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Investigation of groundwater contamination in relation to septic systems in Kitwe West Township, Kitwe, Zambia

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ABSTRACT

This study investigated the quality of groundwater with respect to septic systems in Kitwe West township located in the western part of Zambia's Kitwe district. The study area was selected because most households in the township use boreholes and septic systems as sources of drinking water and wastewater disposal facilities respectively. The study showed the presence of *total coliforms* in 90% of the boreholes while only 30% of the boreholes were contaminated with *fecal coliforms* rendering the water unsafe for drinking. The study revealed that there was no distinct relationship between distance from borehole to septic tank system and the quality of borehole water. It was however observed that for boreholes within a 15 m proximity to individual home-owned dump sites the level of fecal contamination increased as the distance from the boreholes to the dump sites decreased. The study has vividly shown that the location of boreholes and septic tank systems in the same plot of land exacerbated by the presence of solid waste dump sites in a residential plot that depends on groundwater is not advisable. This is because the safety of groundwater cannot be guaranteed even if technical specifications are followed for boreholes and septic tank systems.

Key words: borehole water pollution, distance to dump sites, drinking water sources, septic tanks, water quality

HIGHLIGHTS

- The study area was selected because most households in the township use boreholes and septic systems as sources of drinking water and wastewater disposal facilities respectively.
- Very few such studies have been done in developing countries and particularly in Zambia.
- The study has vividly shown that the location of boreholes and septic tank systems in the same plot of land does not ensure water safety and is incorrect. This may however be dependent on the geology of the area.

INTRODUCTION

Groundwater is one of the most valuable resources essential for irrigation and human use in many important purposes, with the largest amount going toward irrigating crops. Private and public water departments withdraw a lot of groundwater for public uses, such as delivery to homes, industries, firefighting, etc. The world's population is continually growing; this growth has resulted in the increase of demand for essential services. The need for clean and adequate water for domestic use is one of the factors (Mumma *et al.* 2011). This has led to the scarcity of water and limited accessibility of potable water to people. To meet this demand, groundwater has increasingly been used as a source of water globally (Mumma *et al.* 2011). In Sub-Saharan Africa, groundwater has become a preferred source of water for many cities to meet the water demand, due to growth in population. This is evidenced in developing cities like Lusaka where 55% of the water distributed by public utilities comes from groundwater (Foster 2017).

The movement of people to towns and cities has increased in the recent past (CSO 2011). This urbanization, motivated mainly by the search for better ways of living, has been on the rise. According to GRZ (2015), the population in urban areas grew by 51% from a population of 3,426,862 in 2000 to 5,173,450 in 2010. The increase in the urban population has led to allocation of housing plots in many urban areas of the country, most of which are not serviced; that is, have no access to water and sewer systems. This is because the resources of the water utility companies, local government and central government are fully extended trying to maintain the existing facilities. The increased need for housing but limited water supply and sanitation coverage has led to many new developers opting to drill boreholes on their plots. This is the case with Kitwe West, a Zambian township in Kitwe currently with limited piped water supply and sanitation services. The township has several constructed housing units but currently has no piped water supply and waste disposal facilities. This has prompted individual homeowners to develop boreholes and septic tank systems on their residential plots, posing a high risk of groundwater contamination.

A few studies have been carried out in a few selected areas of Zambia and other developing countries and have indicated that groundwater sources in settings similar to Kitwe West were contaminated with heavy metals, pathogens and various chemicals. For instance, Von Hoyer *et al.* (1978) in a study on groundwater contamination in Lusaka, Zambia revealed bacteriological and chemical pollution of all water samples tested. High values were especially recorded in areas that were reliant on hand-dug wells, pit latrines and septic systems. Additionally, a study by Djaouda *et al.* (2018) in Maroua, Cameroon assessing the bacteriological quality of borehole waters intended for human consumption revealed that 72.22% of boreholes were contaminated.

