundwater source locations to the north of Hopley Settlement had ammonia concentrations that exceeded WHO drinking water guideline that was acceptable at 0.2 mg/L in drinking water.

Nitrates: High groundwater concentrations that are permissible in drinking water according to both SAZ standards and WHO guidelines were found in boreholes to the north in Hopley Settlement (i.e. B1, B2 and B3). While the area to the centre and east in Hopley Settlement had nitrate concentrations permissible in drinking water in terms of WHO drinking water guidelines only. Groundwater source locations to the north in Hopley Settlement (i.e. groundwater locations W1 and W2) had groundwater nitrate concentrations not permissible in drinking water according to the two reference documents. Groundwater location W1 had a mean nitrate concentration of 192 mg/L, while sampling location W2 had a mean nitrate concentration of 271 mg/L. The results suggested that wells to the north in Hopley Settlement were more exposed to groundwater source contamination by nitrates.

Chlorides: All groundwater source locations showed nitrate levels that were permissible in drinking water with reference to of SAZ standards. Only groundwater sources to the north (i.e. W1) in Hopley Settlement had groundwater chloride concentration of 278 mg/L that was permissible in drinking water in terms of WHO drinking water guidelines. The results suggested that high pit latrine densities in the north of Hopley Settlement had elevated groundwater chloride concentrations.

Turbidity: Groundwater locations to the north and east in Hopley Settlement were associated with turbidity levels greater than the permissible levels according to both SAZ standards and WHO guidelines in drinking water (B1 and W1). Groundwater sources B1 and W1 had turbidity values of 31 NTU and 7 NTU respectively. The neighbouring groundwater sources B2 and W2 had turbidity values of 5 NTU and 3 NTU, which exceeded SAZ standards of 1 NTU in drinking water which is more stringent than WHO drinking water guidelines which specifies up to 5 NTU. There was evidence of collapsing internal walls of groundwater source W1 as the well internal walls were not lined. The turbidity levels were generally within permissible levels towards the south of Hopley Settlement. Areas to the north and east of Hopley Settlement were also found turbidity levels that were not acceptable in drinking water.

Faecal coliforms: Figure 13 shows the spatial distribution of faecal coliforms. The colour schemes assigned were to reflect the different levels in WHO for spatial distribution of faecal coliforms among the groundwater locations studied based on WHO (1997) guidelines for drinking water quality that gives a comprehensive segregation of the risks. The blue colour was for 0 cfu/100mL sample in conformity with WHO Drinking Water Guidelines, orange colour was for 1 to 100 cfu/100 mL water sample for low to intermediate risk and red colour was for faecal coliform counts greater than 100 cfu/100 mL water sample for high to very high risk areas.

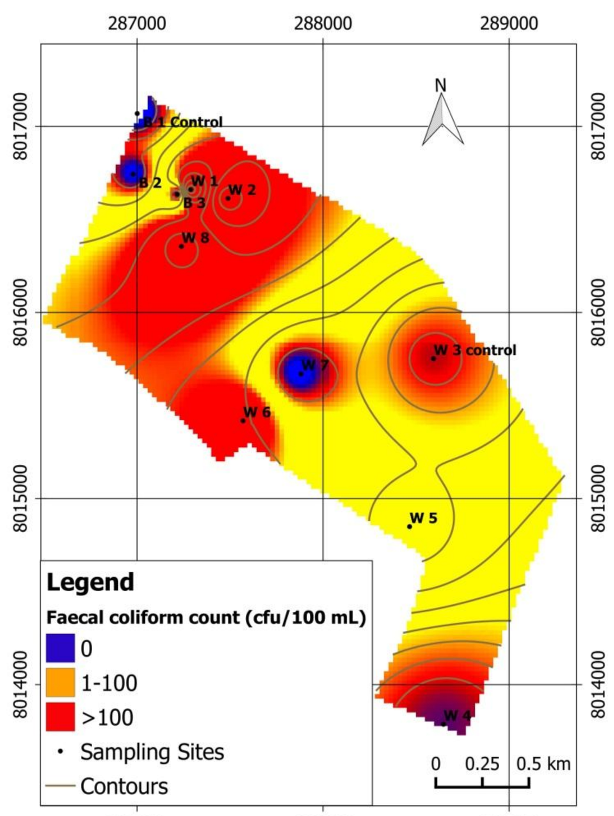


Fig. 13: Spatial distribution of faecal contamination

Faecal coliforms greater than 100 cfu/100 mL water samples were found spatially distributed to the north and west in Hopley Settlement. Mean faecal coliform counts of 240 cfu/100 mL, 153 cfu/100 mL and 223cfu/100 mL were found in groundwater source locations W1, W2 and W8 respectively to the north in the settlement, and 155 cfu/100 mL in groundwater source location W6 to the west of the settlement. The number of pit latrines in a 100 m radius of groundwater source location W1, W2 and W8 was 63, 49 and 61 pit latrines. The southern part in Hopley Settlement had a spatial distribution of faecal coliform counts of between 1 to 100 cfu/100 mL water samples. Groundwater location W5 that is in the southern part of the settlement had a mean groundwater faecal coliform count of 64 cfu/100 mL water sample. Zero cfu/100 mL water samples were found to the northern periphery and south end in Hopley Settlement (i.e. groundwater source locations B1 and B2 to the north and W4 to the south end).

The results also suggested that groundwater sources to the north in Hopley Settlement were at very high risk to faecal coliform contamination. High pit latrine densities were also found in the north of Hopley Settlement. While groundwater source locations to the south of the settlement were at intermediate risk. Groundwater source locations to the northern edge, centre and southern edge in the settlement were in conformity with WHO guidelines. As earlier established, groundwater source locations to the north in Hopley Settlement were at a higher chance of groundwater ammonia, nitrates, chlorides, turbidity including faecal coliforms levels that were not permissible in drinking water.

5.2.3 Relationship between groundwater quality and water level depth

Table 10 shows the mean groundwater level depth and groundwater contaminant concentration among the sampled groundwater source locations while Figure 14 shows the changes in groundwater level depth at each sampling campaign. The mean water level depth from the surface among the sampled groundwater locations varied from 0.2 m to 4 m. Groundwater location W1 and W2 showed the highest groundwater source levels of nitrates, EC, ammonia and chlorides. Groundwater source location W1 had mean depth of 1.4 m and groundwater source mean levels of 6.7, 7.0 NTU, 2.8 mg/L, 240 cfu/100 mL water sample, 192 mg/L, 1570 μS/cm, 4.7 mg/L and 278 mg/L for pH, turbidity, DO, FC, nitrates, EC, ammonia and chlorides respectively. While, groundwater location W2 had groundwater source mean levels of 6.2, 3.2 NTU, 4.2 mg/L, 153 cfu/100 mL water sample, 271 mg/L, 968 µS/cm, 0.46 mg/L and 174 mg/L for pH, turbidity, DO, FC, nitrates, EC, ammonia and chlorides respectively at a mean water level depth of 2.8 m.

Groundwater quality varied with increasing depth. The average depth of the pit latrines was 1.5 m to 2 m and the depth of the water points ranged from 2 m to 8 m. There was a significant positive relationship between groundwater level depth from the surface and groundwater pollution by chlorides, r (18) = 0.764, $p<0.05$. An increase in depth of the groundwater level corresponded with an increase in groundwater chloride concentration.

