International Groundwater Resources Assessment Centre

# GROUNDWATER RESOURCE MANAGEMENT

## IN THE ST. BONAVENTURE TOWNSHIP, LUSAKA

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International Groundwater Resources Assessment Centre

IGRAC (International Groundwater Resources Assessment Centre) facilitates and promotes international sharing of information and knowledge required for sustainable groundwater resources development and management worldwide. Since 2003, IGRAC provides an independent content and process support, focusing particularly on transboundary aquifer assessment and groundwater monitoring.

**IGRAC**
Westvest 7
2611AX Delft
The Netherlands

T:+31 15 215 2325
E: info@un-igrac.org
I: www.un-igrac.org

## FOREWORD

Groundwater is a precious but invisible resource; to assess, monitor, use or protect something which we don't see is not an easy task. Especially in urban areas, which are characterized by numerous (known and unknown) human impacts on groundwater environment.

Groundwater plays an important role in sustainable development of cities, while the cities are growing rapidly: in 1960, the urban population accounted about 34% of the total global population; the last year it reached 54% and still continues to grow. Demand for groundwater is growing accordingly. So how can we ensure a sustainable use of limited groundwater resources in this situation? How can we prevent (or at least mitigate) depletion, pollution, land subsidence or salinization of groundwater in urban areas?

Sharing experiences and knowledge on groundwater resources management in urban areas is certainly a part of the solution. IGRAC is committed to facilitate this process and to further raise attention about this widely spread problem. As a case study, we intentionally did not select a high-density, low-income urban area. Relatively low-density, high-income settlement in a large city in Africa was chosen, showing that groundwater management might be challenging even in these areas. Therefore, this case study - carried out by our colleagues in Lusaka – is a good example of complexity of groundwater problems in urban areas and a valuable lesson learned.

Dr. Neno Kukuric
Director
International Groundwater Resources Assessment Centre (IGRAC)

The University of Zambia (UNZA) was established by Act of Parliament No. 66 of 1965. The first intake of students took place on 17th March 1966. The University of Zambia is situated in Lusaka on two campuses.

The Natural Resources Development College (NRDC) is Zambia's top agricultural college. NRDC offers Diploma level training underwritten by the University of Zambia. The College offers training in various agricultural disciplines.

## Groundwater resource management in the St. Bonaventure Township, Lusaka

[1]Nkhuwa D.C.W., [1]Namafe C.M., [1]Chabwela H., [2]Phiri L., [1]Chompolola A., [1]Mweemba C.E., [1]Kabika J.
[1]University of Zambia, P O Box 32379, Lusaka; [2]Natural Resources Development College, PO Box 310099, Lusaka

ABSTRACT: This paper presents results of a study that was undertaken in the St. Bonaventure Township – a low-density, high-income settlement located about 10 km south-west of Lusaka. The study was undertaken *to assess impacts of septic tanks, if at all, on the quality of groundwater in the aquifer underlying the Township.* Selection of the study site was purposive as all households in the Township use septic tanks to dispose of their excreta and wastewater, while boreholes provide sources of water supply to household. Collection of water samples was done in the dry and wet seasons to determine the effect, if at all, of contrasting levels of saturation in the aquifer and the risk of contamination posed by increased recharge to the groundwater store. Sample analyses for *pH, conductivity, total alkalinity, total hardness, nitrate, chloride, sulphate, calcium, magnesium, sodium, potassium, total coliforms and faecal coliforms* were done at the Environmental Engineering Laboratory (EEL) in the School of Engineering at the University of Zambia. Results showed that from the dry season to the rainy season, there were reductions in the average values of conductivity (766 to 714 mg $l^{-1}$), pH (7.6 to 7.1), total dissolved solids (383.1 to 356.4 mg $l^{-1}$), sulphate 59.7 to 45.3 mg $l^{-1}$) , chloride (42.8 to 41.8 mg $l^{-1}$), nitrate (18.5 to 4.9 mg $l^{-1}$), and calcium (79.7 to 60.6 mg $l^{-1}$). On the other hand, average values for total hardness (348.3 mg $l^{-1}$), total alkalinity (342.8 to 41.3 mg $l^{-1}$), magnesium (37.5 to 65.3 mg $l^{-}$), sodium (34.3 to 51.5 mg $l^{-1}$) and potassium (12.7 to 19.3 mg $l^{-1}$) recorded increases. Reduction and increase in the values of different parameters could be attributed to phenomena of dilution and leaching of contaminants, respectively, due to varyimg levels of saturation of the aquifer.

KEY WORDS: Aquifer, Groundwater Quality, Resource Management, Septic Tanks, St. Bonaventure Township

# CONTENTS

# 1. INTRODUCTION

Groundwater forms the most important source of water supply in many urban, peri-urban and rural areas of Zambia constituting, in some cases, 100% of the demand. Most of the groundwater supplies come from aquifers underlying settlements. This case is particularly true in urban centres where, because of rapid growth of population, cities have experienced heightened human activities that have led to inadequate city planning, development, provision of basic needs and delivery of services to their inhabitants.

This is the case with Lusaka, Zambia's capital city, whose current population, estimated at about two million (GRZ, 2011), is more than 10 times what it was in 1964, when Zambia gained its political independence. Inadequate provision of services, such as housing, safe potable water as well as centralised sewer networks to convey excreta and wastewater by designated authorities, has forced most of the inhabitants of Lusaka to resort to alternative means, such as septic tanks and pit latrines, with a proportion of about 20% and 55%, respectively. Such human practices have made the underlying aquifers vulnerable to pollution.

Currently, there is inadequate knowledge of the dangers posed by use of septic tanks on groundwater quality by inhabitants in low-density settlements. Coupled with their other status of being high-cost settlements, it has usually not been easy to decipher, which one of these settlements is served by septic tanks. As such, there has been no obvious suspicion of the danger posed by these facilities to the quality of groundwater in aquifers that underlie these settlements. Hitherto, only high-density settlements served by pit latrines have been the 'culprits' responsible for groundwater pollution that has caused the almost endemic cholera outbreaks in the city, and especially that these outbreaks affect mostly residents in high-density and low-cost settlements.

This study was undertaken in a low-density and high-cost settlement that is on a self-water-supply system, and served by septic tanks for excreta and wastewater disposal with a view to creating awareness around septic tanks being potential sources of groundwater pollution.

## 2. THE PROJECT AREA

The project area, which is about 200 hectares in extent, is located about 10 km south-west of the Lusaka City Centre (Figure 1). It was initially a farmland, which was converted into a residential township in the late 1980s. Its name was derived from St. Bonaventure College which was, and still is, the oldest institution in the area. Since then, the St. Bonaventure Township has experienced phenomenally rapid and temporal transformation, in terms of settlement activity, especially for the period between 2000 and 2015.

Geologically, the area is underlain solely by pure marble with minor intercalations of dolomitic varieties, both of Katanga (Neoproterozoic) age (Drysdall, 1960; Simpson, 1962), which by its nature, is usually characterised by intense karstification (Lambert, 1962; von Hoyer et al., 1978; Nkhuwa, 1996), and in which groundwater flow is mostly influenced by an integrated and well-developed system of conduits and solution channels (Lambert, 1962). Results from borehole logs drilled in different parts of the city, but in similar geologic terrain, indicate that carbonate rocks have great lateral extents in the subsurface, some of which have been intersected at depths in excess of 100 m below ground surface (von Hoyer et al., 1978). The marble shows variations in fracturing and dissolution intensities, and it is these factors that have greatly influenced it to store and transmit groundwater – making it a very productive and important aquifer for the city water supply.

Generally, the Lusaka aquifer appears to be phreatic, and blanketed by varying thicknesses (0->40 m) of permeable superficial deposits of saprolite and laterite, which can be considered to be in hydraulic connection with deeper aquifers within the karstic bedrock. In this regard, the Lusaka aquifer is generally recharged over its entire exposed and karstified surface. As such, water levels in the aquifer tend to be often shallow (0-6m) in many parts of the city, sometimes with a tendency to interact with surface water. Further, borehole-drilling records from different parts of the city have indicated an apparent relationship between water strikes and large scale fracturing/faulting in the rock.

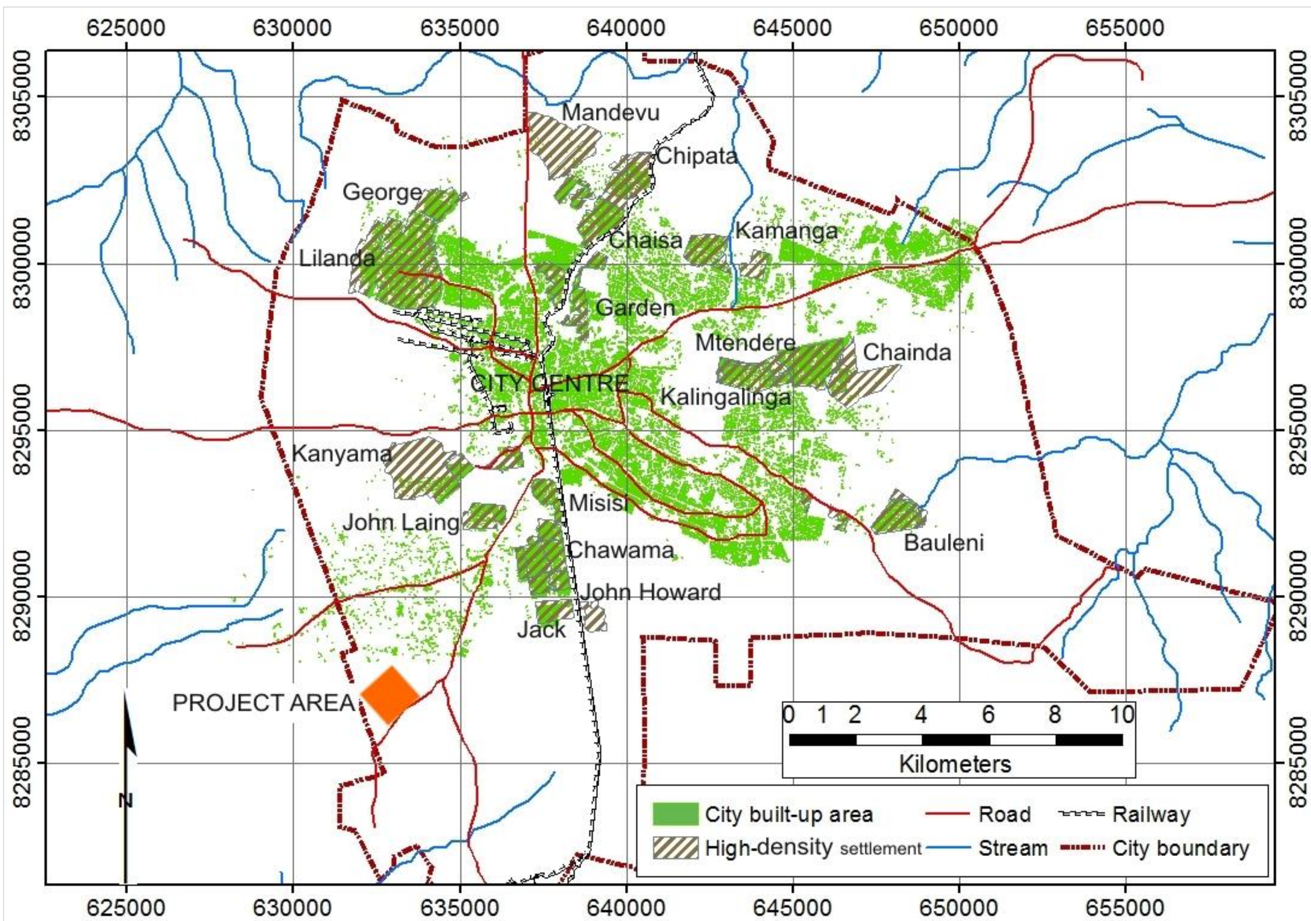


**Figure 1:** Location of the Project area – Saint Bonaventure – south-west of the Lusaka City Centre.

All the households in the Township rely solely on individual septic tank systems for excreta and wastewater disposal. Therefore, the presence of large scale fracturing/faulting would undoubtedly facilitate unattenuated transmission of pollutants to the aquifer.