According to WHO (2003), reliance on groundwater is threatened by the overwhelming numbers of septic systems, improper disposal of household wastes and wastewater. Increase in urban population with little to no sewage disposal facilities is greatly threatening the reliance on groundwater, as most municipalities allocate plots and allow the construction of houses without servicing these areas. This has led to a widespread trend of drilling boreholes for water supply and setting up septic systems for wastewater disposal on the allocated plots. This trend, however, raises concern as to whether such an establishment provides safe and potable water to the users.

This study investigated the quality of groundwater in Kitwe West township, located in the western part of Zambia's Kitwe district, a region whose geologic formation is the Upper Roan group formation, which falls under the Katanga super group. Kitwe West was allocated plots by the Kitwe District municipality and has an area of approx. 480,000 m^2 (48 ha), has 112 developed housing units, and many more are currently under construction. The area has no piped water supply and sanitation services, and this has prompted most residents to sink boreholes on their premises as a source of water and to construct septic systems for their wastewater disposal. Thus, the study area was selected because most households in the township use boreholes and septic systems as sources of drinking water and wastewater disposal facilities respectively.

MATERIALS AND METHODS

Groundwater samples were collected and analysed in the laboratory to determine the physical, chemical and bacteriological quality and were assessed with respect to the World Health Organization (WHO) drinking water guidelines. The groundwater water quality was mainly assessed (among other factors) with respect to distance and type of contaminants. Information on the location of groundwater sources in relation to septic tank systems and other sources of contamination such as dump sites (Figures 1 and 2) was collected and analyzed.

The study was conducted in Kitwe West township of Zambia's Kitwe district (Figure 1), an area consisting of 112 housing units of which 52 are located in isolation from other housing units; that is, with no neighboring houses constructed yet. In this study 15 housing units were selected from residential plots classified as high and medium cost. Most of the housing units in the area adhered to the WHO and Zambia's Water Resources Management Authority (WARMA) borehole-septic system minimum distance regulation of 30 m (WARMA 2018). However, in a few cases, the regulation was not observed when a neighboring household set up their septic systems and boreholes in relation to the neighbor's installations. The sampling points were selected on accounts that the respective housing unit; had a functional borehole and septic system, at least one neighboring household and the proximity of a housing unit's borehole to nearby septic systems.

The study area lies on the upper Roan dolomite aquifer, a consolidated sedimentary aquifer with fracture flow. According to Nkhuwa *et al.* (2018), the water table of the upper Roan aquifer is generally 20 to 35 m below the ground surface. Similarly most of the drilled boreholes in the study area had water pumps installed at depths of approx. 30 m mostly due to the presence of sufficient water despite drilling to the WARMA (2018) recommended depth of 50 m.

A total of 10 boreholes were sampled during the dry season (Figure 2). The collection of water samples was carried out at a frequency of one week over a period of three weeks in the month of July. This culminated in a total of 30 samples analyzed. At each sampling point, 1.5 liters of water samples were collected in sterile polyethylene bottles during each sampling activity. The samples were then analyzed for physical, chemical and bacteriological parameters in accordance with Standard Methods for water and wastewater analysis (APHA 2017).