Table 10: Mean groundwater level depth and groundwater contaminant concentrations

Groundwater sampling site	Mean water level depth (m)	pH	Turbidity (NTU)	DO (mg/L)	FC (cfu/100 mL)	Nitrates (mg/L)	EC (µS/cm)	Ammonia (mg/L)	Chlorides (mg/L)
B1	4.4	6.8	31.0	0.2	0	27.9	1010.5	0.35	144.7
B2	2.4	6.9	5.2	3.3	5	27.9	300	0.08	37.2
B3	1.4	7.1	1.1	3.8	9	13.2	312.5	0.08	42.5
W1	1.4	6.7	7.0	2.8	240	192.0	1570.3	4.70	278.3
W2	2.8	6.2	3.2	4.2	153	271.0	968.3	0.46	173.7
W3	3.0	6.6	2.0	5.4	24	50.2	528.8	0.34	88.6
W4	0.4	6.1	1.3	3.5	19	59.1	250.3	0.04	31.9
W5	0.7	6.7	1.1	3.3	64	70.9	249.5	0.06	31.9
W6	2.1	6.4	2.3	4.1	155	68.6	267.5	0.02	46.1
W7	1.3	6.4	1.9	4.1	5	55.5	335.8	0.04	44.3
W8	0.2	6.7	1.3	4.2	223	47.7	530.8	0.10	75.2

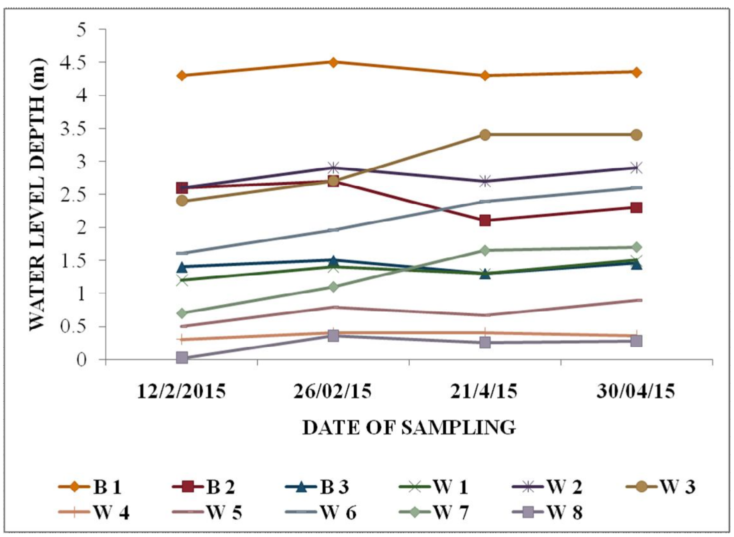


Fig. 14: Changes in water level depth in groundwater source

It was observed that groundwater chloride concentration increased with decrease in water table below ground. The least mean water level depth was 0.7 m at groundwater source W5 and the corresponding mean chloride concentration was 32 mg/L. The highest mean water level depth was 4.4 m below ground at groundwater source location B1 and a corresponding mean chloride concentration of 144 mg/L. The mean water level at groundwater source W6 was 2.1 m and a mean chloride concentration of 46 mg/L. The low chloride concentration at groundwater source location W6 was attributed to the well lined internal walls of the well that provided a filtration barrier. The results suggest that deeper depths of the water level had higher concentrations of chlorides in groundwater sources. The foregoing observation was in contrast to results from a study in Bangladesh where chloride concentrations reached 400 mg/L at shallow depths, but then decreased with depth and distance from pit latrines (Ahmed *et al.*, 2002). Differences in results found in the study by Ahmed *et al* (2002) were attributed to high pit latrine densities in Hopley Settlement and relatively low dilution of the groundwater source locations at deeper depths.

5.2.4 Groundwater quality suitability for drinking

The results of the student t-test showed descriptive statistics (group statistics) and the independent t-test results. Appendix 6 shows the results of the group statistics and independent t-test.

The percentage unacceptable and acceptable was calculated from Equation 3.

$$unacceptable\ or\ acceptable\ (\%) = \frac{n}{N} * 100$$

Equation 3

Where: n = number of group groundwater sources

N = number of all the groundwater sources

A Student t-test was carried out on groundwater quality data of 44 groundwater samples from 11 sampling locations for eight water quality parameters to determine whether each parameter had levels acceptable/unacceptable in drinking water. The pH levels unacceptable in drinking water according to WHO Drinking Water Guidelines were found in 34% of the groundwater samples while 66% was at acceptable levels of between pH 6.5-8.5. Turbidity found in 34% of the groundwater samples exceeded the WHO guideline value of greater than

5 NTU in drinking water, while 66% of the groundwater source samples were at levels below 5 NTU. Dissolved oxygen was found in 64% of the groundwater samples at less than 5 mg/L, while 36% were at concentrations greater than 5 mg/L permissible in drinking water in terms of the WHO drinking water guidelines. The analysed groundwater had 84% of the groundwater samples with faecal coliform counts that exceeded WHO drinking water guideline value of 0 cfu/100 mL in drinking water while 16% were of zero cfu/100 mL. Nitrates that exceeded the maximum WHO guideline value of 50 mg/L in drinking water was found in 50% of the groundwater samples while 50% of the groundwater samples were below 50 mg/L. Only 9% of the groundwater samples had EC at unacceptable levels and 91% were at acceptable levels. Ammonia exceeded the WHO guideline value of greater than 0.2 mg/L in drinking water in 14% of the groundwater samples while 86% were at levels below 0.2 mg/L acceptable in drinking water. Chlorides were found acceptable in drinking water in 100% of the analysed groundwater samples.

The results seemed to suggest that FC, DO and nitrates were problematic in groundwater source contamination as shown by 50% or more of the samples having concentrations that exceeded the recommended levels in drinking water. Results suggested that most of the groundwater sources are exposed to faecal contamination and are at the risk of the presence of pathogenic organisms in drinking water. The pH, turbidity, EC, ammonia and chlorides were less problematic in groundwater source contamination since each contaminant concentration exceeding permissible levels in drinking water was found in less than 50% of the analysed groundwater samples.

5.2.5 Selection of principal parameters in Principal Component Analysis

SPSS 16.0 software was used to carry out PCA to determine the main principal components from the original variables. A number of “stopping rules” were proposed to determine when to stop adding factors (Bryant and Yarnold, 1995). The data was tested for suitability for principal component analysis through the correlation matrix and Bartlett’s Test of sphericity. Table 11 showed Kaiser-Meyer-Olkin Measure of Sampling Adequacy. The data was considered suitable for principal component analysis since the obtained KMO value (0.612) was greater than 0.6 and the Bartlett’s test of sphericity value (0.000) was less than 0.05. Retained items had correlation coefficients of above 0.3.

Table 11: Sampling adequacy using Kaiser-Myer- Olkin (KMO) and Bartlett's Test

Kaiser-Myer- Olkin Measure of Sampling Adequacy		0.612
Bartlett's Test of Sphericity	Approx. Chi-Square	213.465
	df	28
	Sig.	0.000

Table 12 showed the correlation matrix (SPSS output) used to select components suitability for principal component analysis. Items retained included faecal coliforms, nitrates, chlorides; electrical conductivity, ammonia and turbidity that had correlation coefficients of above 0.3. The excluded items included pH and dissolved oxygen.

