International Journal of Environmental Science and Toxicology Research (ISSN: 2408-7262) Vol. 2(9) pp. 191-198, October, 2014
Available online http://www.internationalinventjournals.org/journals/IJESTR

Full Length Research Paper

Effect of Siting Boreholes and Septic Tanks on Groundwater Quality in St. Bonaventure Township of Lusaka District, Zambia

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Abstract

The general objective of the study was to assess the effect of siting boreholes and septic tanks in the same area on the quality of groundwater in St. Bonaventure township of Lusaka District. A cross-sectional study was conducted in St. Bonaventure township involving 55 households. The study site was purposively selected because all households in the township used septic tanks and boreholes for human waste treatment and drinking water supply respectively. Households were randomly sampled from a total of 490 households using stratified systematic method because of the differences in plot sizes. Groundwater samples were collected, distances from groundwater sources to soakaways were measured and direction of groundwater flow was obtained from the department of Water affairs. Logistic regression analysis was used to determine relationships between variables. P-values of less than 0.05 were considered statistically significant. The study showed that about 33 percent of the groundwater samples were contaminated with harmful bacteria. The study revealed that only direction of groundwater flow had a relationship with groundwater quality and there was no relationship between distance from borehole to soakaway and groundwater quality. Siting boreholes and septic tank systems in the same piece of land is not suitable for St. Bonaventure township.

Keywords: Lusaka, Groundwater quality, Borehole, Septic tank, Soakaway, Faecal coliform, Total coliform, Bacteriological contamination.

INTRODUCTION

In many places, particularly in areas with low population densities, it is common to store and treat wastewater on-site where it is produced. To do this, there are a number of technical options for on-site waste management which if designed, constructed, operated and maintained correctly will provide adequate services and health benefits when combined with good hygiene practices. On-site systems include ventilated improved pit latrines, pour-flush toilets and septic tanks (WHO, 2006). A typical on-site wastewater treatment system consists of a septic tank with a soil absorption field that allows treated effluent (settled sewage) to infiltrate into the soil. These systems when functioning well are effective at removing pollutants before they enter into the environment. This process however, depends on certain circumstances such as geological and climatic conditions. The release of pollutants into the environment may result if a septic tank system is improperly sited and constructed (Obropta and Berry, 2005). In addition, failure to adequately address issues of wastewater treatment and disposal can also lead to serious public health and environmental problems (Goonetilleke et al., 2002).

According to McQuillan (2004), conventional septic

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tanks and soakaway are suitable means for on-site sanitation when plot (piece of land) size and subsurface conditions provide adequate natural means of reducing pathogenic organisms and organic matter. Widespread groundwater contamination however, has occurred in many rural areas utilizing on-site wells and septic tank systems. This is because of effluent which is discharged onto the subsurface by soakaways as this often percolates into the same aquifer tapped by wells for domestic water supply. Reynolds and Barrett (2003), state that in the United States, about 34 percent of those served by a public water system utilize groundwater source. In accordance with Simms (2006), up to 40 percent of wastewater associated with new home construction is discharged into on-site systems and hence these systems treat and release vast amounts per day into the environment.

In Zambia and Lusaka in particular, the rapid population growth has brought a number of adverse effects on the delivery of public health services which include sewage treatment and water supply (Kawanga, 2003). In Lusaka, septic tanks are used for sewage disposal, in areas such as Mass media complex, Chalala and St. Bonaventure, the study site. St. Bonaventure township is located in Lusaka's Makeni area about 7km to the south of city centre. In this township on-site treatment of wastewater is practised and private boreholes are the only source for domestic and drinking water supply.

The city of Lusaka however, is built on a marble which is cut by a network of fissures that remain either as open hollows or filled with soil. These fissures manifest themselves on the surface as pits and caves. The presence of these fissures in marbles makes them very vulnerable and susceptible to wide range of environmental factors (Grönwall et al., 2010). A study on groundwater that was conducted in 2010 in selected risky areas of Lusaka such as dump sites, showed high levels of contamination of groundwater with bacteria. Statistics showed that about 60% of these groundwater sources had levels of contamination above 10 total coliforms per 100ml of water; while 30% showed presence of *E. coli* which is an indicator of faecal contamination (Andrea et al., 2010).This study was therefore, conducted to assess the effect of siting boreholes and septic tanks in the same area on bacteriological quality of ground-water in St. Bonaventure township which is a low density area where the perception is that groundwater is the safest.