From this perspective, the situation in St. Bonaventure Township became a cause for concern to some residents, who eventually realised the challenge posed by the sanitation arrangement in their area. This concern was especially kindled by the near-endemic outbreaks of gastrointestinal diseases arising from consumption of polluted water from shallow wells in the nearby un-sewered settlements of Chawama, Misisi, and John Laing, that lie about 6-7 km north-east of the project area.

Water analyses undertaken in these townships by Nkhuwa (2006) revealed widespread physico-chemical and microbial contamination of groundwater attributed to, among others, nitrates and faecal coliforms which undoubtedly, were a result of inadequate and/or poor sanitation. Over time, the overall inadequacy of sanitation in Lusaka has created a major source of pollution for groundwater, resulting in heightened gastrointestinal disease-outbreaks, all attributable to ingestion of contaminated groundwater.

Therefore, the main objective of this research was *to assess impacts of septic tanks, if at all, on the quality of groundwater in the aquifer underlying the Township*, thereby, confirming or dispelling the hypothesis that low-density settlements serviced by septic tanks do not impact groundwater quality like high-density settlements serviced by pit latrines.

## 3. METHODOLOGY

To realise and attain the objective of the study, data and information were acquired through a desk study, and fieldwork involved an inventory of boreholes and septic tanks, sampling of the mapped boreholes, laboratory analyses of samples and analyses of data.

A desk study was undertaken to collect and synthesise existing data and information from a number of studies done in Lusaka. For instance, studies by von Hoyer et al. (1978) covered most parts of Lusaka and they reported high values of nitrates, chloride and sulphate in informal settlements, and high sulphate and phosphate contents in the industrial areas during the 1977/78 rainy season. Some of the more recent studies that have confirmed pollution of groundwater with nitrate, phosphate, and widespread total and faecal coliforms include Mpamba et al. (2008), Nkhuwa (2006, 2000, 1996), de Waele et al. (2004), Kampeshi (2003), Nyambe & Maseka (2000), among others. These studies, which were undertaken in different areas of the city, reported different levels of physico-chemical and bacteriological pollution of groundwater. This pollution was attributed to various sources, including poor sanitary facilities, leaking sewage pipes, industrial effluents, waste disposal sites and underground petroleum tanks, among others. However, most of these studies attributed use of pit latrines in high-density settlements as major sources of microbial pollution, to the exclusion of the many septic tanks serving the low-density, high-income settlements.

During fieldwork, an inventory of boreholes and septic tanks was made on all properties that provided access to the research team. Mapping involved taking X-Y coordinates of borehole and septic tank locations using a hand-held Global Positioning System (GPS) for each household. Results of this mapping campaign were entered in excel spreadsheets and imported into the ArcGIS Programme to produce a map as given in Figure 2.

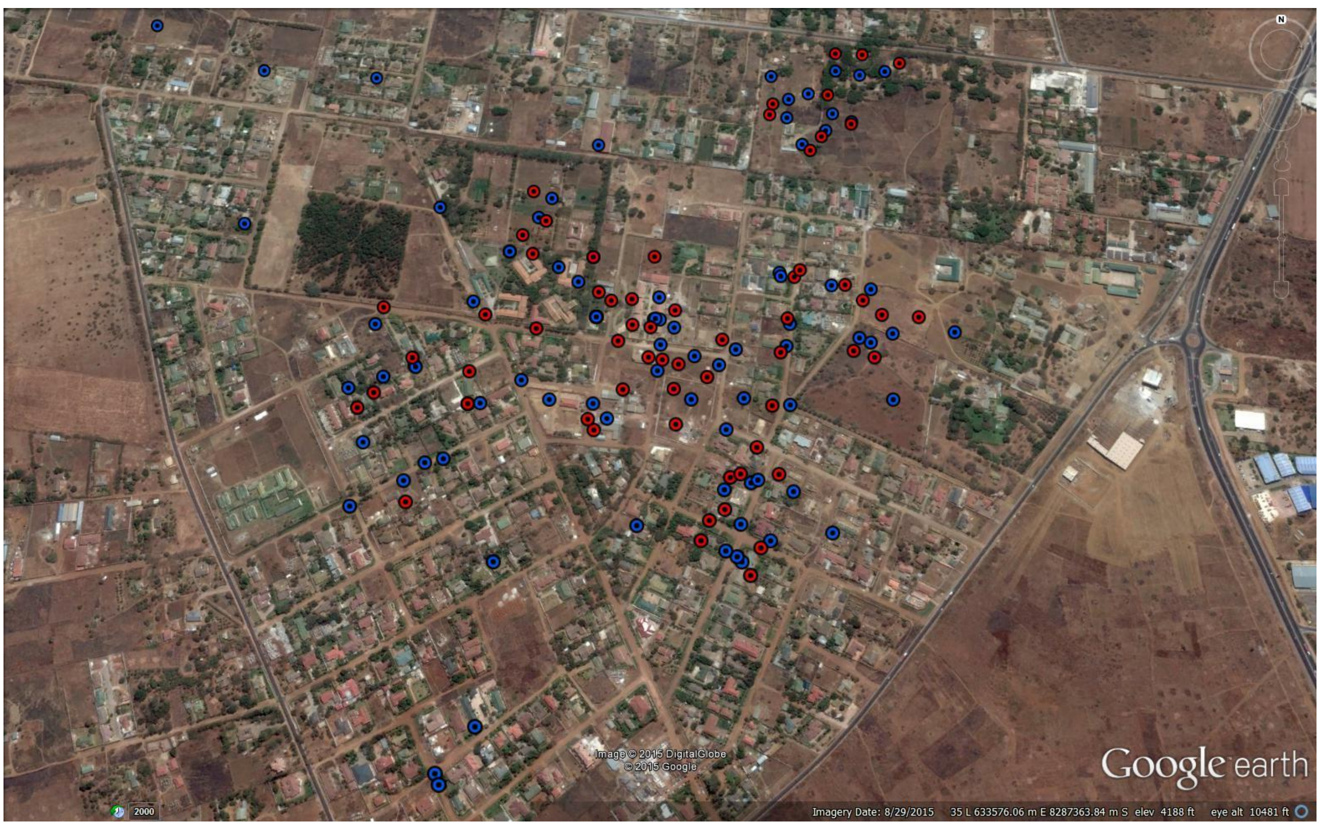


**Figure 2:** Location of boreholes (blue circles) and septic tanks (red circles) in the St. Bonaventure Township. Although all plots use septic tanks and boreholes, researchers mapped only those plots, where they were permitted access, which explains the uneven distribution of mapped points.

Water samples were collected from twenty households that allowed access to the research team into their properties. Sampling was done on 12 November 2013 (dry season), and 27 – 28 March 2014 (rainy season). Although sampling would have been preferred to be done directly from boreholes before water came into contact with any reactive environments in the conveyance system, samples were taken from taps because all the sampled boreholes were sealed, thus, providing the research team with no direct access to the water table. Locations of all sampled points were picked by their GPS coordinates as plotted in Figure 3.


**Figure 3:** Location of sampled points in the St. Bonaventure Township during the two sampling campaigns. *(SP ≡ Sample Point)*

Also worth of mention is the fact that no information was available on the depths and levels of suction of the sampled boreholes. This situation is probably a result of the absence of any regulatory and legal requirement for borehole drillers and/or owners to keep and/or provide such data. A regulatory authority was established only about two years ago by a Water Resources Management Act of 2011, but which has still not been enforced. This is the first time that the country will try to regulate drilling of boreholes and exploitation of groundwater. This is how it has hitherto been possible for individuals to sink borehole in any locality with no regard to how many other boreholes may be in their proximity, their pumping capacities, possible confounding human activities, etc. This, in localities like the St. Bonaventure Township, where each property is shielded off from another with high wall fences, is what might lead to concentration of incompatible human activities *that do not look into each other,* as shown in both Figures 2 and 4. Such are some of the activities that might have the potential of impacting negatively on the quality and quantity of groundwater – a concern that necessitated this investigation.

Water samples were analysed for physico-chemical – *pH and conductivity, chloride, nitrate, sulphate, ammonia, calcium, magnesium, total hardness, calcium hardness* – and microbial – *total coliforms and faecal coliforms* – parameters in order to determine the potability of the water. The choice of parameters to be investigated was governed, in the main, by the limited budget available for the project.

Samples were analysed at the Environmental Engineering Laboratory (EEL) in the School of Engineering at the University of Zambia. The analyses were performed in conformity with *'Standard Methods for the Examination of water and Wastewater APHA, 1998'*.