Table 12: Correlation coefficients of groundwater parameters

	Faecal Coliforms	Ammonia	Nitrates	Chlorides	EC	pH	DO	Turbidity
Faecal Coliforms	1.000	0.246	0.471	0.367	0.373	0.026	0.076	−0.141
Ammonia	0.246	1.000	0.578	0.549	0.613	0.196	−0.201	0.122
Nitrates	0.471	0.578	1.000	0.558	0.574	−0.170	0.038	−0.045
Chlorides	0.367	0.549	0.558	1.000	0.959	−0.118	−0.213	0.354
EC	0.373	0.613	0.574	0.959	1.000	−0.044	−0.312	0.477
pH	0.026	0.196	−0.170	−0.118	−0.044	1.000	−0.121	0.051
DO	0.076	−0.201	0.038	−0.213	−0.312	−0.121	1.000	−0.550
Turbidity	−0.141	0.122	−0.045	0.354	0.477	.051	−0.550	1.000

5.2.6 Number of principal components selected

The Kaiser Criterion of the Eigenvalue of the scree plot was used to extract the principal components (Bryant and Yarnold, 1995) of groundwater contamination. Based on the Eigenvalue screen plot shown in Figure 15, the 8 groundwater parameters (i.e. nitrates, EC, chlorides, ammonia, FC, turbidity, DO and pH) were reduced to three i.e. nitrates, electrical conductivity and chlorides in PCA. Components 1, 2 and 3 (nitrates, EC and chlorides) with total Eigenvalue of greater than 1 (i.e. PCs explaining more than the variance of one parameter) were extracted (Haag and Westrich, 2002). The cumulative percentage for the nitrates, EC and chlorides was 76% and this percentage explained the majority of the variance among the selected groundwater parameters (see Appendix 3).

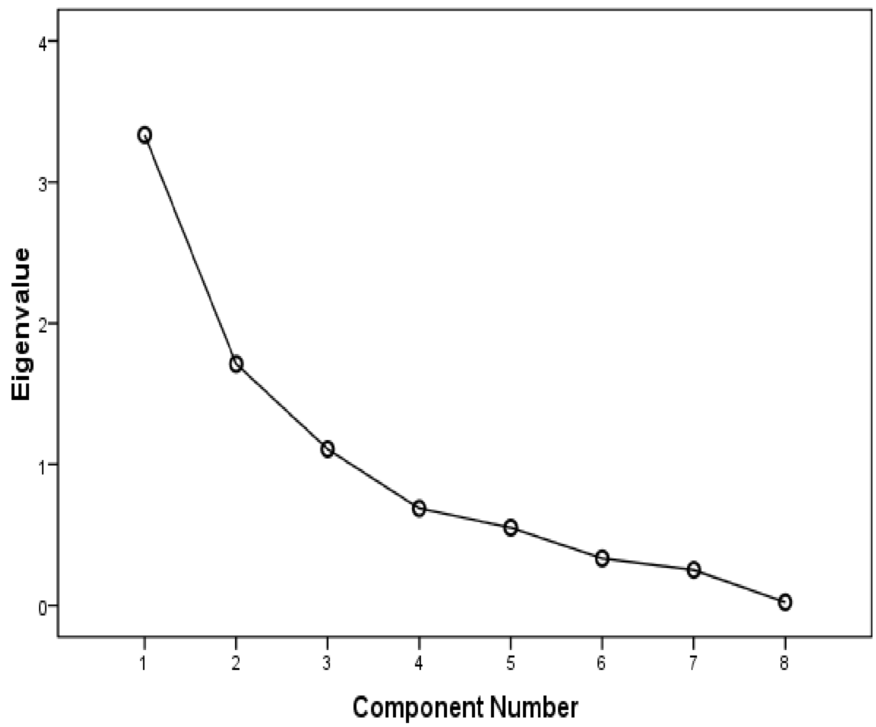


Fig. 15: Relationship between the relative magnitude of the Eigenvalue and the number of factors

Appendix 3 shows the total variance explained table indicating the total Eigenvalue and the explained cumulative percentage of variance used in deciding the number of items. Based on the Eigenvalue, the eight groundwater parameters were reduced to 3 main factors (factors 1, 2 and 3) from the levelling off point(s) in the screen plot. The first factor (nitrates) corresponding to the largest Eigenvalue (3.33) accounted for approximately 42% of the total variance. The second factor (EC) corresponding to the second Eigenvalue (1.712) accounted for approximately 21% of the total variance. The third factor (chlorides) corresponding to the third Eigenvalue (1.108) accounted for approximately 14% of the total variance. The remaining 5 factors have Eigenvalue of less than unity. Any factor with an Eigenvalue greater than 1 was considered significant. PCA concluded that nitrates, chlorides and electrical conductivity were the principal parameters negatively impacting on groundwater quality.

There was a strong positive relationship between electrical conductivity and chlorides, $r(42) = 0.959$, $p < 0.05$. Chlorides accounted for 92% of the variability in electrical conductivity. There was also a positive relationship between electrical conductivity and nitrates, $r(42) = 0.574$, $p < 0.05$. High levels of chlorides and nitrates had a corresponding increase in electrical conductivity as indicated by the water quality results of sampling site W1 that recorded levels of above 1000 μS/cm. Nitrates accounted for 33% of electrical conductivity variability. Electrical conductivity is due to presence of dissolved charged ions and contributes significantly to TDS (Hoko, 2005). There was a positive relationship between nitrates and chlorides, $r(42) = 0.558$, $p < 0.05$ (Banks *et al.*, 2002). Elevated levels of chlorides and nitrates in groundwater source locations were accompanied with corresponding higher levels of electrical conductivity (see Table 10).

5.2.7 Relationship between pit latrine density and groundwater contamination

The pit latrine density was correlated with groundwater contamination by nitrates, ammonia, chlorides and faecal coliforms. Nitrates and chlorides were selected because they explained the majority of the variance of the data set in PC analysis. The most important contaminant from a public health perspective is faecal coliforms and they suggest risk to groundwater source contamination by pathogenic microorganisms (WHO, 2011). Higher turbidity levels can protect disease causing microorganisms such as viruses, parasites and some bacteria (WHO, 1997). Ammonia is derived either directly from pit latrine waste (Graham and Polizzotto, 2013).

The results of the relationship between pit latrine density and groundwater contamination are shown in Table 13. The pit latrine densities were obtained from earlier selection of absolute radius of 15 m, 30 m, 50 m and 100 m. There was a decrease in groundwater contamination by nitrates, ammonia and chlorides as the distance of the groundwater increased from 15 m to 100 m. The results suggested that groundwater source contamination by nitrates, ammonia and chlorides was more related to the 15 m and 30 m setback distance of the groundwater source locations to pit latrines. Setback distances beyond 50 m seemed to have no effect on groundwater contamination by nitrates, ammonia and chlorides. The number of pit latrines in 15 m and 30 m radius ranged from 0-5 and 0-8 pit latrines respectively.

Table 13: Relationship between groundwater contamination and pit latrine densities

		Nitrate	Ammonia	Faecal coliforms	Chlorides
Density 15	Pearson Correlation	0.552**	0.684**	0.425**	0.843**
	Sig. (2-tailed)	0.000	0.000	0.004	0.000
	N	44	44	44	44
Density 30	Pearson Correlation	0.301*	0.441**	0.412**	0.262
	Sig. (2-tailed)	0.051	0.003	0.006	0.103
	N	44	44	44	44
Density 50	Pearson Correlation	0.528**	0.487**	0.562**	0.508**
	Sig. (2-tailed)	0.000	0.001	0.000	0.000
	N	44	44	44	44
Density 100	Pearson Correlation	0.525**	0.354*	0.654**	0.323*
	Sig. (2-tailed)	0.001	0.032	0.000	0.012
	N	44	44	44	44

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

There was generally an increase in the positive relationship between groundwater source contamination by faecal coliforms and an increase in pit latrine density. Other than proximity of the nearest pit latrine to the groundwater source location, high faecal coliform counts in groundwater source locations seemed to relate more to the increasing number of pit latrines from 15 m to 100 m setback distances and also ground surface water runoff into wells with inadequately protected well head. The number of pit latrines in 15 m to 100 m ranged from 0-63 pit latrines.