MATERIALS AND METHODS

This was a cross-sectional study; the quality of groundwater was the main subject of investigation. Groundwater samples were collected and analysed in the laboratory to ascertain its bacteriological quality. Results were classified as either satisfactory (groundwater sample having total coliform count of 0 to 10 per 100 ml and faecal coliform count equal to 0), or unsatisfactory (groundwater sample having total coliform count of more than 10 per 100 ml or faecal coliform being present in 100 ml) in accordance with World Health Organization guidelines of 2003 on drinking water quality.

Siting of boreholes and septic tanks is determined mainly by two factors which include the distance from groundwater source to soakaway and direction of groundwater flow in the area. This study therefore, collected information on location of groundwater sources in relation to soakaways, in terms of direction of groundwater flow and distance from groundwater source to soakaways. The study also collected data on maintenance of septic tanks and soakaways; plot sizes on which septic tanks and groundwater sources are located, age of septic tanks/soakaways and use of groundwater per household.

The study was conducted in St. Bonaventure township of Lusaka district. The study site was purposively selected because all households in the township used septic tanks and boreholes for human waste treatment and domestic/drinking water supply respectively. The study population involved 490 households in St. Bonaventure that were classified under high and medium cost plots.

EPI INFO version 7 was used to calculate the sample size from a total population of 490 households, and using the expected frequency of 20 percent (bacteriological contamination of groundwater sources), a sample size of 55 households was found at 95 percent confidence level. The number of households was assumed to be equal to the number of boreholes and septic tanks in St. Bonaventure township because all households in the study site were not connected to Lusaka water and sewerage company that supplies water to other areas of Lusaka district.

The sample for households was randomly selected using stratified systematic sampling. Strata were defined by one major characteristic which was the size of plots on which households were located. St. Bonaventure residential site had a total number of 490 households comprising two specific plot sizes. The plots were classified under medium plots (30 meters x 45 meters) which consisted of 223 households while high cost (35 meters x 50 meters) had 267 households. The importance of plot sizes was on assumption that they might have effect on siting groundwater sources and septic tank systems within the plot boundaries. It was therefore, important to employ stratified sampling method in order to capture these specific subgroups within the study population. To achieve this, the total number of households in each stratum was divided by the sample size using the formula:

$$k = \frac{N}{n}$$

Where
k = sampling interval,
n = sample size and
N = population size.

Thus, k = 490/55 and finally, k = 9. This meant that the starting point was any number from 1 to 9 on each list. Households that corresponded to numbers from 1 to 9 on the two lists were subjected to a draw and the starting point was determined. After the first number was picked, every 9th household was selected. At the end of the procedure, 30 households from high cost and 25 households from low cost were selected.

During data collection the water tap at each household was first sterilized by a flame from cotton wool soaked in methylated spirit as the source of heat. After sterilization the tap was opened and allowed to run for 30 seconds and thereafter 300ml of groundwater was collected in sterile bottles that were sterilized by Environmental Engineering Laboratory (EEL) in the School of Engineering at the University of Zambia. Groundwater samples were transported to EEL every day at the end of the activity in a cold box with frozen ice packs to preserve the quality of groundwater.

An inspection guide was used to check on the environmental conditions around septic tanks and soakaways and these included general maintenance and hygiene. Direction of groundwater flow around St. Bonaventure township was collected from the department of Water affairs in Lusaka district. This was recorded in relation to location of each borehole and the nearest soakaway at each household. A 100 m tape measure was used to physically measure the distance between each selected borehole and the nearest soakaway.

Stata version 11 computer package was used for both data entry and analysis. Results of the analysis of bacteriological groundwater quality (dependent variable) using total and faecal coliforms as main indicators were coded. Independent variables included: distance from groundwater source to soakaway; direction of groundwater flow; plot size, use of groundwater, maintenance of septic tank systems; dampness around soakaways and age of septic tank system.