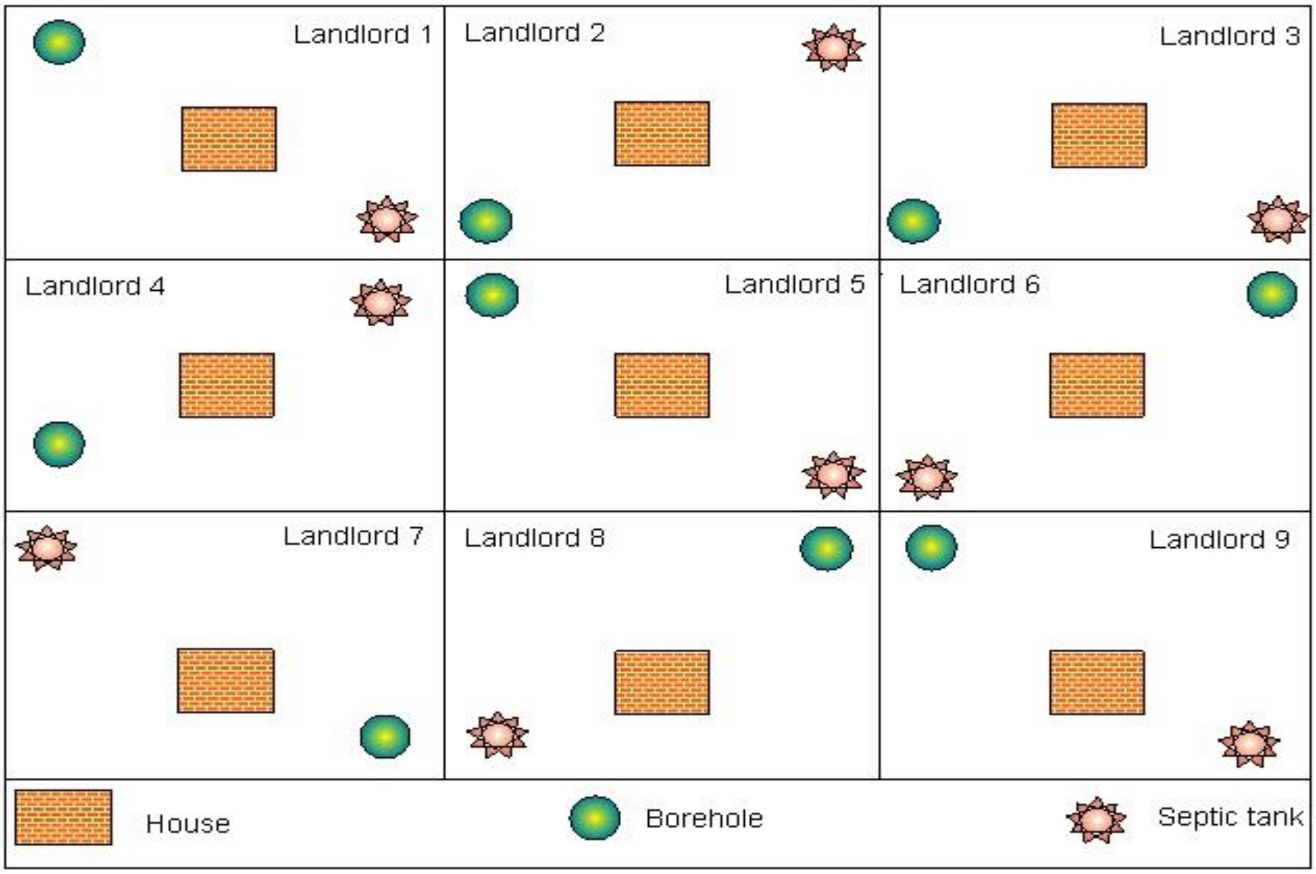


**Figure 4:** Cartoon portraying what might be happening in new areas of property development, which because they are all shielded from each other by high wall fences, might result in location of incompatible human activities next to each other.

## 4. RESULTS AND DISCUSSIONS

Groundwater analyses collected from different locations of the St. Bonaventure Township during the dry (November 2013) and wet (March 2014) seasons were used to yield information about (i) environments through which groundwater might have circulated, (ii) its quality and (iii) its suitability for different purposes – *drinking, domestic, agricultural and industrial activities* – among others. On the basis of concentrations of different constituents, the suitability of the groundwater in the Township was determined, especially for domestic purposes.

Table 1 summarises the physico-chemical data transformed into descriptive statistical parameters – *minimum, maximum, average, median and standard deviation* – for the two sampling periods in the *dry and wet seasons*.

**Table 1:** Summary statistics of physico-chemical parameters in groundwater for the St Bonaventure Township during the:

| | (A) Dry season (November 2013) | | | | | (B) Wet season (March 2014) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Min** | **Max** | **Average** | **Median** | **Std. Deviation** | **Min** | **Max** | **Average** | **Median** | **Std. Deviation** |
| **Conductivity** | 694 | 863 | 766 | 762.5 | 47.4 | 609 | 777 | 713.7 | 709.5 | 38.4 |
| **pH** | 6.9 | 8.4 | 7.6 | 7.5 | 0.3 | 6.8 | 7.4 | 7.1 | 7.1 | 0.2 |
| **TDS** | 348 | 431 | 383.1 | 382.5 | 23.2 | 299 | 389 | 356.4 | 354 | 20.2 |
| **Total Hardness** | 256 | 470 | 348.3 | 327 | 73.1 | 292 | 572 | 422 | 434 | 66.6 |
| **Total Alkalinity** | 246 | 458 | 342.8 | 321 | 69.2 | 288 | 504 | 410.3 | 423 | 57.3 |
| **$SO_4^{2-}$** | 6.6 | 93.8 | 59.7 | 65.8 | 22.3 | 12.5 | 97 | 45.3 | 40.2 | 24 |
| **$Cl^-$** | 15 | 59 | 42.8 | 43.5 | 10.8 | 30 | 65 | 41.8 | 38 | 9 |
| **$NO_3^-$** | 0.6 | 27.6 | 18.5 | 17.5 | 7.1 | 1 | 9.5 | 4.9 | 3.7 | 3.2 |
| **$Mg^{2+}$** | 23.4 | 61.4 | 37.5 | 40.1 | 9.9 | 31.7 | 95 | 65.3 | 64.3 | 15.7 |
| **$Ca^{2+}$** | 40 | 120.8 | 79.7 | 76.8 | 26.5 | 25.6 | 91.2 | 60.6 | 67.2 | 19.3 |
| **$Na^+$** | 26.5 | 50.6 | 34.3 | 33.4 | 6.2 | 46.9 | 60.5 | 51.5 | 50 | 3.8 |
| **$K^+$** | 4 | 36.7 | 12.7 | 11 | 6.8 | 3.1 | 40.6 | 19.3 | 18.2 | 7.3 |

Min. ≡ Minimum; Max. ≡ Maximum; pH ≡ concentration of the Hydrogen ion; TDS ≡ Total dissolved solids

Dry season values for pH ranged from 6.9 to 8.4 with an average of 7.6, while wet season values were 6.8 and 7.4 with an average of 7.1. Within this range of pH, groundwater in the project area was alkaline, but lying within the WHO's permissible range of 6.5 and 8.5. Additionally, these pH values typified those generally found in carbonate terrains, which according to Ford and Williams (1989), usually fell between 6.5 and 8.9, and through their investigations, they also established that enhanced solubility of carbonate minerals occurs following hydration of $CO_2$ as follows:

$$CO_2 + H_2O + CaCO_3 \leftrightarrow Ca(HCO_3)_2 \leftrightarrow Ca^{2+} + H^+ + HCO_3^- + CO_3^{2-} \quad (1)$$

Other than natural solubility, such pH values in the St. Bonaventure Township's groundwater would also be influenced by solubility of carbonate minerals by *acidic* wastewater from septic tanks. The pH range of 6.8 to 8.4 for the study area's groundwater would indicate the predominance of $HCO_3^-$ and $OH^-$ over the $CO_3^{2-}$ – an argument that is also advanced by Fetter (1994) for groundwater in similar geological terrains (Figure 5).

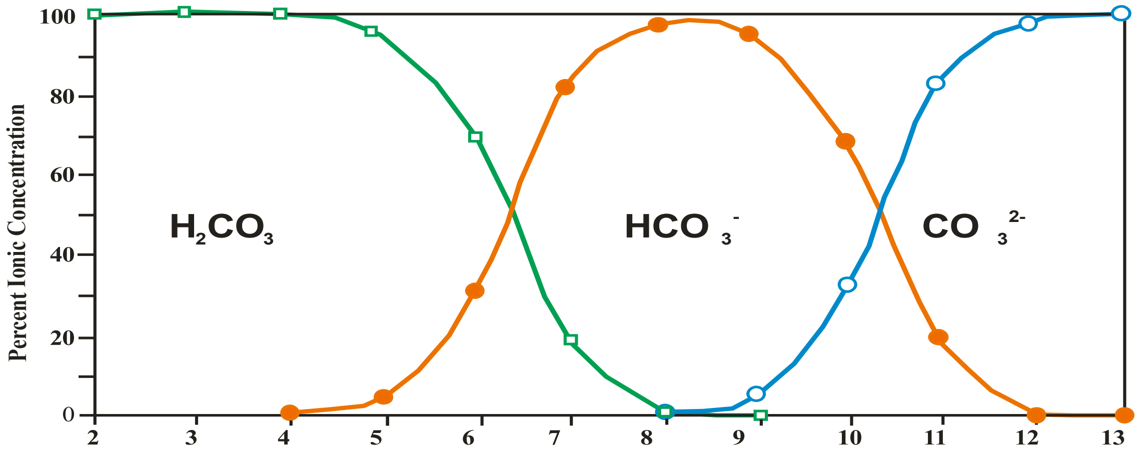


**Figure 5:** Variation of major inorganic species dissolved at 25°C (Adapted and slightly modified after Fetter, 1994).

Total Dissolved Solids (TDS) averaged 383.1 mg $l^{-1}$, and ranged from 348 mg $l^{-1}$ to 431 mg $l^{-1}$ in the dry season, while the wet season values ranged from 299 mg $l^{-1}$ to 389 mg $l^{-1}$ with a mean of 356.4 mg $l^{-1}$. Conductivity, which normally bears a direct relationship to TDS, had values that ranged from 694 to 863 µS/cm, with a mean of 766 µS/cm in the dry season, and 609 µS/cm to 777 µS/cm with a mean of 713.7 µS/cm in the wet season (Figure 6). Trends of both TDS and conductivity showed reductions from the dry season to the wet season (Figure 6).

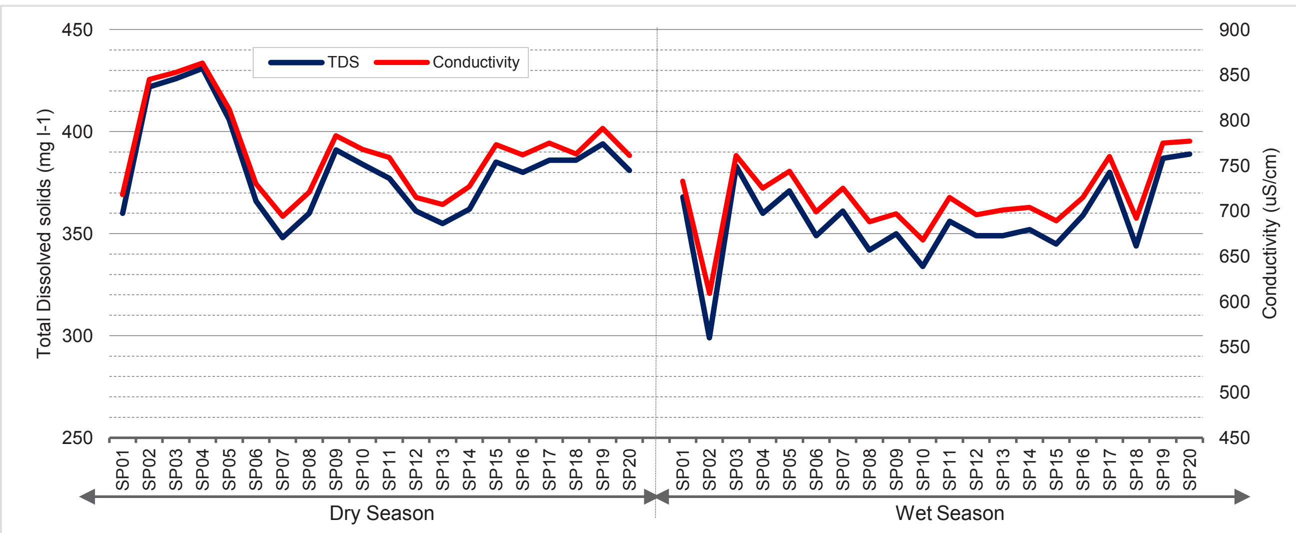


**Figure 6:** Trends of, and the relationship between Total Dissolved Solids (TDS) and Conductivity in the St Bonaventure Township's groundwater samples taken in the dry (Nov. 2013) and wet (Mar. 2014) seasons. (SP ≡ Sample Point)

However, although the general decrease of both TDS and conductivity from the dry season to the wet season was true for most locations, others showed slight increases, while in yet others, values remained almost the same.