5.2.8 Relationship between soil permeability and spatial distribution of selected groundwater parameters

A summary of the soil permeability analysis for the soil sampling sites SB1, SB3, SW2, SW5 and SW6 is presented in Table 14. The soil sampling sites corresponded to pit latrine drainage field to groundwater source locations B1, B3, W2, W5 and W6. Table 14 also shows the distance between the nearest pit latrine and groundwater source; and the estimated travel time in days for the liquid to reach the groundwater source.

Table 14: Results of estimated travel time and travel distance of the liquid

Soil sampling site	*K* values (m/s)	Distance of nearest upstream pit latrine from groundwater source(m)	Travel time (s)	Travel time (days)
SB1 (control)	8.0×10^{-7}	40	50,000,000.0	579
SB3	4.1×10^{-7}	13	31,707,317.0	367
SW2	7.3×10^{-7}	13	17,808,219.0	206
SW5	2.2×10^{-7}	10	45,454,545.0	526
SW6	2.3×10^{-6}	10	4,347,826.0	50

Note *K*-permeability*1 day = 86,400 seconds

Travel time for contaminates to reach the groundwater source varied from 50 days for SW6 upto 579 days for SB1. The travel time was estimated from permeability coefficient and the distance of the nearest pit latrine from the groundwater source location. Soil sampling site SW6 showed the highest permeability value of 2.3×10^{-6} m/s. According to Bear (1972) the hydraulic conductivity values were related to consolidated rocks that are linked to soils of relatively low permeability.

Table 15 shows results of pathogen survival in soil that was calculated from the permeability coefficients of the sampled soil sites. The estimated travel time for pit latrine contents to reach a groundwater source was converted to months to estimate the pathogen survival in soil before reaching the groundwater source location.

Table 15: Soil permeability, travel times and pathogen survival in soil

Soil sampling site	**Travel time(days)**	**Pathogen survival(months)**
SB1 (control)	579	19
SB3	367	12
SW2	206	7
SW5	526	18
SW6	50	2

The survival times of organisms in soil are given in Table 16 (WHO, 1992). The estimated time for pit latrine contents (travel time) to reach groundwater was compared to pathogen survival times in soil in order to explain the risk of groundwater source contamination by pathogenic microorganisms. It should be noted that these pathogen survival times are approximate, being dependent on local factors such as climate, the concentration and species of organisms. Soil sampling site SW6 had the highest permeability coefficient and the nearest pit latrine distance of 10 m. The travel time was 50 days and comparing with pathogen survival time the results suggest that high permeability coefficients and short setback distances were at greater risk to bacteria, viruses and helmiths contamination.

Table 16: Pathogen survival time in soil (WHO. 1992)

Pathogen	**Survival Times For Pathogens In Soil**
Bacteria	Few days to 3 months
Vibrio cholera	<3 weeks
Faecal coliform	<2 months
Viruses	Months
Enteroviruses	<3 months
Protozoa (cysts)	Few days to few weeks
Entamoeba species	<3 weeks
Helmiths	Months
Ancylostoma species	<3 months
Ascaris species	Many months
Flukes	Hours

Table 17 shows the mean levels for FC, ammonia, nitrates, chlorides, EC, pH, turbidity and DO for groundwater source locations B1, B3, W2, W5 and W6 and the corresponding soil sampling sites in the vicinity of the groundwater source locations was SB1, SB3, SW2, SW5 and SW6. Soil sampling site SW2 and SW6 showed a travel time of seven months and two months respectively making groundwater locations W2 and W6 prone to pathogen contamination (WHO, 1992). Groundwater source locations W2 and W6 were found north and west in Hopley Settlement. The mean faecal coliform count at groundwater location W2 and W6 was 153 cfu/100 mL and 155 cfu/100 mL respectively (distances from the nearest pit latrine upstream of the groundwater source location was 13 m and 10 m respectively). Groundwater source locations W2 and W6 had also elevated groundwater nitrates and chlorides. Groundwater source location W2 had 271 mg/L chlorides and 174 mg/L chlorides, while W6 had 69 mg/L nitrates and 46 mg/L chlorides. There were generally lower groundwater contaminant levels as the soil permeability decreased.

Table 17: Mean levels of groundwater parameters corresponding to soil sampling locations

Soil sampling site	Corresponding Groundwater location	FC (cfu/100 mL)	Ammonia (mg/L)	Nitrates (mg/L)	Chlorides (mg/L)	EC (µS/cm)	pH	Turbidity (NTU)	DO (mg/L)
SB1	B1	0	0.35	27.9	144.7	1010.5	6.8	31.0	0.2
SB3	B3	9	0.08	13.2	42.5	312.5	7.1	1.1	3.8
SW2	W2	153	0.46	271.2	173.7	968.3	6.2	3.2	4.2
SW5	W5	64	0.06	70.9	31.9	249.5	6.7	1.1	3.3
SW6	W6	155	0.02	68.6	46.1	267.5	6.4	2.3	4.1

The results of the studies carried out by Dzwairo *et al*. (2006) observed that pit latrines were microbiologically impacting groundwater quality up to a distance of 25 m from the groundwater source. Cave and Kolsky (1999) observed that bacteria travel up to 3 m in the direction of groundwater flow and they diminish with distance. In a study from Botswana, Lewis *et al*. (1980) found that the highest chloride concentrations occurred in soils closest to pit latrines. By analyzing water samples from installed boreholes in a settlement in Epworth in Zimbabwe, Zingoni *et al*. (2005) demonstrated that the highest nitrate concentrations in groundwater were associated with the highest population and pit latrine densities within the settlement. The results also showed that areas to the north and west in Hopley Settlement were at a greater chance of groundwater contamination, and were associated with high permeability values.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions were drawn from the results:

1. The study revealed that high population density had a corresponding increase, increase in groundwater parameters exceeding levels unacceptable in drinking water according to WHO Drinking Water Guidelines and SAZ Drinking Water Standards.
2. The results showed that areas to the north and west in Hopley Settlement were more problematic to groundwater source contamination that exceeded recommended levels in drinking water i.e. FC, ammonia and nitrates, which have public health implications when consumed.
3. The study concluded that groundwater sources to the north of Hopley Settlement had a greater percentage of groundwater parameters exceeding permissible levels in drinking water. This area was associated with the highest pit latrine density of up to 79 pit latrines in 100 m radius of a groundwater source.
4. The permeability results suggested that the soils had the capacity to attenuate microorganisms before contaminating groundwater provided that there was adequate separation distance between the groundwater source location and he nearest pit latrine. Areas to the north and west in Hopley Settlement had relatively high permeability values and higher groundwater contamination.

6.2 Recommendations

It is, therefore, recommended that:

1. It was recommended to improve on water and sanitation infrastructure by the application of low cost technologies (e.g. EcoSan) in the management of human waste in order to protect groundwater resources in peri-urban areas.
2. The use of household water treatment techniques such as the use of chlorine based substances is recommended where groundwater is exposed to faecal coliform contamination.

3. Due to nitrate, chloride and faecal coliform contamination of groundwater, it is also recommended to protect the well head and also line pit latrines with concrete to minimize seepage of pit latrine contents.

REFERENCES

Ahmed, K.M., Khandkar, Z.Z., Lawrence, A.R., Macdonald, D.M.J., Islam, M.S., 2002. Appendix A: an investigation of the impact of on-site sanitation on the quality of groundwater supplies in two peri-urban areas of Dhaka, Bangladesh, Assessing Risk to Groundwater from On-site Sanitation: Scientific Review and Case Studies. British Geological Survey, Keyworth, UK: Available: http://r4d.dfid.gov.uk/pdf/outputs/r68692.pdf [accessed 14 March 2015]. pp. 37-67.