Logistic regression model was employed to determine whether there was a relationship between bacteriological quality of groundwater and distance from groundwater sources to soakaways. Logistic regression model was also employed to determine whether there was a relationship between locations of groundwater sources and soakaway with respect to direction of groundwater flow including the other environmental factors. P-values of less than 0.05 were considered statistically significant.

RESULTS

The indicators used in this study to determine the bacteriological quality of groundwater were total coliform, faecal coliform and *Escherichia coli* (*E. coli*) and can be seen in table 1.

Table 1 shows that majority of groundwater samples (67.3 percent) collected were satisfactory in terms of total coliform per 100ml. Similar results were seen for faecal coliform per 100ml of groundwater as indicated by 67.3 percent being satisfactory. For *E. coli*, 89.1 percent of the groundwater samples were free from contamination. Unsatisfactory results were recorded in 32.7 percent of groundwater samples for total coliform and faecal coliforms while *E. coli* was only evident in 10.9 percent of groundwater samples.

Out of 55 boreholes that were sampled for bacteriological groundwater quality analysis, results in figure 1 show that 73 percent were sited 30 metres and more away from the nearest soakaways while the remaining 27 percent were sited less than 30 metres from soakaways.

Data on direction of groundwater flow in figure 2 indicate that out of 55 boreholes that were sampled for bacteriological groundwater quality analysis, 64 percent were sited up-slope from the nearest soakaways in relation to groundwater flow while 36 percent were sited down-slope.

Ideally, direction of groundwater flow and distance from groundwater source to potential sources of pollution (soakaways) determine the location of groundwater sources in order to protect the groundwater from contamination. Results of logistic regression analysis in table 2 give in detail the relationship between groundwater quality (Dependent variable**)** in terms of total coliform and some environmental factors (independent variables) it could be associated with.

Table 2 indicates that groundwater quality was transformed into a dichotomous variable, i.e. equal to ‘1’ for cases where the total coliform count per 100ml of groundwater was 0 to 10 and ‘0’ for cases where the count was greater than 10 in 100ml of groundwater. Results showed that only direction of groundwater flow came out as significant at 5 percent significance level with the p-value of 0.005. The odds ratio for the direction of groundwater flow was 0.118. Distance from water source to soakaway was insignificant at 5 percent significance level with the p-valve of 0.845 and the odds ratio was 0.993.

Similar to the case of total coliform count per 100ml of groundwater, table 3 shows that groundwater quality was transformed into a dichotomous variable, i.e. equal to ‘1’ for cases where the faecal coliform count per 100ml of groundwater was equal to 0 and ‘0’ for cases where the count was 1 or greater. Only direction of groundwater flow was associated with faecal coliform count per 100ml of groundwater at 5 percent significance level with the p-value of less than 0.001. The odds ratio for the direction of groundwater flow was 0.042. The distance between groundwater source and soakaway was not significant at 5 percent significance level with

Table 1. Groundwater Bacteriological Quality

Type of Contaminants	Bacteriological Quality of Groundwater		Total
	Satisfactory	Unsatisfactory	
Total coliform	37 (67.3%)	18 (32.7%)	**55 (100%)**
Faecal coliform	37 (67.3%)	18 (32.7%)	**55 (100%)**
E. coli	49 (89.1%)	6 (10.9%)	**55 (100%)**