The origin of dissolved solids in groundwater in the project area might have included soluble salts that produced ions such as $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $HCO_3^-$, $SO_4^{2-}$, or $Cl^-$, all of which are present in measurable quantities as shown in Table 1. The ions $Ca^{2+}$, $Mg^{2+}$ and $HCO_3^-$ might have originated from cation exchange, in which $Ca^{2+}$ replaced $Mg^{2+}$ in marble, which constitutes the host rock underlying the project site, and $Na^+$ probably from some sodium-bearing compounds. The source of $SO_4^{2-}$ and $Cl^-$, is not very certain, but would most likely have originated from anthropogenic sources in the area, e.g. fertilisers that were once used in agricultural activities in the area, or wastewater from septic tanks.

Overall, the increases in average TDS and conductivity in the dry season might have been a result of evaporative enrichment and/or cation exchanges in the aquifer, governed by catalytic factors responsible for driving equation (1), assuming the other ions had localised anthropogenic origins. Variations in concentrations with location, on the other hand, was probably indicative of variations in borehole depths and/or suction points, and/or anthropogenic influences arising from either groundwater abstractions or seepage from surface water bodies, including septic tanks.

Total hardness values averaged 348.3 mg $l^{-1}$, ranging from 256 to 470 mg $l^{-1}$ in the dry season, and 422 mg $l^{-1}$, with a range of 292 to 572 mg $l^{-1}$ in the wet season.

Chemically, total hardness, in groundwater, is defined as the sum of polyvalent cations dissolved in water (Wilson (?), the most abundant being calcium ($Ca^{2+}$) and magnesium ($Mg^{2+}$). Unlike most other parameters, total hardness showed a reduction from the dry season to the wet season (Figure 7). Plots of $Ca^{2+}$and $Mg^{2+}$ indicate their variable contribution to total hardness, which seems to depend on season.

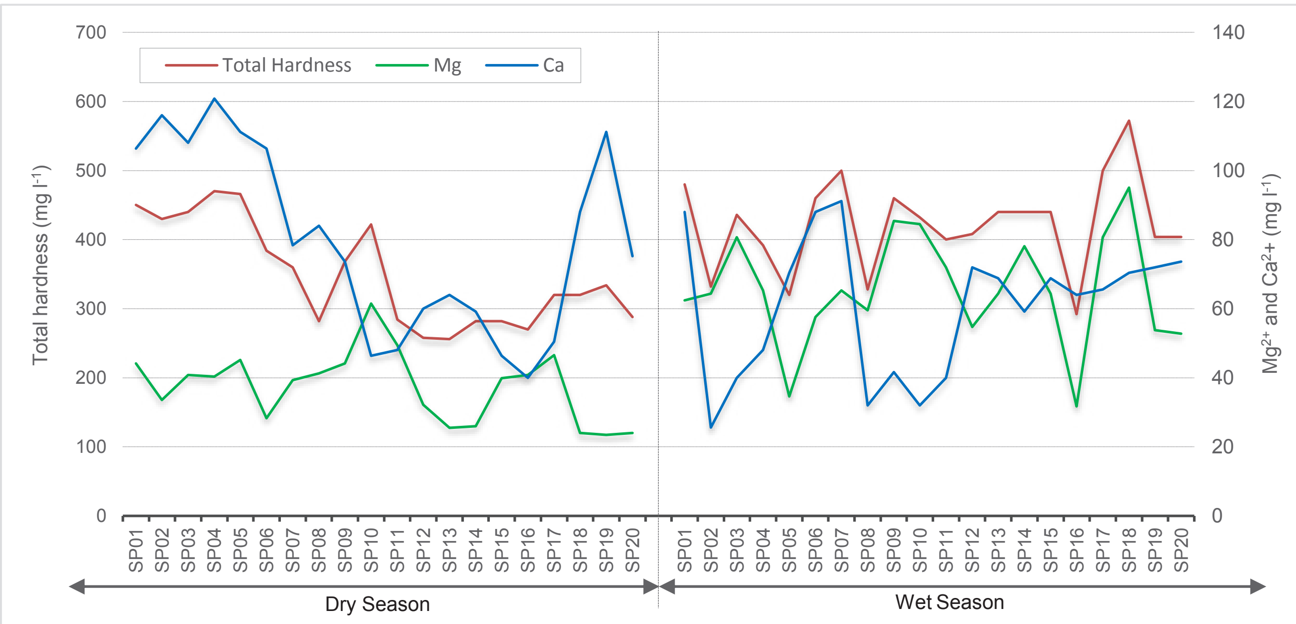


**Figure 7:** Variation of total hardness, and with $Ca^{2+}$ and $Mg^{2+}$ concentrations at different sample locations in St. Bonaventure Township's boreholes in the dry season (Nov. 13) and wet season (Mar. 14) (SP ≡ Sample Point).

$Ca^{2+}$, averaging 79.7 mg $l^{-1}$ (40 - 120.8 mg $l^{-1}$) in the dry season and 60.6 mg $l^{-1}$ (25.6 - 91.2 mg $l^{-1}$) in the wet season, appears to have exerted a lot more influence on the total hardness, particularly in the dry season. $Mg^{2+}$, which averaged 37.5 mg $l^{-1}$ (23.4 - 61.6 mg $l^{-1}$) in the dry season, and 65.3 mg $l^{-1}$ (31.7 - 95 mg $l^{-1}$) in the wet season, appears to have had a lot more influence on total hardness in the wet season.

Except for two locations, total hardness on the rest of the other locations appeared to be an average of the $Ca^{2+}$and $Mg^{2+}$ concentrations in the dry season, whereas in the wet season, it appeared to approximate to the summation of the two cations, the contribution from other sources, notwithstanding. Higher concentrations of $Ca^{2+}$ in the dry season, and lower in the wet season than $Mg^{2+}$, and the subsequent increase in total hardness in the wet season might have been caused by (Figure 8):

a) Calcium (and bicarbonate) ions being adsorbed across the **boundary layer** into the bulk solution, resulting in degassing of the saturated solution in the boundary layer to release $CO_2$ to the atmosphere during the dry season, thereby also releasing $Ca^{2+}$ cations into the solution.
b) The reverse of (a) being true in the wet season, in which there was *'depletion'* of $Ca^{2+}$ ions in the water, probably caused by increased saturation in the aquifer and/or precipitation of calcium carbonate.

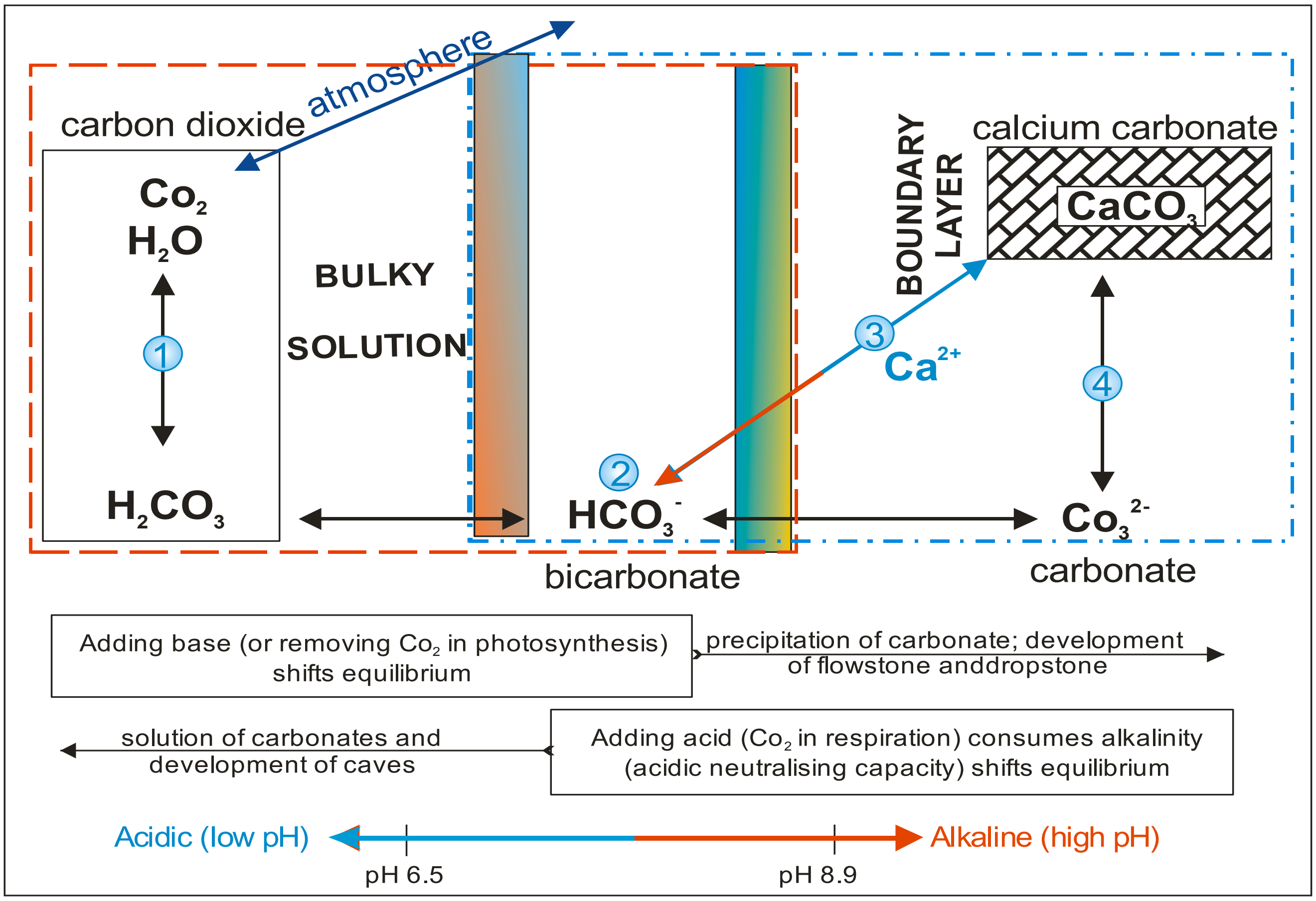


**Figure 8:** A schematic presentation of principal components of a carbonate rock dissolution/precipitation in aqueous solutions due to enrichment/depletion of $CO_2$ in the system (Modified after White, 1988; Dreybrodt, 1988; Jakus, 1977)

The increase in $Mg^{2+}$ ions in water in the wet season in a terrain that is underlain predominantly marble is probably a result of $Ca^{2+}$ exchanging for $Mg^{2+}$ in the boundary layer (Figure 8), or from a source that is most likely to be unnatural (anthropogenic). Spikes in the plots of all the three parameters, on the other hand, might have been influenced by variations in borehole depths and suction levels among others. These factors might have exposed groundwater to different conditions – temperature, levels of acidity caused by seepage from septic tanks, recharge amounts, intensity of evaporation, etc. – that could have catalysed weathering processes differently, resulting in preferential uptake of $Mg^{2+}$, and release of $Ca^{2+}$ into solution in the dry season, and vice-versa, in the wet season.