Albonico, M., Allen H, Chitsulo L, Engels D, Gabrielli AF, Savioli L., 2008. Controlling Soil-Transmitted Helminthiasis in Pre-School-Age Children through Preventive Chemotherapy. PLoS neglected tropical diseases 2(3): 1-11.

Amnesty International, 2010. No Chance to Live, Newborn Deaths at Hopley Settlement, Zimbabwe. Amnesty International, London: http://www.amnestyusa.org/sites/default/files/nochancetolivereport.pdf [accessed July 15, 2015].

APHA/AWWA/WEF, 2005a. “Method 4500-NH3 G: Nitrogen (Ammonia) Automated Phenate Method.” Standard Methods for the Examination of Water and Wastewater. 21st Edition. http://www.standardmethods.org/ [accessed June 3, 2015].

APHA/AWWA/WEF, 2005b. Standard Methods for the Examination of Water and Wastewater: 21st ed., Washington D.C, USA.

Arogo, J., Westerman, P.W., Heber, A.J., Robarge, W.P., Classen, J.J., 2001. Ammonia in animal production - a review. Paper number 014089, 2001 presented at the ASAE Annual Meeting July 30- August 1, 2001. American Society of Agricultural and Biological Engineers, Sacramento, USA.

ASTM, 2003. Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter, ASTM D5084-03. ASTM International, West Conshohocken, PA: http://www.astm.org/Standards/D5084.htm [accessed May 28, 2015].

Banerjee, G., 2011. Underground pollution travel from leach pits of on-site sanitation facilities: a case study. Clean Technologies and Environmental Policy, 13(3): 489-497.

Banks, D., Karnachuk, O., Parnachev, V., Holden, W., Frengstad, B., 2002. Groundwater contamination from rural pit latrines: examples from Siberia and Kosova. J Chartered Inst Water Environ Manage 16(2): 147-152.

Barnett, H., Ormiston, S., 2010. Manual for On-site Wastewater SystemsDesign and Management: MANAGING OUR ENVIRONMENT. 2010/EXT/1102, Horizons Regional Council, Auckland.

BGS, 2001. Guidelines for assessing the risk to groundwater from on-site sanitation. British Geological Survey Commissioned Report, CR/01/142. , British Geological Survey, Wallingford, UK. Available: http://www-esd.worldbank.org/esd/ard/groundwater/pdfreports/Guidelines_assessing_risk_to_Gdwtr.PDF [accessed 14 March 2015].

BGS, 2002. Assessing Risk to Groundwater from On-site Sanitation: Scientific Review and Case Studies., British Geological Survey: Groundwater Systems and Water Quality Programme Commissioned Report CR/02/079N, Keyworth, UK. Available: http://r4d.dfid.gov.uk/pdf/outputs/r68692.pdf [accessed 14 March 2015].

Blarasin, M., Cabrera, A., Frigerio, C., Bettera, S., 2002. Appendix C: Risk of groundwater pollution by on-site sanitation, geochemical models and geoindicators, Rio Cuarto City, Argentina. In: Assessing Risk to Groundwater from On-site Sanitation: Scientific Review and Case Studies. British Geological Survey, Keyworth, UK, pp. 94-105. Available: http://r104d.dfid.gov.uk/pdf/outputs/r68692.pdf [accessed 28 March 2015].

Broderick, T.J., 2012. Notes on the Harare Groundwater Situation, Harare: Available: http://archive.kubatana.net/docs/watsan/broderick_harare_groundwater_1210.doc [accessed 20 April 2015].

Bryant, F.B., Yarnold, P.R., 1995. Principal-components analysis and exploratory and confirmatory factor analysis ,Reading and understanding multivariate statistics., In L. G. Grimm & P. R. Yarnold ed. American Psychological Association, Washington, DC. Available: http://www.statisticssolutions.com/factor-analysis-sem-factor-analysis/ [accessed 21 April 2015]

Cairncross, S., Hunt, C., Boisson, S., Bostoen, K., Curtis, V., Fung, I.C., Schmidt, W.-P., 2010. Water, sanitation and hygiene for the prevention of diarrhoea. International journal of Epidemiology, 39(suppl 1): i193-i205.

Caldwell, E.L., 1938. Studies of subsoil pollution in relation to possible contamination of the ground water from human excreta deposited in experimental latrines. J Infect Dis, 62(3): 272-292.

Caldwell, E.L., Parr, L.W., 1937. Ground water pollution and the bored hole latrine. The Journal of Infectious Diseases, 61(2): 148-183.

Carroll, S., Goonetilleke, A., Thomas, E., Hargreaves, M., Frost, R., Dawes, L., 2006. Integrated Risk Framework for Onsite Wastewater Treatment Systems Environmental Management 38(2): 286-303.

Cave, B., and , Kolsky, P., 1999. WELL Study, Groundwater, latrines and health,Task No: 163, WEDC, Loughborough University, UK.

CCME, 2006. A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines. PN 1332. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba.

Chander, G., Markham, B., 2003. Revised Landsat-5 TM radiometric calibration procedures and postcalibration dynamic ranges Geoscience and Remote Sensing. IEEE Transactions (41): 2674 - 2677.

Chave, P., Howard, G., Schijven, J., Appleyard, S., Fladerer, F., Schimon, W., Schmoll, O., Chilton, J., Chorus, I., 2006. Groundwater protection zones. Protecting groundwater for health: managing the quality of drinking-water sources: 465-492.

Chidavaenzi, M., Bradley, M., Jere, M., Nhandara, C., 2000. Pit latrine effluent infiltration into groundwater: the Epworth case study. Schriftenr Ver Wasser Boden Lufthyg (105): 171-177.

Chidavaenzi, M., Jere, M., Bradley, M., 1997. Pit latrine effluent infiltration into groundwater, WEDC CONFERENCE. WATER, ENGINEERING AND DEVELOPMENT CENTRE, pp. 59-62.

Chirisa, I., Gaza, M., Banduko, E., 2014. Housing Cooperatives and the Politics of Local Organization and Representation in Peri-Urban Harare, Zimbabwe. African Studies Quarterly, 15(1). Available: https://sites.clas.ufl.edu/africa-asq/files/Volume-15-Issue-1-Chirisa-Gaza-and-Bandauko.pdf [accessed 20 March 2015]

Choudhary, R., Rawtani, P., Vishwakarma, M., 2011. Comparative study of drinking water quality parameters of three manmade reservoirs i.e Kolar, Kaliasote and Kerwa Dam. Current world environment, 6(1): 145-149.

City of Harare, 2015. Hopley diarrhoeal statistics for 2014 to 2015. Harare City Health Department, Zimbabwe (unpublished)

Corapcioglu, M.Y., Haridas, A., 1985. Microbial transport in soils and groundwater: a numerical model. Adv. Water Resour.(8): 188-200.

Cronin, A.A., Hoadley, A.W., Gibson, J., Breslin, N., Komou, F.K., Haldin, L., 2007. Urbanisation effects on groundwater chemical quality: findings focusing on the nitrate problem from 2 African cities reliant on on-site sanitation. Journal of Water and Health,: 5, 441-454.

Dillon, P., 1997. Groundwater pollution by sanitation on tropical islands, UNESCO International Hydrological Programme IHP-V Project 6-1., Paris, France.

Dyer, B., 1941. Studies of ground water pollution in an alkaline alluvium soil. Ind J Med Res, 29(4): 867-877.

Dzwairo, B., Hoko, Z., Love, D., Guzha, E., 2006. Assessment of the impacts of pit latrines on groundwater quality in rural areas: A case study from Marondera district, Zimbabwe. Physics and Chemistry of the Earth, Parts A/B/C, 31(15-16): 779-788.