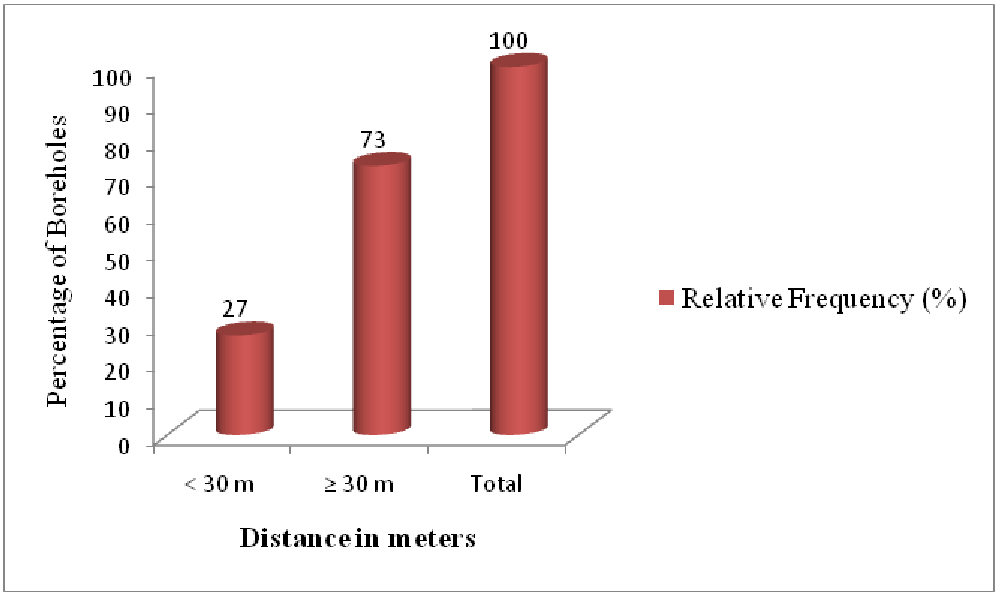

Figure 1. Location of Boreholes in Relation to Distance from Soakaway

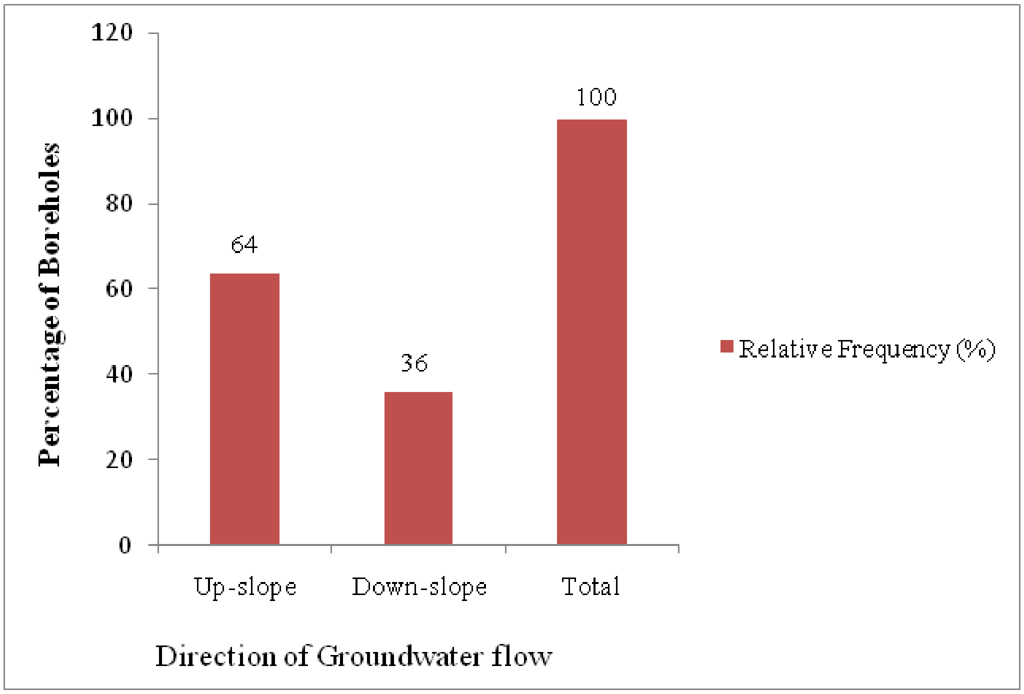

Figure 2. Location of Boreholes and Soakaways in Relation to Direction of Groundwater Flow

Table 2. Logistic regression model for total coliform as a dependent variable

Variable Description	B	S.E.	Wald	df	Sig.	Exp(B)
Direction of groundwater flow,1 =up-slope, 0 = Down-slope	-2.133	0.755	7.983	1	0.005	0.118
Distance from water source to soakaway,1= ≥ 30 m and 0 = < 30 m	-0.007	0.034	0.038	1	0.845	0.993
Heavy water use, 1= Evident, Not evident	-2.39	1.69	1.999	1	0.157	0.092
Plot size,1= high cost, 0 = Low cost	-0.39	0.754	0.267	1	0.605	0.677
Age of septic tank, 1= <4 years, 0 = > 4 years	-0.318	0.908	0.123	1	0.726	0.727
Ever desludged, 1= desludged, 0 = Not desludged	0.858	1.362	0.397	1	0.529	2.358
Dampness,1= Evident, 0 = Not evident	-1.278	0.984	1.685	1	0.194	0.279
Heavy equipment parked on septic tank, 1= evident and 0 = Not evident	0.847	1.78	0.227	1	0.634	2.334

Note: **B**: Logistic regression coefficients; **Wald**: Wald statistics (Chi-Square); **df**: Degree of freedom; **S.E**: Standard errors; **Sig**: Significance; **Exp (B)**:Odds ratio.