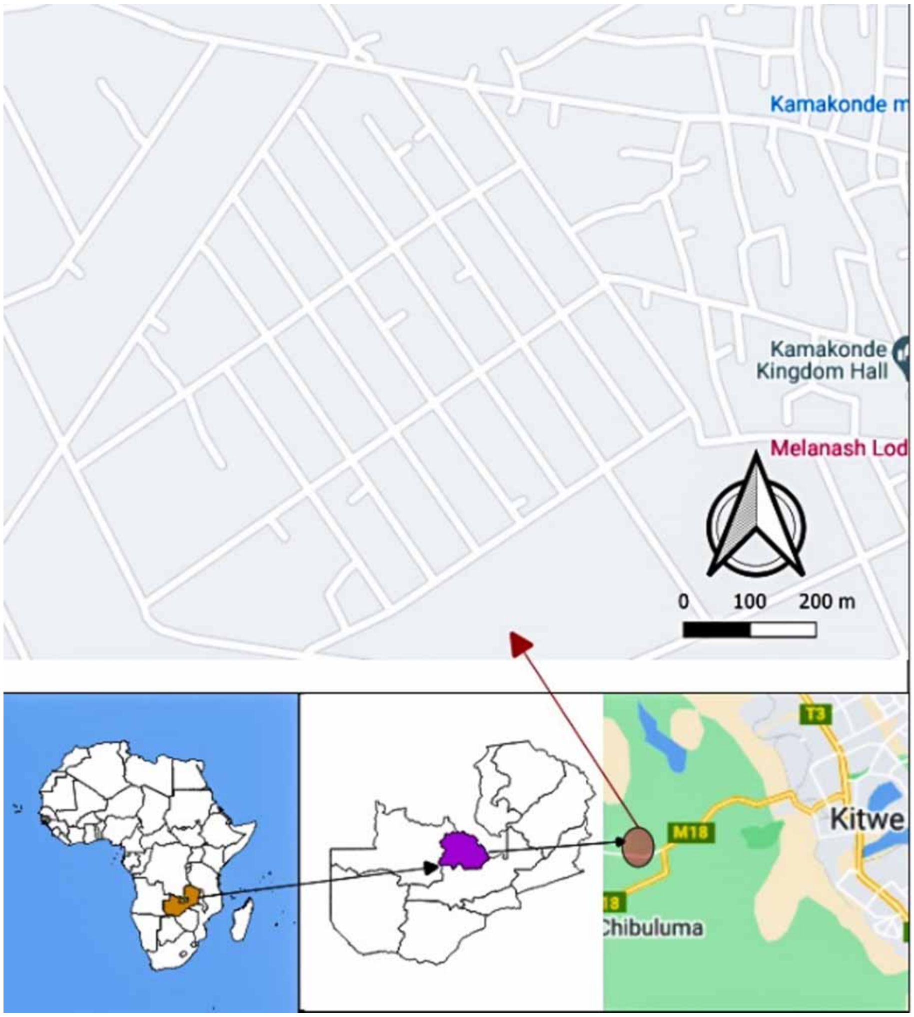

Figure 1 | Map of Kitwe West Township.

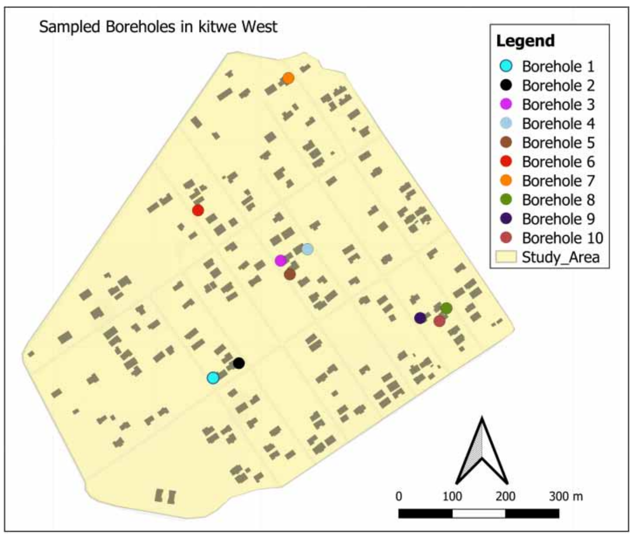

Figure 2 | Location of sampled boreholes in Kitwe West.

The physico-chemical parameters considered were pH, Turbidity, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Nitrates, Sulphates and Chlorides. These parameters were chosen in accordance with their general importance in drinking water quality and the availability of laboratory equipment. Turbidity was measured using the Hach 2100p turbidimeter while pH was measured using the Eutech Benchtop pH 700 meter. EC and TDS were measured using the Vuro 651 TDS/Conductivity meter. Nitrates, sulphates and TSS were measured using a bench scale Ultraviolet-visible (UV-Vis) spectrophotometer. Measurement of nitrates was carried out by treating 50 ml of water sample with hydrochloric acid and this was later analyzed by the spectrophotometer. To measure sulphates, 5 ml of sulphate buffer solution was added to 20 ml of water sample; a spoon full of barium chloride was then added. The solution was later analyzed by the spectrophotometer. For the analysis of chlorides, 3 to 5 drops of potassium chromate indicator solution were added to 50 ml of water sample and titrated with silver nitrate.