EPA, 2011. Drinking Water ADVICE NOTE Advice Note No. 11: European Communities (Good Agricultural Practice for Protection of Waters) Regulations S.I. NO. 610 OF 2010: Advice Note for Local Authorities on Technical Assessments and Prior Investigations Version 1. Available: https://www.epa.ie/pubs/advice/drinkingwater/Advice%20Note%20No11.pdf [accessed 14 March 2015]

EPU, 2012. Green Communities. Environmental Protection Agency, US.Available: https://archive.epa.gov/greenbuilding/web/html/ [accessed 28 April 2015]

Fernández, L., Miguel, Á.M., Gray, P.R., Bauernfeind, H., Fesselet, A., Maes, J.F., Peter, 2011. Descriptive spatial analysis of the cholera epidemic 2008-2009 in Harare, Zimbabwe: a secondary data analysis. Transactions of the Royal Society of Tropical Medicine and Hygiene, 105(1): 38-45.

Foody, G.M., 2002. Status of land cover classification accuracy assessment. Remote sensing of environment, 80(1): 185-201.

Franceys, R., Pickford, J., Reed, R., 1992. A Guide to the Development of on-Site Sanitation, World Health Organization, Geneva: Available: http://www.who.int/water_sanitation_health/hygiene/envsan/onsitesan.pdf [accessed 29 March 2013].

Gorsuch, R.L., 1983 Factor analysis. , 2 ed. Lawrence Erlbaum Associates, Hillsdale, NJ.

Graham, J.P., Polizzotto, M.L., 2013. Pit Latrines and Their Impacts on Groundwater Quality : A Systematic Review. Environmental Health Perspectives(121): 521-530.

GWP, 2014. The Links between landuse and groundwater. Global Water Partnership: Perspectives paper http://www.gwp.org/Global/ToolBox/Publications/Perspective%20Papers/perspective_paper_landuse_and_groundwater_no6_english.pdf: [accessed 6 February 2015]

Haag, I., Westrich, B., 2002. Processes governing river water quality identified by principal component analysis. HYDROLOGICAL PROCESSES(16): 3113-3130.

Haruna, R., Ejobi, F., Kabagambe, E.K., 2005. The quality of water from protected springs in Katwe and Kisenyi parishes, Kampala city, Uganda. African health sciences(5): 14-20.

Hoko, Z., 2005. An assessment of the water quality of drinking water in rural districts in Zimbabwe. The case of Gokwe South, Nkayi, Lupane, and Mwenezi districts. Physics and Chemistry of the Earth, Parts A/B/C, 30(11-16): 859-866.

Hoko, Z., 2008. An assessment of quality of water from boreholes in Bindura District, Zimbabwe. Physics and Chemistry of the Earth, Parts A/B/C, 33(8-13): 824-828.

Howard, G., Pedley, S., Barrett, M., Nalubega, M., Johal, K., 2003. Risk factors contributing to microbiological contamination of shallow groundwater in Kampala, Uganda. Water Research, 37(14): 3421-3429.

IGRAC, 2013. Groundwater Monitoring in the SADC Region: International Groundwater Resources Assessment Centre:Overview prepared for the Stockholm World Water Week 2013, http://www.un-igrac.org/dynamics/modules/SFIL0100/view.php?fil_Id=242 [accessed April 18, 2015].

Jacks, G., Sefe, F., Carling, M., Hammar, M., Letsamao, P., 1999. Tentative nitrogen budget for pit latrines-eastern Botswana. Environmental Geology, 38(3): 199-203.

Jacobsen, M., Webster, M., Vairavamoorthy, K., 2012. The Future of Water in African Cities: Why Waste Water? The World Bank, Washington, DC.

Jolliffe, I.T., 1986. Principal Component Analysis, Springer Series in Statistics. Springer-Verlag, New York, 271.

Keith, L., Patton, G., Lewis, D., Edwards, P., 1996. Determining what kinds of samples and how many samples to analyze. Washington, DC: American Chemical Society: http://www.waterboards.ca.gov/drinking_water/certlic/labs/documents/elap_techinfo/1060.pdf [accessed 10 June 2015].

Kibena, J., Nhapi, I., Gumindoga, W., 2014. Assessing the relationship between water quality parameters and changes in landuse patterns in the Upper Manyame River, Zimbabwe. Physics and Chemistry of the Earth, Parts A/B/C, 67: 153-163.

Lawrence, A., Macdonald, D., Howard , A., Barrett, M., Pedley, S., Ahmed, K., 2001. Guidelines for Assessing the Risk to Groundwater from On-Site Sanitation. , British Geological Survey, Keyworth, Nottingham: Available: http://www-esd.worldbank.org/esd/ard/groundwater/pdfreports/Guidelines_assessing_risk_to_Gdwtr.PDF [accessed 5 March 2015].

Ley, R.E., Peterson, D.A., Gordon, J.I., 2006. Ecological and evolutionary forces shaping microbial diversity in the human intestine. Cell, 124(4): 837-848.

Maheshwari, S., 2013. Environmental Impacts of Poultry Production. Poult Fish Wildl Sci 1: 101. doi:10.4172/pfw.1000101.

McConville, J., Wittgrem, H.B., 2014. Peri-urban Sanitation and Water Service Provision. Challenges and opportunities for developing Countries

McGuigan, F.J., 1996. Experimental Psychology: Methods of Research. Pearson, New York. Available: https://www.goodreads.com/book/show/2036612.Experimental_Psychology_Methods_of_Research [accesses 15 March 2015]

Mitas, L., Mitasova, H., 1999. Spatial Interpolation. In: P.Longley, M.F.Goodchild, D.J. Maguire, D.W.Rhind (Eds.), Geographical Information Systems: Principles, Techniques, Management and Applications,Wiley.

Morris, B.L., Lawrence, A.R., Stuart, M.E., 1994. The impact of urbanization on groundwater quality (Project Summary Report), British Geological Survey Technical Report WC/94/56, Keyworth, Nottingham

Mulenga, M., Manase, G., Fawcett, B., 2004. Building Links for Improved Sanitation in Poor Urban Settlements: Recommendations from Research in Southern Africa 1st ed. Institute of Irrigation and Development Studies Southampton. Available: http://pubs.iied.org/pdfs/G02220.pdf [accessed 14 March 2015]

Nhapi, I., 2009. The water situation in Harare, Zimbabwe: a policy and management problem. Water Policy(11): 221-235.

Nyama, M.G., 2013. Harare Slum Upgrading Profiles, Compiled by Dialogue on Shelter and Zimbabwe Homeless People’s Federation In Partnership with City of Harare, http://www.google.co.zw/url?q=http://sdinet.org/wpcontent/uploads/2015/04/Harare_Slum_Upgrading_Profiles.pdf [accessed 31 December 2015).

Nyatsanza, T., Chaminuka, L., 2013. An assessment of the provision of clean water and sanitation services for people with disabilities in peri-urban areas: A case of Harare in Zimbabwe. International Open & Distance Learning Journal, 1(3): 82-88.

Padmasiri, J.P., Jayatilake, G.M., Kotuwegedara, J.P.K., 1992. Groundwater pollution from double pit latrines. In: Water, Environment and Management, Proceedings of the 18th WEDC Conference, 30 August-3 September 1992 Kathmandu, Nepal, pp. 239-241; Loughborough, UK:Water, Engineering and Development Centre, Loughborough University of Technology

Powell, K.P., Taylor, R.G., Cronin, A.A., Barrett, M.H., Pedley, S., Sellwood, J., Trowsdale, S.A., Lerner, D.N., 2003. Microbial contamination of two urban sandstone aquifers in the UK. Water Research, 37: 339-352.