Table 3. Logistic regression model for faecal coliform as a dependent variable

Variable Description	B	S.E.	Wald	df	Sig.	Exp(B)
Direction of Water flow, 1=up-slope, 0 = Down-slope	-3.165	.904	12.261	1	.000	.042
Distance from water source to soakaway,1= ≥ 30 m and 0 = < 30 m	.060	.037	2.640	1	.104	1.062
Heavy water use, 1= Evident, 0 = Not evident	-1.143	1.733	.435	1	.510	.319
Plot size,1= High cost, 0 = Low cost	-.649	.793	.670	1	.413	.523
Age of septic tank, 1= <4 years, 0 = > 4 years	.038	.999	.001	1	.970	1.039
Ever desludged , 1= desludged, 0 = Not desludged	.574	1.864	.095	1	.758	1.775
Dampness,1= Present, 0 = Absent	-.520	.928	.314	1	.575	.595
Heavy equipment parked on septic tank, 1= evident and 0 = Not evident	.370	1.887	.039	1	.844	1.448

B: Logistic regression coefficients; **Wald**: Wald statistics (Chi-Square); **df**: Degree of freedom
S.E: Standard errors; **Sig**: Significance; **Exp (B)**:Odds ratio

the p-valve of 0.104 and the odds ratio was 1.062.

DISCUSSION

The general picture of groundwater bacteriological analysis in this study showed that majority (67.3 percent) of groundwater samples collected from boreholes at households in St. Bonaventure township were satisfactory, while 32.7 percent were unsatisfactory. These results indicate that some households used groundwater that was not safe for drinking purposes. According to WHO (2003), drinking water from untreated sources like boreholes is said to be safe when total coliform count is 1 to 10 per 100 ml and faecal coliform count is 0 in 100 ml. This therefore, indicates that about 33 percent of households in St. Bonaventure use groundwater for drinking and domestic purposes that is not safe. According to Dissanayake et al., (2004) 80 percent of sicknesses and deaths among children in the world are caused by unsafe drinking water. WHO (2003), also states that on average, every 8 seconds in the world, a child dies as a result of contaminated water intake. Zambia and Lusaka in particular is not exceptional; if this practice is allowed to go on without taking corrective measures, morbidity and mortality due to waterborne infections that have been highlighted at global level as a result of drinking contaminated water may even get worse locally.

Location of Boreholes in Relation to Direction of Groundwater Flow

Logistic regression analysis results of bacteriological quality of groundwater (total coliform count in 100ml of groundwater) indicated that only direction of groundwater flow had a relationship with groundwater quality at 5 percent significance level with p-value equal to 0.005 and the odds ratio of 0.118. Since the odds ratio for the direction of groundwater flow was less than 1 (0.118), it therefore, meant that up-stream location of boreholes was 0.118 times more likely to lead to a reduction in total coliform count per 100ml of groundwater.

Similar results were observed from logistic regression analysis for the faecal coliform. In this case, direction of groundwater flow came out as having a relationship with faecal coliform count at 5 percent significance level with p-value less than 0.001 and the odds ratio of 0.042. This indicates that up-slope location of boreholes with respect to soakaway was 0.042 times less likely to lead to presence of faecal coliform in 100ml of groundwater.

The outcomes in both total coliform and faecal coliform logistic regression analyses were in line with WHO guidelines of 2001 on drinking water safety which require the location of boreholes to be up-slope from any potential source of pollution. These results therefore, show that if boreholes are located down-slope from soakaways which are a potential source of contamination, they are more likely to be contaminated with total coliform and faecal coliform bacteria. This could indicate that there was no coordination among partners in groundwater resource management at initial stages of groundwater development in Lusaka district and St. Bonaventure township in particular. These results further suggest that residents of St. Bonaventure township did not follow proper guidelines for siting boreholes and septic tanks.