In addition, to the polyvalent cations of $Ca^{2+}$and $Mg^{2+}$, total hardness also appeared to have been affected by some non-carbonate salt ions, e.g. $Cl^-$ and $SO_4^{2-}$. A plot of total hardness alongside $Cl^-$ and $SO_4^{2-}$ appears to show some favourable correlation with $Cl^-$, but with no clearly discernible correlation with $SO_4^{2-}$. The wide ranges in concentrations of $Cl^{-1}$ (15 - 59 mg $l^{-1}$ for the dry season, and 30 - 65 mg $l^{-1}$ for the wet season) and $SO_4^{2-}$ (6.6 - 93.8 mg $l^{-1}$ for the dry season, and 12.5 - 97 mg $l^{-1}$ for the wet season) do not appear to reflect influences that are normal. These 'huge' variations and spikes in concentrations, especially in the wet season, probably reflect influences that are anthropogenic in nature, but different for each ion – wastewater for $Cl^{-1}$ and normal leaching from soils for $SO_4^{2}$ – but which also end up influencing the total hardness, even in terms of spikes, during the wet season (Figure 9).

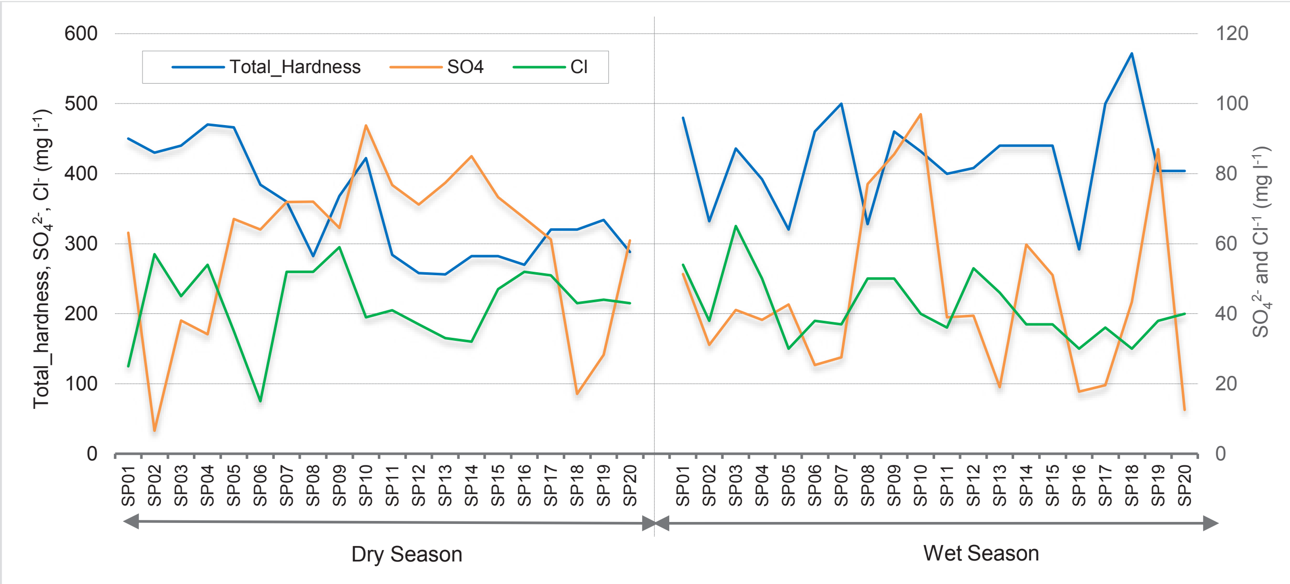


**Figure 9:** Variation of total hardness, $SO_4^{2-}$ and $Cl^-$ concentrations with location in the dry season (Nov. 13) and wet season (Mar. 14) in sampled St. Bonaventure Township's boreholes (SP ≡ Sample Point).

The minimum pH values for groundwater of 6.8 and 6.9 are within the range of the optimum range of 6.3, at which the amount of dissolved carbon dioxide in water equals the amount of bicarbonate ($HCO_3^-$) ion – representing a system that is more or less in equilibrium. The pH values of 6.9 - 8.4 in the dry season, and 6.8 - 7.4 in the wet season of groundwater in the project area represent ranges, within which the $HCO_3^-$ dissociates to yield $H^+$ and $CO_3^{2-}$ ions. This means at a 6.3 > pH < 8.4, the system is predominantly composed of the anion $HCO_3^-$, and minor, if at all, $CO_3^{2-}$ anion.

Further, total hardness of groundwater in the project area was in excess of 450 and 550 mg $l^{-1}$ in the dry and wet seasons, respectively. According to Mohsen (2010; in Ewusi et al., 2013), limits of total hardness that are most recommended in water usually range from 80 to 100 mg $l^{-1}$ $CaCO_3$. Sawyer *et al.* (2003; in Ewusi et al., 2013) recommend that any groundwater that exceeds the limit of 300 mg $l^{-1}$ $CaCO_3$ should be considered to be very hard. In this regard, most boreholes in the project area exceed the maximum permissible total hardness limit of 500 mg $l^{-1}$ for drinking water.

Even according to the WHO's international standards' and the US Environmental Protection Agency's (EPA) most desirable limit of 100 mg $l^{-1}$, total hardness results in the project area indicate that most of the water fits the description of **'very hard'** as it fell way beyond the maximum permissible and desirable limits as shown by the classification of water on the basis of total hardness as shown in Table 2.

**Table 2:** The Water Hardness Classifications scheme (reported as $CaCO_3$ equivalents).

| Classification | $CaCO_3$ equivalent (mg $l^{-1}$) |
|---|---|
| Soft | <75 |
| Moderately hard | 75 - 150 |
| Hard | 150 - 300 |
| Very hard | >300 |

***Source:*** U.S's EPA (EPA, 1986)

Karst terrains, as exemplified by the one underlying the project area, constitute areas that possess distinctive groundwater circulation systems and landforms arising from high rock solubility and well-developed secondary porosity created by $CO_2$-rich water infiltrating and circulating underground (Richter and Lillich, 1973; Ford and Williams, 1989). Therefore, carbonate systems are very important in carbonate rock settings because, among others, they **buffer** natural water with respect to pH, owing to their content of inorganic carbon species – a property referred to as **alkalinity** – a measure of the water's capacity to neutralise acid.

Average total alkalinity values in groundwater in the project area were 342.8 mg $l^{-1}$ (246 - 458 mg $l^{-1}$) in the dry season and 410.3 mg $l^{-1}$ (288-504 mg $l^{-1}$) in the wet season. Within a pH range of between 6.8 and 8.4, groundwater in the project area must have been predominated by bicarbonate ($HCO_3^-$). This means, total alkalinity, within the pH range of groundwater in the project area, the greatest contribution to alkalinity came from $HCO_3^-$ Such ionic configurations also conform to a chemical system described by Ford and Williams (1989) as one, in which carbonate minerals experience enhanced dissolution following hydration of $CO_2$. However, some of these ionic configurations could also have been influenced by solubility of carbonate minerals by *acidic* wastewater from septic tanks.

So, if total hardness and alkalinity are influenced by similar ions, then they must also bear very close relationship with each other. This close relationship, which is indeed projected in Figure 10. This relationship would imply, according to Burton Jr. and Pitt (2002), that the carbonate fractions of **hardness** (expressed as $CaCO_3$ equivalents) are chemically equivalent to the bicarbonates of **alkalinity** present in water. This then also means the alkalinity in groundwater in the project area formed mainly from carbonate rocks (marbles) that contained mostly $CaCO_3$.

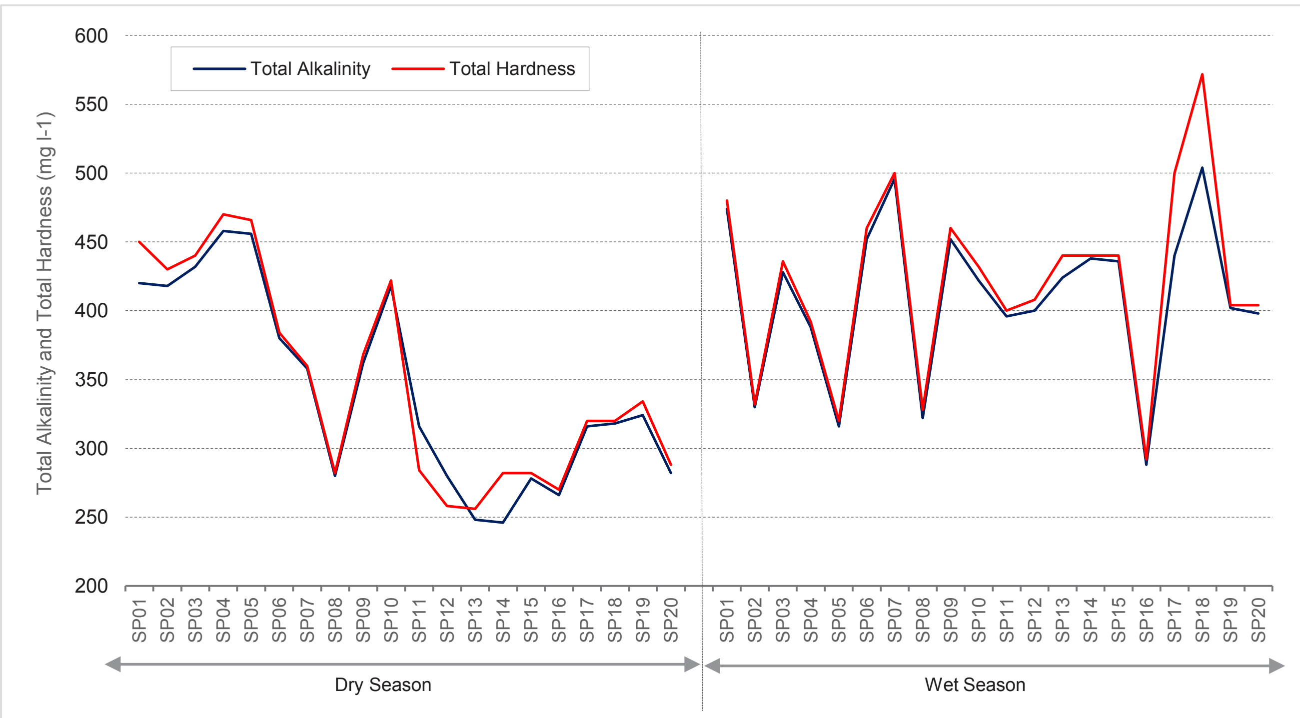


**Figure 10:** The relationship between alkalinity and hardness in the dry season (Nov. 13) and wet season (Mar.2014) in the St. Bonaventure Township's groundwater. (SP ≡ Sample Point)

Groundwater in the project area gave high alkalinity values – all of them in excess of 150 mg $l^{-1}$. Such high alkalinity values have been known to have great potential to contribute to **scale** (lime) build-up – or formation of calcium carbonate in the boundary layer as shown in Figure 8 – in the plumbing systems, thereby eventually clogging them. This is what residents of the St. Bonaventure Township might need to keep checking on in their plumbing systems, especially when/if they begin to notice a reduction in the amount of water coming from their taps.