Pujari, P., Padmakar, C., Labhasetwar, P., Mahore, P., Ganguly, A.K., 2012. Assessment of the impact of on-site sanitation systems on groundwater pollution in two diverse geological settings-a case study from India. Environ Monit Assess, 184(1): 251-263.

Ramakrishna, B.S., 2007. The normal bacterial flora of the human intestine and its regulation. Journal of clinical gastroenterology, 41: S2-S6.

Robins, N., Chilton, P., Cobbing, J., 2007. Adapting existing experience with aquifer vulnerability and groundwater protection for Africa. J Afr Earth Sci 47(1): 30-38.

Rosa, G., Clasen, T., 2010. Estimating the scope of household water treatment in low-and medium-income countries. The American journal of tropical medicine and hygiene, 82(2): 289-300.

Simmons, K., 2014. Soil Sampling, SESD (SCIENCE AND ECOSYTEM SUPPORT DIVISION) OPERATING PROCEDURE. U.S Environmental Protection Agency, Athens, Georgia. http://www.epa.gov/region4/sesd/fbqstp/Soil-Sampling.pdf [accessed 7 August 2015].

Still, D., Nash, S., 2002. Groundwater contamination due to pit latrines located in a sandy aquifer: a case study from Maputaland, Water Institute of Southern Africa Biennial Conference. Durban, South Africa: Water Institute of Southern Africa, pp. 1-6.

SWH, 2007. Planning for Drinking Water and Sanitation in Peri-Urban Areas 21, Swedish Water House (SWH), Sundbyberg, Sweden.

Taylor, R., Cronin, A., Pedley, S., Barker, J., Atkinson, T., 2004. The implications of groundwater velocity variations on microbial transport and wellhead protection – review of field evidence. FEMS Microbiology Ecology, 49(1): 17-26.

Tsinda, A., Abbott, P., Pedley, S., Charles, K., Adogo, J., Okurut, K., Chenoweth, J., 2013. Challenges to Achivieving Sustainable Sanitation in Informal Settlements of Kigali, Rwanda International Journal of Environmental Research and Public Health v10(12): 6939-6954

UNICEF/ WHO, 2015. Progress on Sanitation and Drinking Water – 2015 update and MDG assessment., UNICEF and World Health Organization Geneva , Switzerland : http://www.wssinfo.org/fileadmin/user_upload/resources/JMP-Update-report-2015_English.pdf [assessed June 8, 2015].

USGS, 2004. Factors affecting ground-water quality in Oakland County, Michigan, U.S. Geological Survey. U.S. Department of the Interior: Fact Sheet 2004-3102, Oakland, Michigan.

Vinger, B., Hlophe, M., Selvaratnam, M., 2012. Relationship between nitrogenous pollution of borehole waters and distances separating them from pit latrines and fertilized fields. Life Sci J 9(1): 402-407.

WaterAid, 2011. Technology Notes. Available: http://www.wateraid.org/documents/plugin_documents/technology_notes_2011.pdf [accessed 5 March 2015].

WHO, 1992. A Guide to the Development of on-Site Sanitation, Switzerland: http://www.who.int/water_sanitation_health/hygiene/envsan/onsitesan.pdf?ua=1 [accessed 29 May 2015].

WHO, 1997. Guidelines for drinking-water quality Surveillance and control of community supplies Second ed. World Health Organization, Geneva, Switzerland :http://www.who.int/water_sanitation_health/dwq/gdwqvol32ed.pdf [accessed May 7, 2015].

WHO, 2002. Environmental Health, Eastern Mediterranean Regional Center for Environmental Health Activities (CEHA). World Health Organization, Geneva, Switzerland.

WHO, 2008. Guidelines for Drinking-water Quality THIRD EDITION INCORPORATING THE FIRST AND SECOND ADDENDA Volume 1 Recommendations, Geneva, Switzerland: http://www.who.int/water_sanitation_health/dwq/fulltext.pdf [accessed July 24, 2015].

WHO, 2011. Guidelines for Drinking-water Quality, 4th ed. World Health Organization, Geneva, Switzerland :http://whqlibdoc.who.int/publications/2011/9789241548151_eng.pdf [accessed May 4, 2015].

WHO/UNICEF, 2006. Meeting the MDG drinking water and sanitation target the urban and rural challenge of the decade. World Health Organization and UNICEF, Geneva, Switzerland: http://www.wssinfo.org/fileadmin/user_upload/resources/1198239354-JMP_06.pdf [accessed April 8, 2015].

WHO/UNICEF, 2013. Progress on sanitation and drinking-water, update-2013. World Health Organization and UNICEF: Available: http://apps.who.int/iris/bitstream/10665/81245/1/9789241505390_eng.pdf [accessed May 20, 2015], Geneva, Switzerland.

WHO/UNICEF, 2014. Progress on Drinking Water and Sanitation, 2014 UPDATE. World Health Organization and UNICEF, Geneva, Switzerland: http://www.who.int/about/licensing/copyright_form/en/index.html [accessed April 20, 2015].

Xu, Y., Usher, B., 2006. Groundwater pollution in Africa. CRC Press, London, UK.

ZESN, 2008. Zimbabwe Election Support Network), Constituency profile, Harare.

ZIMSTAT, 2012. Census Preliminary Report, Zimbabwe National Statistics Agency, Harare.

Zingoni, E., Love, D., Magadza, C., Moyce, W., Musiwa, K., 2005. Effects of a semi-formal urban settlement on groundwater quality: Epworth (Zimbabwe): Case study and groundwater quality zoning. Physics and Chemistry of the Earth, Parts A/B/C, 30(11-16): 680-688.

APPENDICES

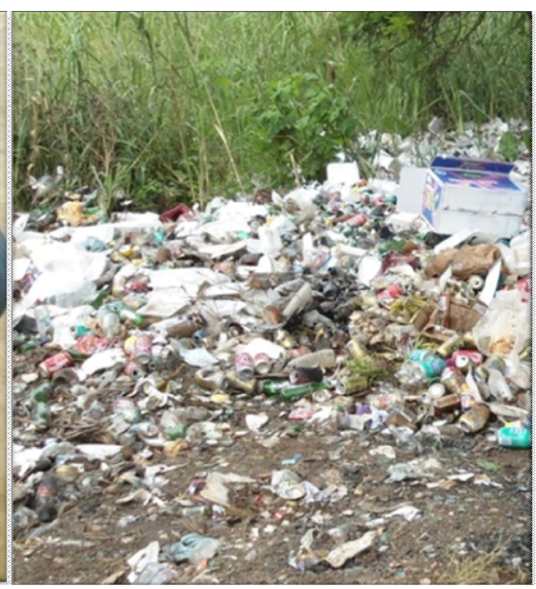
Appendix 1: Photographs of pit latrine, well and refuse dump in Hopley Settlement

Hopley Settlement photographs showing filled up pit latrine (a), pit latrine superstructure (b), hand dug out well (c) and refuse dumpsite [Taken: March 11, 2015]

(a)

(b)

(b)



(c)

Appendix 2: SAZ drinking water standards and WHO drinking water guidelines

PARAMETER	**UNITS**	**SAZ 560:1997 Recommended standard limit**	**WHO (2011) DRINKING WATER GUIDELINES**
pH		6.5-8.5	6.5-8.5
Chloride	mg/L	<250	<300 mg/L
Turbidity	NTU	<1	<5NTU
Conductivity	µS/cm at 20 ^{o}C		<1 380
Faecal coliforms	cfu/100mL	0	0
Nitrates	mg/L N	10	50
Ammonia	mg/L	Not specified	<0.2
Dissolved oxygen	mg/L	>5	Not specified