Distances between Borehole and Soakaways

There was no relationship between groundwater quality and the distance from borehole to soakaway. In this study, the distance from groundwater source to soakaway came out insignificant with p-values equal to 0.104 and 0.845 for faecal coliform and total coliform respectively. The odds ratio for faecal coliform was 1.062 while total coliform was 0.993. The two odds ratios indicate that there was no clear relationship between distance from groundwater source to soakaway and bacteriological quality of groundwater.

These findings were contrary to UNHCR guidelines of 2006 for siting groundwater sources, which set the minimum distance between a borehole and any potential polluting activity at 30 meters. This could indicate that there were other factors that might have influenced bacteriological quality of groundwater in St. Bonaventure township such as geological formation.

Grönwall et al., (2010) state that Lusaka's ground formation is mainly of limestone landscape which is characterized by caves, fissures, rocks and underground streams. The presence of the stated features in the ground means that there are open spaces underground that may allow groundwater to move freely. These characteristics may enable groundwater to move faster than it could if they were absent. According to Grönwall et al., (2010) this may reduce the contact time between wastewater and predatory microorganisms that are present in the soils around soakaways for them to remove pathogens from wastewater. The end result could be contamination of groundwater sources with bacteria that could be of human faecal origin including those groundwater sources located more than 30 meters away from soakaways.

Other Factors Associated with Groundwater Quality

This study examines further other factors associated with groundwater quality including: plot size, water usage at household level, operation and maintenance of septic tank systems, age of septic tank systems, environment and dampness around septic tanks.

Age of Septic Tank Systems

The age of septic tank system did not come out as a significant factor in this study and the odds ratio of 1.039 for faecal coliform indicates that there was no clear relationship between groundwater quality and the age of septic tank system. This is not in conformity to Howard et al., (2006) who state that there is a biologically active layer that forms in the soils around soakaways and it takes some time to become effective in removing some pathogens through predation and filtration. This means that groundwater from boreholes that are near soakaways that were newly constructed may be at risk of faecal coliform contamination. Total coliform count, however, showed some different relationship with the age of soakaways. The odds ratio of 0.727 indicates that to some extent, boreholes that are less than 4 years are less likely to get contaminated with total coliform bacteria. The explanation to this finding could be that total coliform might have come from other sources besides soakaways and hence not related to the age of septic tank and soakaways that are nearest to the groundwater sources.

Size of Plot on which Households were Located

The size of plots on which households were located had no relationship with the number of faecal coliform and total coliform in groundwater with p-values of 0.413 and 0.605, respectively, at 5 percent significance. On the contrary, odds ratios showed some protective effect on groundwater quality against both faecal coliform and total coliform when households were located on bigger plots. In this study, households that were located on bigger plots, boreholes on these locations were 0.5 times less likely to get faecal coliform contamination and 0.7 times less likely to record high count of total coliform in 100ml of groundwater. According to Geary and Gardneron,(1996) on factors related to plot sizes and siting boreholes and soakaways, the density ranges for septic tanks should be 15 – 25 per square kilometres to ensure protection of groundwater. It however, states that where groundwater contamination is not an issue and land values take precedence over the need to protect groundwater quality, environmentally sustainable plot size allocation should be in the range of 0.4 to 1 hectare. It could therefore, be concluded that land size allocation would depend on the subsurface conditions, environmental and public health values of groundwater resources in the particular area.

Storage of Heavy Equipment around Soakaways

Similarly, storage of heavy equipment around septic tank systems was insignificant (p-value 0.844) at 5 percent significance but the odds ratio of 1.448 meant that there was some relationship with presence of faecal coliform in groundwater. This study indicates that boreholes that were located near soakaways that had heavy equipment stored on them were 1.448 times more likely to be polluted with faecal coliform bacteria. Similar result was observed for total coliform at 5 percent significance with a p-value equal to 0.634 and the odds ratio of 2.334.