Membrane filtration was used to identify microbial indicators (*Total Coliforms (TC) and Fecal Coliforms (FC)*) in accordance with Standard Methods (APHA 2017). For each borehole water sample, 100 ml of sample was filtered through a sterile 0.45 μm pore diameter graded membrane filter under partial vacuum. The filter was removed with sterile forceps and placed on culture media in a petri dish. The m-Endo and m-FC culture media were used for the identification of *Total Coliforms* and *Fecal Coliforms*, after 24-hr incubation at 35 °C and 44 °C respectively. A typical colony coliform on m-Endo media has a pink to dark-red colour and a blue to green colour on m-FC. The resulting colony forming units (CFU) were subsequently identified.

All the analyses for each water quality parameter were done in accordance with *Standard Methods for water and wastewater analysis* (APHA 2017) and all instruments were calibrated using fresh calibration solutions during each parameter measurement.

Data analysis was carried out using Microsoft Excel and results of the physical, chemical and biological parameters of water at the different sampling points are presented in this paper.

RESULTS AND DISCUSSION

The water quality analysis results are given in Table 1. Turbidity values ranged from 0.46 NTU to 22.6 NTU. Borehole D had the least turbidity value of 0.46 NTU whereas borehole I had the highest turbidity value of 22.6 NTU (Table 1). The electrical conductivity of the sampled water varied from 27.9 μS/cm to 184 μS/cm. The highest value of electrical conductivity was observed from water samples of borehole C, whilst the lowest was from borehole F. The average electrical conductivity value of the sampled boreholes was 93.36 μS/cm. The pH values of the water samples varied from 6.42 to 7.17 pH units (Table 1). The TDS values ranged from 17.3 mg/l to 120 mg/l. The mean TDS value for the sampled borehole sites was 63.1 mg/l. The value of TSS varied from one borehole to another in the range of 2 mg/l to 19.7 mg/l (Table 1).

Chloride levels ranged from 21.67 mg/l to 30 mg/l for the 10 borehole sites. The average chloride level was 26.6 mg/l. Borehole sites G and J had the highest chloride levels at 30 mg/l followed by sites B and I. The least chloride value was from borehole site A, this was followed by site C at 22.3 mg/l. Borehole site F had the maximum sulfate level at 4 mg/l, followed by site A at 3.3 mg/l. The lowest sulfate level was 1 mg/l for borehole site D, this was followed by sites B, C, E and G with sulfate levels of 2 mg/l. The average sulfate level was 2.3 mg/l. Nitrate levels for all selected 10 boreholes were less than 0.01 mg/l, as shown in Table 1.

The highest *total coliform* value was 385 CFU/100 ml observed for water samples from borehole B (Figure 4), this was followed by 248 CFUs from borehole D. The least colony forming units for total coliforms was 0 observed for water samples from site J, this was followed by site E at 1 (Figure 3).

Fecal coliforms were present in only 3 of the 10 sampled boreholes. Borehole I had the highest *fecal coliform* CFU count at 77, this was followed by D at 21 CFUs then site A at 5 CFUs.

Distances of boreholes and septic systems are shown in Table 2. Borehole J was closest of all the boreholes to the septic systems with a mean distance of 24.1 m and a minimum distance of 16.1 m. Borehole I had the longest mean distance at 43.4 m.