Appendix 3: Extraction Method (PCA) used to decide the number of items selected

Component	Initial Eigenvalue			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.334	41.676	41.676	3.334	41.676	41.676
2	1.712	21.398	63.074	1.712	21.398	63.074
3	1.108	13.845	76.919	1.108	13.845	76.919
4	0.688	8.600	85.520			
5	0.551	6.890	92.410			
6	0.333	4.164	96.574			
7	0.252	3.146	99.720			
8	0.022	0.280	100.000			

Appendix 4: Groundwater field measurements results

DATE	SAMPLING PONT	pH	TURBIDITY (NTU)	DISSOLVE OXYGEN (mg/L)	DEPTH OF WATER LEVEL (m)
	B 1	6.8	22.8	2.19	4.3
	B 2	7	11.6	2.92	2.6
	B 3	7.2	0.38	4.68	1.4
	W 1	6.7	1.95	2.63	1.2
	W 2	6.3	0.78	5.12	2.6
12/2/2015	W 3	6.3	2.75	6.04	2.4
	W 4	6.5	1.08	2.64	0.3
	W 5	6.6	1.02	3.37	0.5
	W 6	5.6	1.23	3.9	1.6
	W 7	6.5	3.87	3.3	0.7
	W 8	6.1	0.78	3.32	0.02
	B 1	6.9	32.2	2.15	4.5
	B 2	6.8	2.97	3.28	2.7
	B 3	7.1	1.7	3.99	1.5
	W 1	6	4.94	2.79	1.4
	W 2	5.3	8.11	4.41	2.9
26/02/15	W 3	6.2	3.64	5.83	2.7
	W 4	5.9	0.82	3.57	0.4
	W 5	6.7	0.86	3.34	0.8
	W 6	6.7	4.35	4.2	1.95
	W 7	5.9	2.5	3.92	1.1
	W 8	6.9	0.84	4.47	0.35
	B 1	6.4	34.3	2.11	4.3
	B 2	6.9	3.3	3.64	2.1
	B 3	7.1	1.76	3.31	1.3
	W 1	7	7	2.95	1.3
	W 2	6.7	1.31	3.7	2.7
21/4/15	W 3	7	1.02	5.62	3.4
	W 4	6	2.06	4.5	0.4
	W 5	6.8	1.68	3.31	0.67
	W 6	6.8	2.25	4.67	2.4
	W 7	6.8	0.47	4.53	1.65
	W 8	6.8	2.25	5.62	0.25

	B1	6.6	34.8	2..09	4.35
	B 2	6.8	3.01	3.47	2.3
	B 3	7.1	0.72	3.35	1.45
	W 1	6.9	14.1	2.68	1.5
	W 2	6.3	2.31	3.6	2.9
30/04/15	W 3	7	0.73	4.09	3.4
	W 4	6.1	1.36	3.25	0.35
	W 5	6.8	0.91	3.25	0.9
	W 6	6.4	1.45	3.5	2.6
	W 7	6.4	0.75	4.49	1.7
	W 8	6.8	1.28	3.3	0.27

Appendix 5: Groundwater laboratory results

DATE	SAMPLE	FC (cc/100 mL sample)	NITRATES (mg/L)	ELECTRICAL CONDUCTIVITY (µs/cm)	AMMONIA (mg/L)	CHLORIDES (mg/L Cl-)
12/02/15	B 1	0	20.00	871	0.00	141.8
	B 2	8	15.30	288	0.01	42.5
	B 3	13	18.40	339	0.02	56.7
	W 1	280	30.00	1470	0.44	290.7
	W 2	57	183.15	1020	0.01	212.7
	W 3	0	20.10	589	0.03	106.4
	W 4	6	17.60	243	0.05	35.5
	W 5	39	15.23	221	0.01	35.5
	W 6	17	18.53	244	0.00	42.5
	W 7	8	20.31	366	0.00	56.7
	W 8	0	10.10	503	0.23	113.4
	Negative Control	0				
26/02/15	B 1	0	24.25	886	0.14	141.8
	B 2	5	23.70	301	0.00	28.4
	B 3	1	14.47	281	0.08	28.4
	W 1	280	148.77	1397	0.04	269.4
	W 2	114	253.11	1027	0.21	177.3
	W 3	88	62.83	616	0.00	127.6
	W 4	0	50.33	219	0.00	28.4
	W 5	96	58.84	250	0.00	28.4
	W 6	25	57.38	293	0.00	35.5
	W 7	9	52.55	336	0.10	35.5
	W 8	62	43.10	535	0.00	92.2
	Negative Control	0				
21/04/15	B 1	0	28.50	1035	0.00	152.6
	B 2	2	32.10	285	0.12	35.5
	B 3	6	10.54	291	0.10	35.5
	W 1	114	267.85	1687	8.30	269.4
	W 2	280	323.91	923	0.63	141.8
	W 3	6	105.89	440	0.13	56.7
	W 4	44	84.33	267	0.09	28.4
	W 5	69	104.46	268	0.14	21.3

	W 6	360	98.23	267	0.06	63.8
	W 7	1	79.54	327	0.03	35.5
	W 8	450	69.00	539	0.05	85.1
	Negative Control	0				
	B 1	0	38.76	1250	0.00	142.5
	B 2	4	40.48	326	0.20	42.5
	B 3	16	9.25	339	0.12	49.6
	W 1	286	321.12	1726	10.0	283.6
	W 2	162	324.66	903	1.00	163.1
30/04/15	W 3	2	12.11	470	1.21	63.8
	W 4	24	84.33	272	0.02	35.5
	W 5	53	105.20	259	0.10	42.5
	W 6	218	100.33	266	0.02	42.5
	W 7	3	69.45	314	0.01	49.6
	W 8	380	68.65	546	0.10	99.3
	Negative Control	0				

Appendix 6: Groundwater acceptance for drinking water requirements

PARAMETER	GROUP STATISTICS				INDEPENDENT SAMPLES TEST t-test for equity of means			
	Water quality	**N**	**Mean**	**%**		**t**	**df**	**Sig. (2 tailed)**
Faecal Coliforms	Unacceptable	37.0	97.0	84	Equal variances assumed	2.0	42.0	0.05
	Acceptable	7.0	0.0	16	Equal variances not assumed	4.6	36.0	0.00
Nitrates	Unacceptable	22.0	137.4	50	Equal variances assumed	5.6	42.0	0.00
	Acceptable	22.0	23.3	50	Equal variances not assumed	5.6	21.6	0.00
Ammonia	Unacceptable	6.0	3.6	14	Equal variances assumed	5.4	42.0	0.00
	Acceptable	38.0	0.1	86	Equal variances not assumed	2.0	5.0	0.10
Turbidity	Unacceptable	15.0	11.6	34	Equal variances assumed	4.0	42.0	0.00
	Acceptable	29.0	1.9	66	Equal variances not assumed	3.0	14.1	0.01
Chlorides[1]	Unacceptable	0.0			Equal variances assumed			

[1]One of the group in the water suitability decision grouping variable is missing

	Acceptable	44.0	90.4		Equal variances not assumed			
pH	Unacceptable	15	6.1	34	Equal variances assumed	−10.3	42.0	0.00
	Acceptable	29	6.8	66	Equal variances not assumed	−8.7	18.9	0.00
Dissolved oxygen	Unacceptable	28	3.5	64	Equal variances assumed	−1.9	42.0	0.06
	Acceptable	16	4.1	36	Equal variances not assumed	−1.7	21.9	0.10
Electrical conductivity	Unacceptable	4	1570.0	9	Equal variances assumed	7.5	42.0	0.00
	Acceptable	40	475.4	91	Equal variances not assumed	11.9	27.3	0.00