Concentrations of both $Na^+$ and $K^+$ are higher in the wet season than dry season. $Na^+$ had average values of 51.5 mg $l^{-1}$ in the wet season and 34.3 mg $l^{-1}$ in the dry season, while $K^+$ averaged 19.3 mg $l^{-1}$ and 12.7 mg $l^{-1}$ in the wet and dry seasons, respectively. The increase in both $Na^+$ and $K^+$ is most likely resulting from anthropogenic activities as there are no alkali-feldspar-containing rocks in the area that would weather to release $Na^+$ and $K^+$. The anthropogenic influence seems apparent on some locations, where $Na^+$, but particularly $K^+$, show spikes, both in the dry and wet seasons (Figure 11).

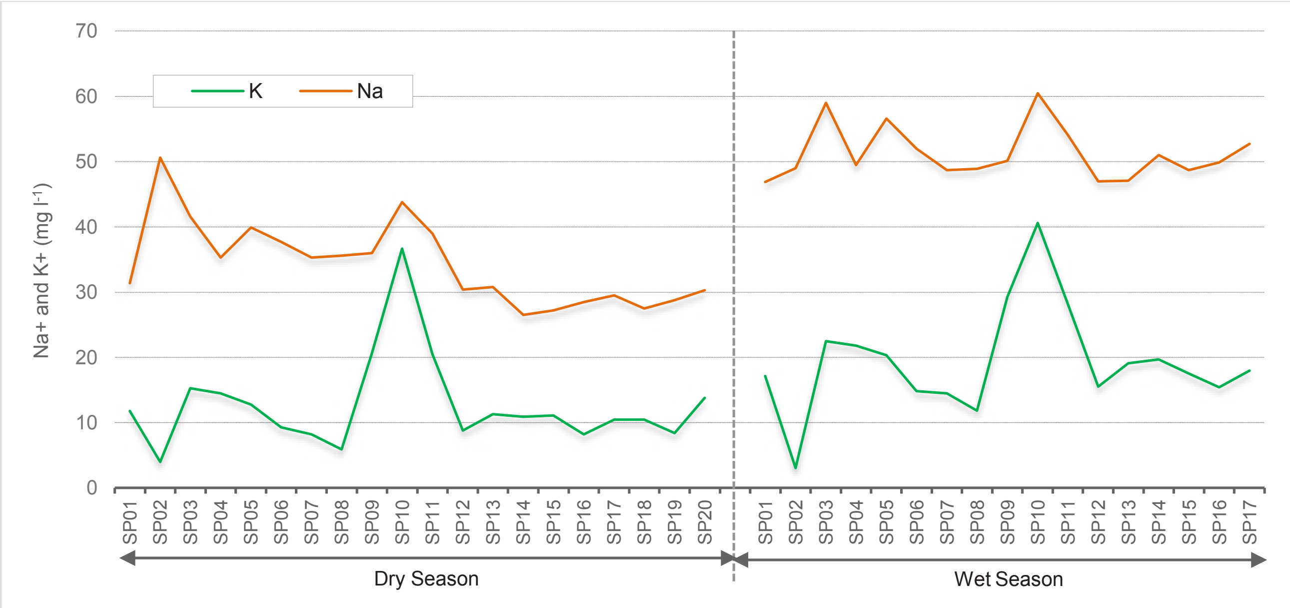


**Figure 11:** Variations of $Na^+$ and $K^+$ in the dry season (Nov. 13) and wet season (Mar. 2014) in the St. Bonaventure Township's groundwater. (SP ≡ Sample Point)

Nitrate ($NO_3^-$) values averaged 18.5 mg $l^{-1}$ (0.6 - 27.6 mg $l^{-1}$ during the dry season, and 4.9 mg $l^{-1}$ (1-9.5 mg $l^{-1}$) in the wet season. This shows a reduction from the dry season to the wet season (Figure 12), although site, SP2, appears to experience no major change in concentration between seasons. What is evident is that in both the dry and wet seasons, all values were below 50 mg $l^{-1}$. However, according to the EPA's guideline of 10 mg $l^{-1}$ for drinking water, all locations but two, exceeded this value in the dry season. Thus, making water unpotable for domestic use with regard to this value during the dry season.

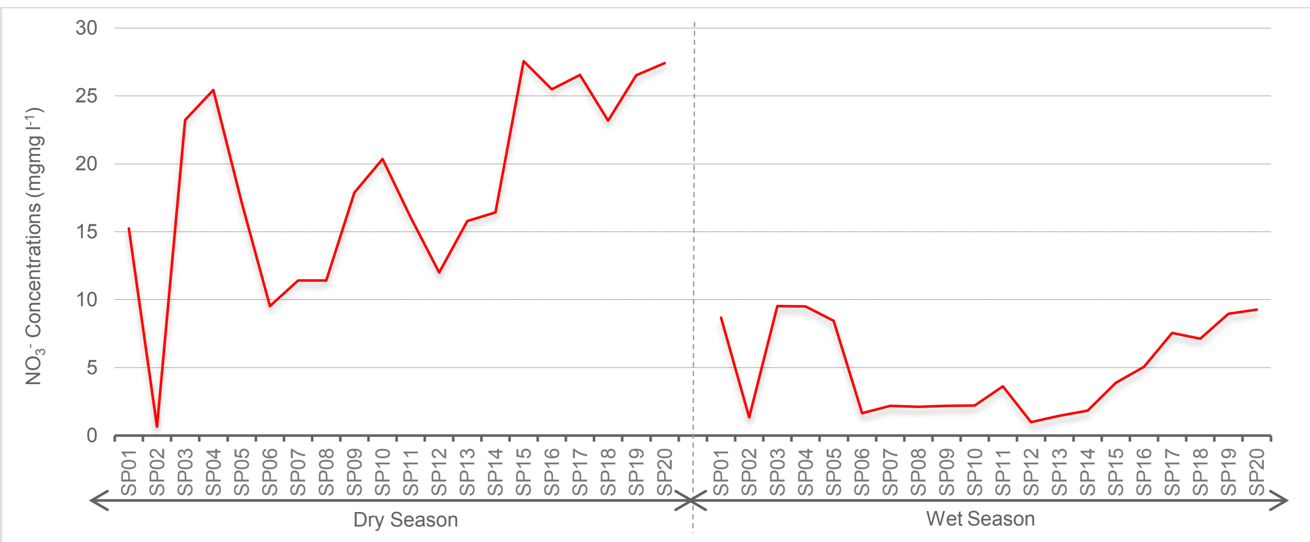


**Figure 12:** Variations of $NO_3^-$ in the dry season (Nov. 2013) and wet season (Mar. 2014) in the St. Bonaventure Township's groundwater. (SP ≡ Sample Point)

The exceptionally low values in the wet season may be attributed, just like other parameters with similar behaviour, and as discussed above, to dilution in the aquifer arising from increased saturation. Variations in $NO_3^-$-concentrations for the different sample-points might also be attributed to differences in borehole depths and suction levels. However, its presence in groundwater in this area is undoubtedly indicative of a wastewater source. This conforms to the suggestion by Putra (2010) that water with a nitrate:chloride ($NO_3^-$: $Cl^-$) ratio falling between 1:1 and 1:20 (Figure 13) has wastewater for its origin.

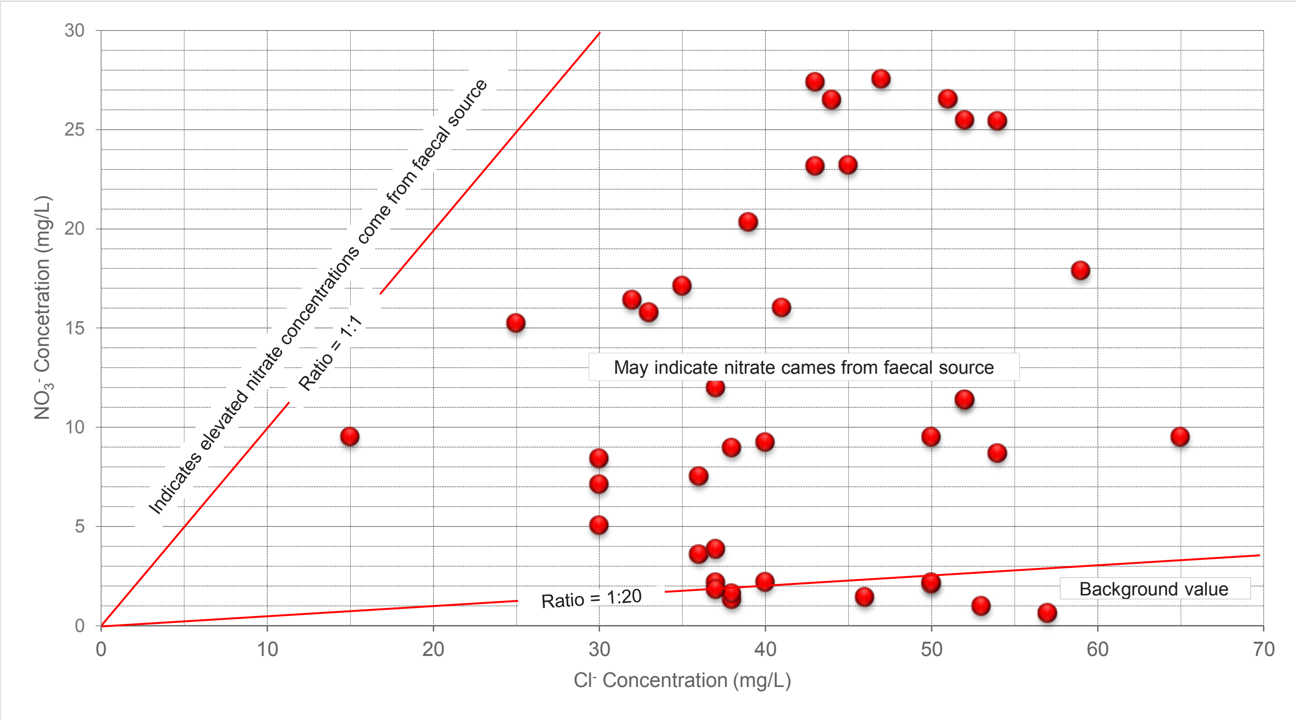


**Figure 13:** $NO_3^-$ versus $Cl^-$ concentration in the St. Bonaventure's groundwater (Nov. 13 and Mar. 2014).

The St. Bonaventure Township has only been in existence in the last decade and half, which might imply that most septic tanks would not have seriously started *soaking away* owing to either the small family sizes per household or due to increased efficiency of the sub-surface system to attenuate contaminants before they percolates to the aquifer. However, presence of contaminants of anthropogenic origin in groundwater indicates that there is a problem. If this is the case, what might be expected is that the older the septic tank system becomes, the higher the contaminant enrichment will become in the groundwater. This situation will be compounded by two major reasons, namely:

a) Inadequate or hardly any emptying of septic tanks: most septic tanks in the low-cost settlements across the length and breadth of the city, do not get emptied until and unless they overflow. This situation has been caused by inadequate numbers of vacuum tankers available.
b) Because of costs attached to the provision of these emptying services, residents do not readily volunteer to use these facilities.
c) In the course of time, capability of subsurface processes to attenuate contaminants will progressively decrease as a result of natural reductions in the efficiency of the system.