The major potential contamination sources (in addition to septic systems) that were located near the sampled boreholes were all noted and their distances away from the boreholes were also measured. The measured distances are shown in Table 3. Individual dump sites and old filled pit latrines were identified as potential contamination sources (most residents

Table 1 | Water quality results for Kitwe West Borehole water vs WHO drinking water guidelines

Parameter	WHO Limit	ZABS Limit		Borehole A	Borehole B	Borehole C	Borehole D	Borehole E	Borehole F	Borehole G	Borehole H	Borehole I	Borehole J
Turbidity (*NTU*)	*5*	*5*	Mean	2.44	4.93	1.05	0.46	5.64	4.57	9.87	9.07	22.6	7.17
			Max	3.86	5.04	1.38	0.75	7.80	6.70	12.10	10.4	24.6	7.17
			σ	1.01	0.25	0.26	0.21	1.53	1.53	1.67	0.94	1.45	–
Conductivity ($\mu S/cm$)	*1,500*	*1,500*	Mean	123.7	132.4	184.0	69.2	107.5	27.9	47.3	115.3	79.5	46.8
			Max	136	138.4	186.3	70.9	112.8	28.7	48.3	116.3	128.2	46.8
			σ	9.9	5.9	1.66	1.35	5.9	0.65	1.30	0.82	4.4	–
pH	*6.5–8.5*	*6.5–8.0*	Mean	6.92	7.06	7.04	6.94	6.85	6.42	6.83	6.85	7.03	7.17
			Max	6.96	7.24	7.20	7.05	6.86	6.66	6.86	6.99	7.46	7.17
			σ	0.04	0.14	0.11	0.30	0.01	0.24	0.03	0.13	0.30	–
TDS (mg/L)	*1,000*	*1,000*	Mean	79.0	85.7	120.0	45.9	69.1	17.3	30.3	74.8	79.5	29.2
			Max	87.0	88.9	121.2	48.4	71.5	18.8	31.3	75.4	82.8	29.2
			σ	6.06	3.29	1.02	1.85	3.14	1.04	0.92	0.45	2.49	–
TSS (mg/L)	*50*	*50*	Mean	4.7	4	2	3.3	3.3	4.7	19.7	7.7	10.3	13
			Max	8	6	3	5	6	5	21	10	12	13
			σ	2.49	1.41	0.82	1.25	1.89	0.47	1.25	1.70	1.25	–
Nitrates (mg/L)	*10*	*10*	Mean	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			Max	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			σ	0	0	0	0	0	0	0	0	0	0
Chlorides (mg/L)	*250*	*250*	Mean	21.67	29.67	22.30	24.30	28.00	22.67	30.00	27.33	29.70	30.00
			Max	23	32	24	27	29	24	32	30	32	30
			σ	0.94	1.70	1.7	2.06	0.82	1.25	1.41	2.50	1.7	–
Sulfates (*mg/L*)	*400*	*400*	Mean	3.33	2	2	1	2	4	2	2.3	2.7	2
			Max	5	2	2	1	3	5	3	3	4	2
			σ	1.25	0	0	0	0.82	0.82	0.82	0.47	0.94	–
Total Coliforms (*CFU/100 ml*)	*0*	*0*	Mean	197	385	13	248	1	25	165	38	220	0
			Max	216	302	20	330	3	57	310	54	380	0
			σ	20	94	5	58	1.41	24	103	13	117	–
Fecal Coliforms (*CFU/100 ml*)	*0*	*0*	Mean	5	0	0	21	0	0	0	0	77	0
			Max	7	0	0	25	0	0	0	0	93	0
			σ	1.25	0	0	3	0	0	0	0	11	–