This is in line with Obropta and Berry (2005) who state that driving or parking vehicles on septic tanks and areas around soakaways would compact the soil, as well as possibly damage the pipes, tanks or other components of the septic tank system. This may have been due to the soils around soakaways being compacted; hence reducing the porosity of the soils around the system. This could therefore, have a negative effect on functioning of septic tank system as it may lead to overflowing of untreated wastewater resulting into pollution of top soils and finally percolating into the ground.

Utilization of Groundwater

The study showed no relationship between the number of both faecal coliform and total coliform in groundwater and large utilization of groundwater at household level (p-values of 0.50 and 0.157 at 5 percent significance) although this had some protective effect on groundwater quality against both faecal coliform (odds ratio of 0.319) and total coliforms (odds ratio of 0.092) when households used high volumes of water. In this case, households that used large quantities of groundwater were 0.319 times less likely to have faecal coliform contamination of borehole water. Similarly, households that use large volumes of groundwater were 0.092 times less likely to have total coliform contamination of borehole water. This is contrary to Rusinga (2004) who state that drawing large volumes of groundwater makes the water in the ground to move from much further a point towards the area from which groundwater is drawn. These results further indicate that there may be something wrong with the geological formation around St. Bonaventure township that needs further investigation.

Dampness around Septic Tanks

The results of this study indicate that if dampness is present around septic tank system, the nearest water source is less likely to be contaminated with bacteria. Contrary to these findings, Obropta and Berry (2005) state that a failing septic tank system and its effects on nearby groundwater sources could be noted by presence of dampness over the soakaway and vigorously growing green vegetation is noticed around the area. Obropta and Berry (2005) further note that the effluent may contaminate drinking groundwater source with infectious disease causing organisms and other pollutants. In this study however, there was no relationship between dampness around septic tanks and the quality of groundwater (p-values of 0.575 for faecal coliform and 0.194 for total coliform). These findings could also indicate that there was something wrong underground which may need further studying in St. Bonaventure Township.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This study established that 67.3 percent of boreholes in St. Bonaventure township had water that was safe for drinking purposes and 33 percent of boreholes were contaminated with bacteria that were likely to be pathogenic in nature. This implies that 33 percent of households were at risk of contracting waterborne diseases such as Cholera, Dysentery, Typhoid and other diarrhoeal diseases. The study also revealed that direction of groundwater flow had a relationship with the quality of groundwater with p-values equal to 0.001 and less than 0.001 for total coliform and faecal coliform respectively at 5 percent significance level. This study further revealed that there was no relationship between distance from borehole to soakaway and the quality of groundwater in St. Bonaventure township. This could be attributed to other factors that might have influenced the quality of groundwater such as geological formation (presence of fissures and rocks) and need further investigation.

It can therefore, be concluded that location of boreholes and septic tank systems in the same piece of land is not suitable for St. Bonaventure township and Lusaka at large. This is because safety of groundwater could not be guaranteed even when technical and public health requirements are followed during siting of groundwater sources and septic tank systems especially in terms of distance between groundwater source and soakaway.

RECOMMENDATIONS

Partners dealing with environmental management issues such as: Zambia environmental management agency, department of Water affairs, Geological department and Lusaka city council should collaborate each time projects that involve groundwater development and on-site wastewater treatment are to be implemented. Lusaka water and Sewerage Company should consider providing piped water supply and sewerage services in St. Bonaventure township in order to protect the community against waterborne diseases.

ACKNOWLEDGEMENTS

We wish to express our gratitude to our sponsor the University of Zambia for enabling us undertake this study without which it would have been very difficult to achieve. We would like to thank Mr. Y. Siulapwa for the guidance in the selection of the research topic and Mr. A. Nguluwe for his contribution during research proposal development. We also would like to acknowledge the Lusaka city council for facilitating the research process and finally the Research Assistants Juanita Ntemba Mumba, Nang'amba Nachombe and Obvious Nchimunya for braving the scorching heat from the sun during data collection.

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How to cite this article: Banda LJ, Mbewe AR, Nzala SH, Halwindi H (2014). Effect of Siting Boreholes and Septic Tanks on Groundwater Quality in St. Bonaventure Township of Lusaka District, Zambia. Int. J. Environ. Sci. Toxic. Res. Vol. 2(9):191-198