Bacteriological analyses of water samples from 20 sampled points in the project area showed two sites with total coliforms of 18 and 25 counts /100 ml in the dry season and no record of faecal coliforms. In the wet season, four locations gave total coliforms of 34, 15, 20 and 42 counts / 100 ml and one location gave 15 and 5 counts / 100 ml of total and faecal coliforms, respectively (Figure 14).

The results indicated an increase in the microbial contamination counts for the March 2014 (wet season) sampling campaign in that of the 20 sampled boreholes, 80% showed no bacteriological contamination in the project area's groundwater. Without any extra information, this situation could easily have been misinterpreted as advanced by MacDonald et al. (1999) in their study in the city of Dhaka, to mean among others, that:

a) On-site sanitation had had no impact on the quality of groundwater in the project area.
b) Most pathogenic micro-organisms at many sampled sites experienced a reduction in their numbers over time due to natural die-off.
c) There was attenuation of pathogens before they could reach the water table.

d) The process of d*ispersion and dilution* could have spread the microorganisms more widely as a result of the tortuous pathways taken by water during its migration through an aquifer.

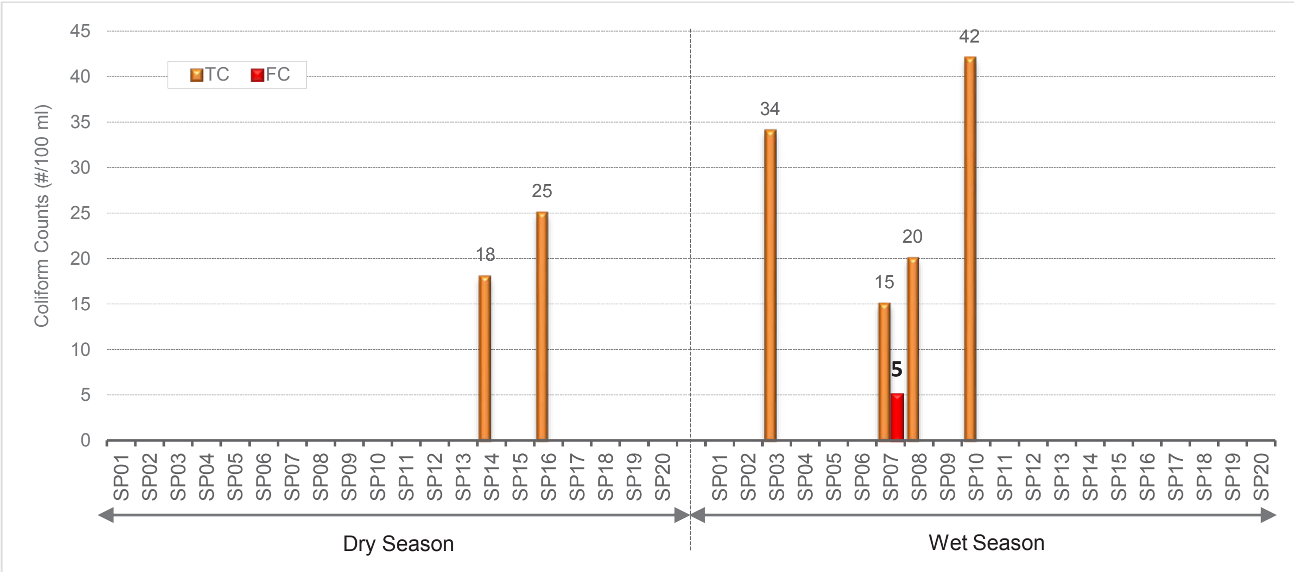


**Figure 14:** Coliform counts in St. Bonaventure's groundwater in the dry season (Nov. 13) and wet season (Mar. 2014).

(TC ≡Total coliforms; FC ≡ Faecal coliforms; SP ≡ Sample Point)

However, the *absence* of ubiquitous bacteriological contamination in the wet season of March 2014 would seem to have had a different influencing factor. That is, although wet season sampling was done in March, when rainfall is usually supposed to be at its peak in Zambia, March 2014 was relatively dry. The month received a total of only 19.9 mm of rainfall over five days in the early part of the month, namely 2.9 mm on the 1$^{st}$ day; 3.7 mm on the 2$^{nd}$ day; 4.2 mm on the 3$^{rd}$ day; 4.6 mm on the 7$^{th}$ day; and 4.5 mm on the 10$^{th}$ day (Figure 15). As such, there was probably not much infiltration that percolated to the water table to flash pathogens into the groundwater store. However, the requirement for drinking water to conform to drinking water guidelines is that no coliform bacteria should be detected for every 100 ml of drinking water tested.

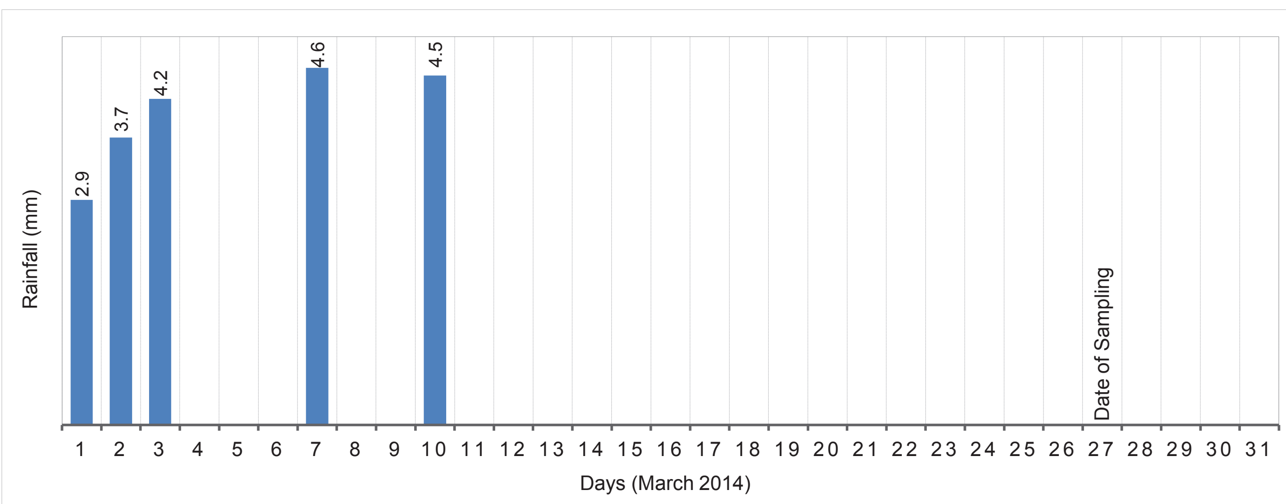


**Figure 15:** The number of rainfall days in March 2014, when the wet season sampling campaign was done in the St. Bonaventure Township

The lack of ubiquitous contamination of groundwater in March 2014 on account of the month not having received a lot of rain is confirmed by results from the same area from a sampling campaign undertaken in April 2013. In that year, the month of April received a little more rainfall than in March 2014.

Bacteriological results from this sampling campaign showed that 20 (36%), 18 (33%) and 5 (9%) out of the 55 samples tested, were contaminated with total, faecal and Escherichia (E.) coli coliform bacteria, respectively (Figure 16).

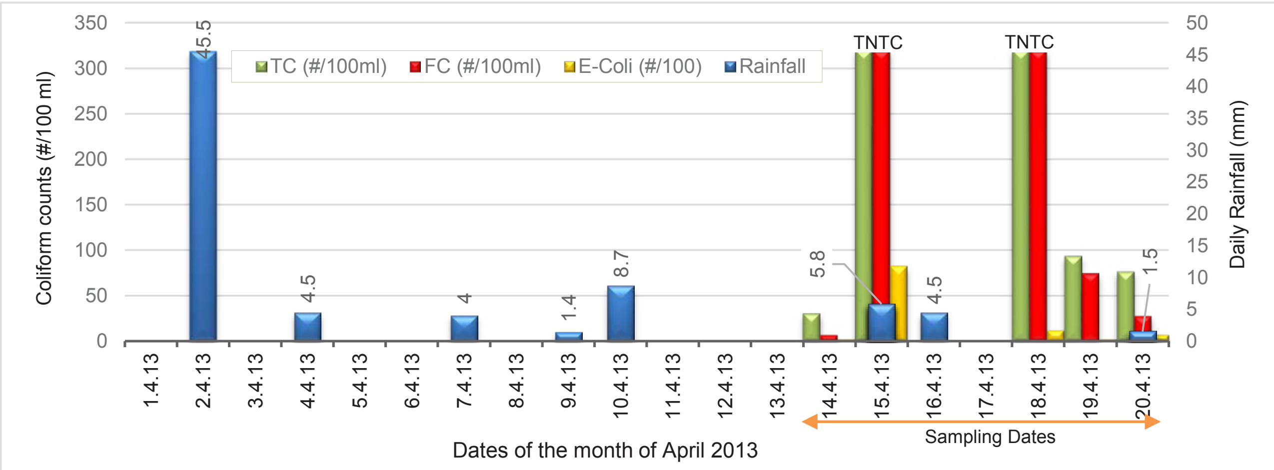


**Figure 16:** Coliform counts in St. Bonaventure's groundwater in the wet season (Apr. 2013).
***Data source:*** Banda (2013)

What is apparent from the above result is that an increase in rainfall leads to increased infiltration and percolation, thereby heightening the flashing of pathogens into the aquifer. Therefore, if rainfall were to be normal, as is usually expected for the months of March and April, contamination would have been widespread in the area.

## 5. COMPARISON WITH RESULTS FROM A HIGH-DENSITY SETTLEMENT

Variations of different physico-chemical and bacteriological parameters in groundwater with varying levels of saturation in the aquifer underlying the St. Bonaventure Township were compared with those from John Laing – a high-density settlement about five (5) kilometres north-east of the project area. John Laing residents use pit latrines to dispose of their excreta and rely shallow wells for their water supply. Four sets of samples were collected from the settlement's shallow wells during dry and wet seasons (Nov. 2003; Mar. 2004; Oct. 2004; Mar. 2005).

Results of most physico-chemical parameters were high for samples collected during the dry seasons (Nov. 2003 and Oct. 2004), while those for faecal coliforms were low. During the wet seasons (Mar. 2004 ad Mar. 2005) however, concentrations of physico-chemical parameters showed a marked reduction, while faecal coliforms increased drastically. The relationship between selected physical-chemical parameters of conductivity, nitrate, chloride and sulphate against faecal coliforms is clearly illustrated in a plot shown in Figure 17.