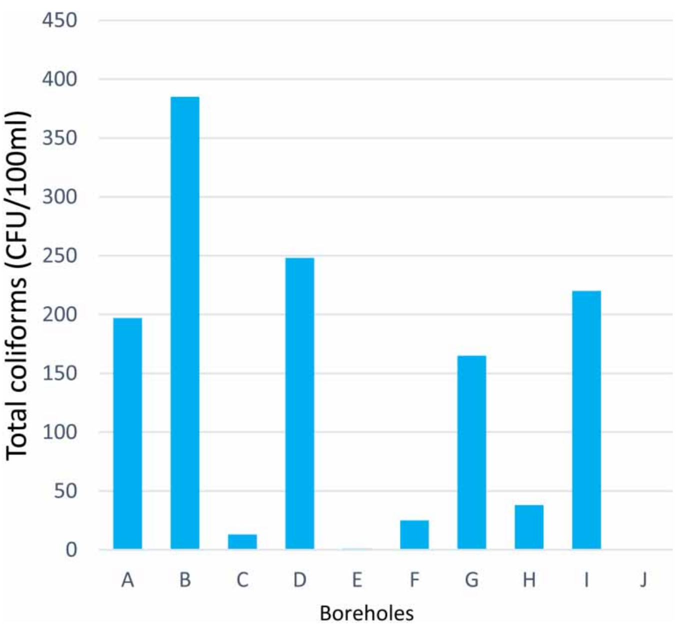

Figure 3 | *Total coliforms* results for each borehole.

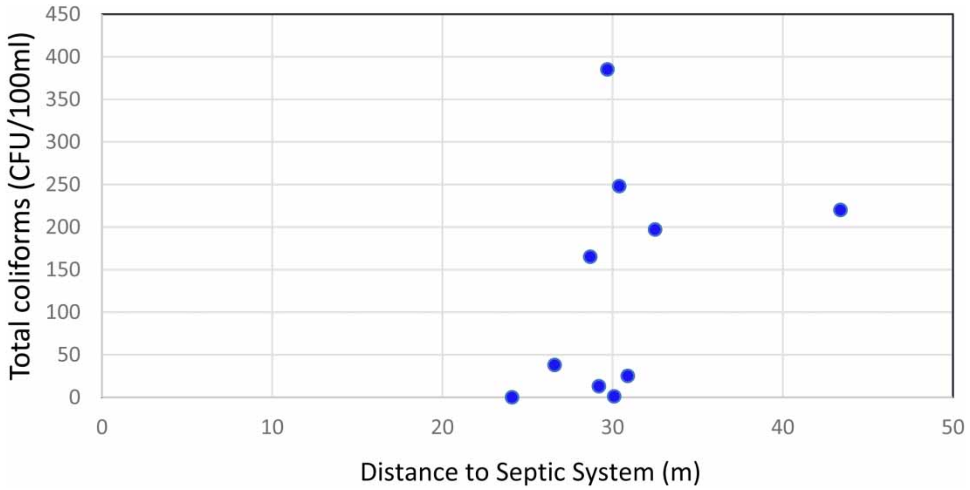

Figure 4 | *Total coliforms* against mean distance of boreholes to septic systems.

Table 2 | Max, min and mean distance of boreholes to septic systems

Borehole	A	B	C	D	E	F	G	H	I	J
Septic systems	Distances of septic tank systems to boreholes (m)									
	28.8	25.3	24.2	25.6	25.2	25.6	25.4	21.4	26.5	25.6
	37.4	35.5	34.1	33.7	26.8	34.1	32	25.1	42.2	16.1
	31.4	28.4	29.3	31.8	38.4	33.1		33.2	61.5	29.6
Mean distance	32.5	29.7	29.2	30.4	30.1	30.9	28.7	26.6	43.4	24.1
Max dist.	37.4	35.5	34.1	33.7	38.4	34.1	32	33.2	61.5	29.6
Min dist.	28.8	25.3	24.2	25.6	25.2	25.6	25.4	21.4	26.5	16.1

Table 3 | Distance of potential contamination sources to boreholes

Borehole	A	B	C	D	E	F	G	H	I	J
	Distances of potential contamination sources to boreholes (m)									
Dumping place	13.4	50	52	8.2	56	–	–	44	7.2 23	20
Filled pit latrine	–	–	–	–	–	–	–	–	–	–
Min distance	13.4	50	52	8.2	56	–	–	44	7.2	20

however showed ignorance over the location of buried pit latrines). Boreholes A, D, and I had the least distances away from solid waste dumping sites with borehole I being the nearest at 7.2 m.