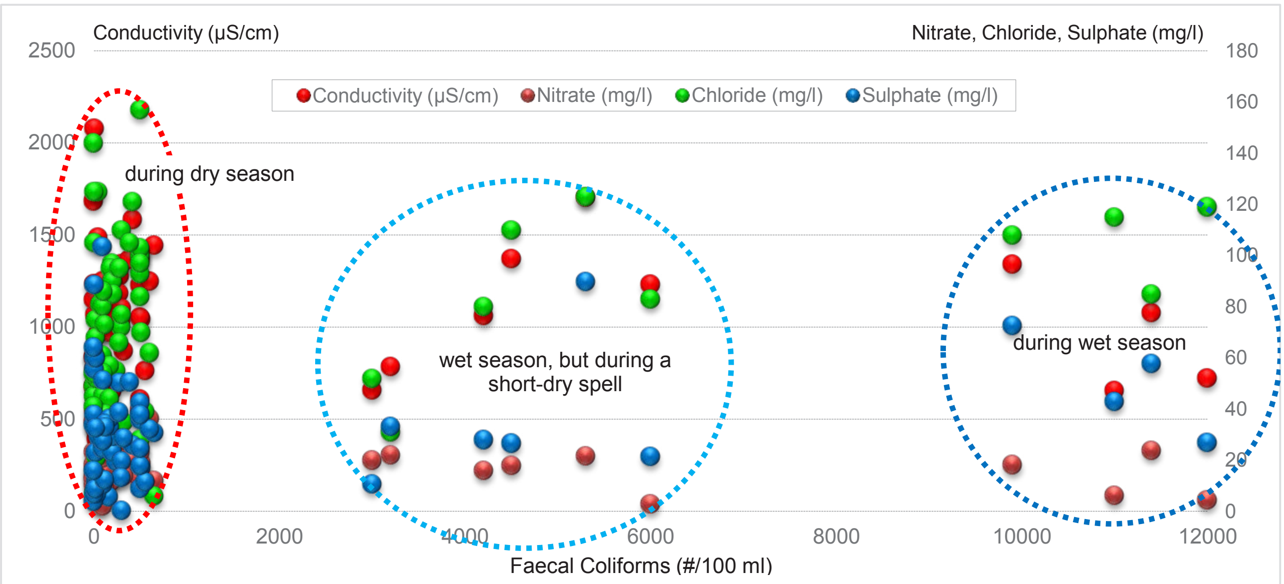


**Figure 17:** Plot of physico-chemical parameters against faecal coliforms for sample points (mostly shallow wells) in John Laing Township during the wet and dry seasons (Nov.'03; Mar.'04; Oct.'04; Mar.'05). Modified after Nkhuwa (2006).

The cause for the reductions in concentrations of most physico-chemical parameters, and an increase in faecal coliforms during the wet seasons, particularly in shallow wells, is undoubtedly a reflection of changes in levels of saturation in the aquifer. Increased recharge must have resulted in *'dilution'* of chemical parameters and an increase in coliforms through *flushing* of pit latrines' leachate into the aquifer as illustrated in Figure 18. In some instances, pit latrines get flooded, thereby bringing faecal matter in direct contact with groundwater.

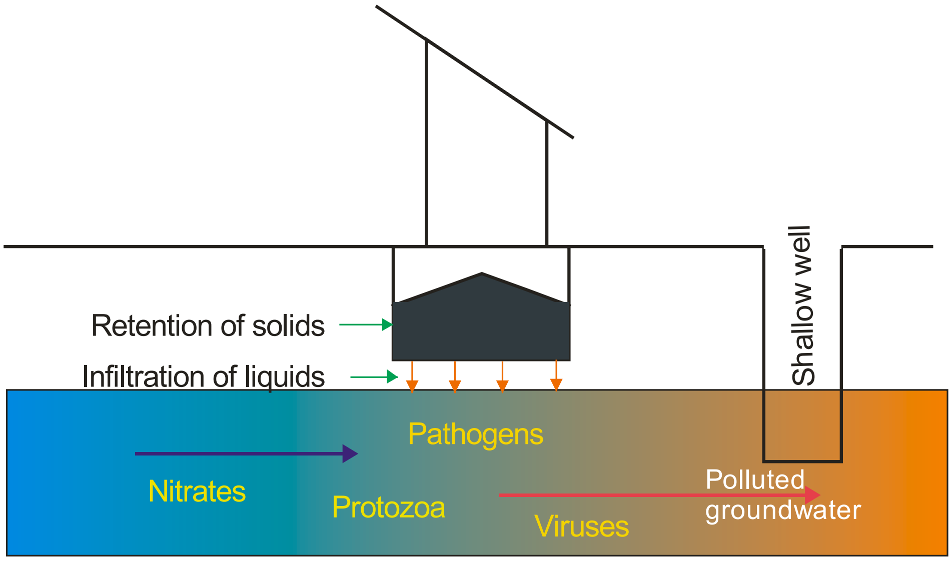


**Figure 18:** Pollution of groundwater from a pit latrine. (Modified after GTZ (Werner, 2005))

The difference in the depths of groundwater abstraction between shallow wells and boreholes is what causes the difference in levels of pollution between these two sources, such that even when most shallow wells show evidence of pollution, boreholes might not.

Differences in depths of groundwater abstraction between shallow wells and boreholes, as well as among the different boreholes, affect the contaminant pathways to the aquifer and suction points. This phenomenon can be illustrated by a cartoon shown in Figure 19:

a) For deep boreholes, it would be most unlikely for pathogens to survive if they were transported through pathway 1 from a septic tank to a borehole via the aquifer. Therefore, pollution would affect different boreholes with different depths of abstraction differently. This could probably explain why different boreholes in the project area are polluted differently in both the dry and wet seasons.

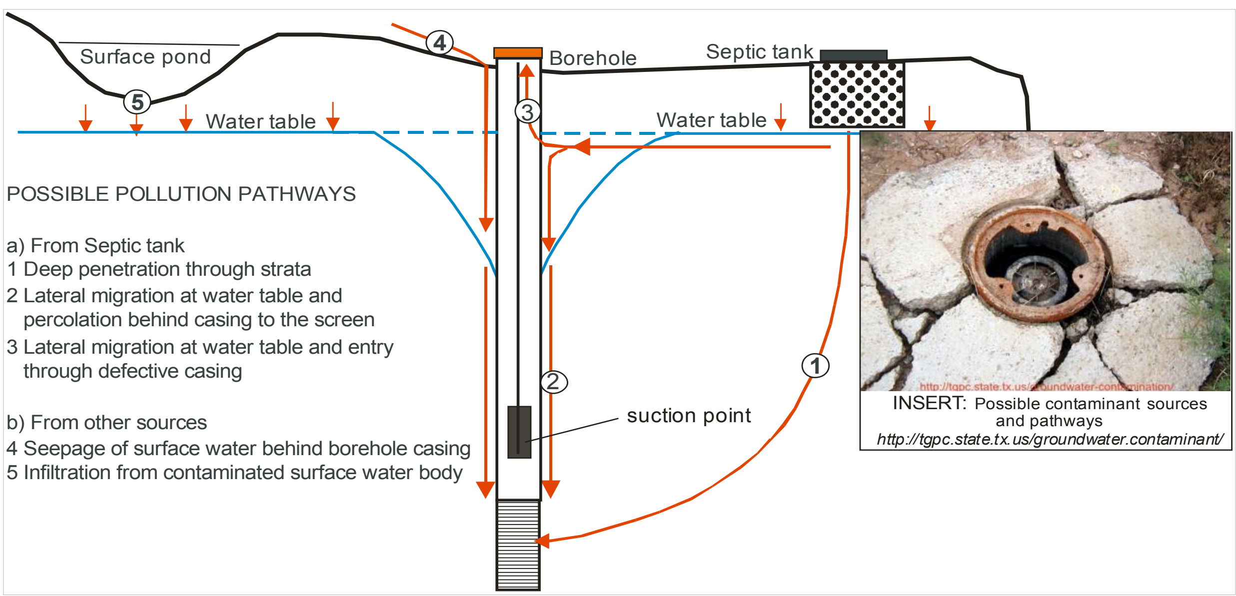


**Figure 19:** An illustration of possible sources and pathways for contaminants to groundwater stores. (Adapted and modified from MacDonald et al. (1999)).

b) The likelihood for contaminants to move to the well-screens via more direct routes, such as through pathways 2, 3, 4 or 5, probably resulting from, for example, inadequate or deteriorated well-head works (insert of Figure 19), would be very high. Some of these pathways might be exacerbated by presence of leaks in borehole casings at shallow depths probably due to corrosion or inadequate joints. Such deficiencies would allow ingress of effluent from soak-aways to the aquifer through lateral movement of leachate at shallow depths. In areas with thin unsaturated zones beneath soak-aways, and where permeability of shallow layers were high, leachate would quickly find its way into the aquifer and water supply system, particularly in places like the project area which is underlain by karstified marbles.

With regard to rainfall intensity, it has been demonstrated in this study how groundwater contamination differed between March 2013 and March 2014 due to differences in the amounts of rainfall received in this in the two different years (Figures 14 and 16).
In this regard, it would appear that, in spite of the fewer number of boreholes sampled in the project area, the pollution trend with changing levels of saturation (increased recharge) in the aquifer would lead to similar levels of bacteriological pollution in boreholes and in shallow wells.

## 6. DISCUSSION

Overall, concentrations of ions in the St. Bonaventure Township's groundwater were highly variable. This variation is probably a reflection of many influences, including rainfall, weathering, increases in mineral content as groundwater moved through pores and fracture openings in soil/rock and evaporation, groundwater withdrawals through pumping and/or evaporation with no recharge to the aquifer and differences in the depths of borehole and suction-points.

However, the above notwithstanding, the following observations must to be made with regard to the potability of water in the project area:

a) Although concentrations of total dissolved solids generally fell below the EPA's guideline of 500 mg $l^{-1}$ for drinking water, few locations had values that nearly approached 450 mg $l^{-1}$, indicating a potential for an impending groundwater quality problem with regard to this parameter for years with normal rainfall intensity in the future.

b) Concentrations of nitrate exceeded the EPA's guideline of 10 mg $l^{-1}$ for drinking water in the dry season, but dropped during the wet season probably due to dilution. Therefore, **water was not potable** with respect to nitrate in the dry season.

c) In order for drinking water to conform to the EPA's guidelines with regard to coliform bacteria, THERE SHOULD BE NO TOTAL COLIFORMS OR ESCHERICHIA (E) COLI for every 100 ml of drinking water tested. This means that for a number of boreholes in the project site, water was not potable with respect to microbial parameters.

## 7. CONCLUSION

From data and information obtained from this case study, it is very apparent that threats of groundwater pollution in Lusaka are posed from both high-density, low-cost settlements that are served by pit latrines as well as from low-density, high-cost townships, such as St. Bonaventure, that use septic tanks to dispose of their excreta and wastewater.

The greatest challenge for the future in Lusaka is that city growth and expansion will predominantly on pieces of land that were initially considered unsuitable for such human activities, and which have virtually no provision of any kind of service, let alone piped water or sewer lines. Such new development, inevitable as it might be, will only heighten the use of on-site sanitation for excreta and wastewater disposal, and on self-provision (boreholes) for their water supplies. While allowing for significant improvements in the availability of *good quality* drinking water, in the short term, the combined scenario of on-site sanitation and self-provision has potential for polluting and 'mining' groundwater on a very large scale in Lusaka.

Considering that groundwater is one important adaptation measure for the anticipated increasing effects of climate variability/change, such practices pose great threats to the sustainable development, utilisation, and management of existing and available groundwater resources in the city. Therefore, findings of this study should give a clarion call on city planners, water authorities, residents of the St. Bonaventure Township and all future property development proponents in the city to adopt disposal practices that will contribute to ensuring that Lusaka provides a safe and protected environment, in which its inhabitants will be able to live a healthy and productive life free from contracting diseases that are otherwise preventable.

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International Groundwater Resources Assessment Centre

United Nations
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Cultural Organization

International
Hydrological
Programme

IGRAC
Westvest 7
2611AX Delft
The Netherlands

T: +31 15 215 2325
E: info@un-igrac.org
I: www.un-igrac.org