The turbidity of water samples ranged from 0.46 to 22.6 NTU. Borehole D had the lowest value whereas borehole I had the highest. Fifty percent of the sampled boreholes had acceptable turbidity values of less than 5 NTU as recommended by both the WHO (2017) and ZABS (2010). The results showed no relationship between distance of boreholes and septic systems. The highest electrical conductivity was 184 μS/cm observed from borehole C. Conductivity is related to the amount of dissolved solids in the water, high conductivity values (greater than 1,000 μS/cm) have been observed in polluted waters or those that receive land run-off (Horne & Goldman 1994). In contrast low conductivity values (0 to 200 μS/cm) are indicators of pristine or background conditions (Horne & Goldman 1994). The electrical conductivity from the sampled boreholes was below 200 μS/cm, a value less than the 1,500 μS/cm maximum permissible limit recommended by ZABS (2010). This correspondingly signifies low dissolved solids content in the groundwater. The values of pH conformed to ZABS (2010) guidelines for drinking water as they ranged from 6.42 to 7.17. A distinct correlation between distance of boreholes and septic systems was not observed. This suggests that each household used their own preferred distances.

Total dissolved solids (TDS) are comprised of inorganic salts and organic matter that are dissolved in water. TDS values ranged from 17.3 mg/l to 120 mg/l. The amount of TDS did not vary with the distance of groundwater sources away from septic systems. Boreholes with almost the same distance from septic systems had different values of TDS. All the sampled boreholes conformed to the WHO (2017) and ZABS (2010) recommendation of 1,000 mg/l TDS value for drinking water. TSS values ranged from 2 mg/l to 19.7 mg/l; relatively low values were observed, this might be attributed to some form of protection of the water sources against pollution by suspended particles.

Chloride levels ranged from 21.67 mg/l to 30 mg/l, the highest levels being observed at boreholes B and I. Chloride levels were all below the WHO (2017) and ZABS (2010) limit of 250 mg/l. No notable relationship was found between the amount of chlorides and the distance of source from septic system. Low sulfate levels were found in all the sampled boreholes, the highest being 4 mg/l observed at borehole D. According to WHO (2017), sulfates occur naturally and highest levels usually occur in groundwater. The presence of low sulfate levels suggests little or no contamination from external sources. Additionally, this shows that the mineral content in which most of the groundwater is accessed from contains low sulfates. ZABS (2010) further recommends that a maximum possible limit of 400 mg/l be present in safe drinking water. The amount of nitrates for all sampled boreholes was less than 0.01 mg/l. According to the document on nitrate and nitrites in drinking water by WHO (2011), the natural nitrate concentration in groundwater under aerobic conditions is a few milligrams per liter. This shows that nitrate-rich sources (effluent from septic system) had minimal effect on the quality of groundwater in the sampled boreholes. Thus, the quality of the sampled boreholes with regard to nitrates conformed to the ZABS (2010) limit of 10 mg/l. It should be noted that the ZABS drinking water standards were developed based on the WHO guidelines and are in most cases the same as WHO drinking water guidelines.

The results of biological analysis showed the presence of *total coliforms* in 90% of the water samples. The highest amount of 385 CFU/100 ml was detected at borehole B (Table 1 and Figure 3). A conclusive relationship linking the amount of CFUs detected and the spacing of borehole from septic system could not be established as shown in Figure 4. This is because *total coliforms* show a representation of bacteria present in the sampled water, which includes bacteria from soil, plants and animals. WHO (2017) recommends 0 CFU/100 ml in drinking water.

Fecal coliforms were detected in 30% of the sampled boreholes the value ranging from 5CFU/100 ml (borehole A) to 77 CFU/100 ml (borehole I). The results did not distinctly show correlation between the amount of CFUs and spacing distance of water sources and septic systems as shown in Figure 5 below.

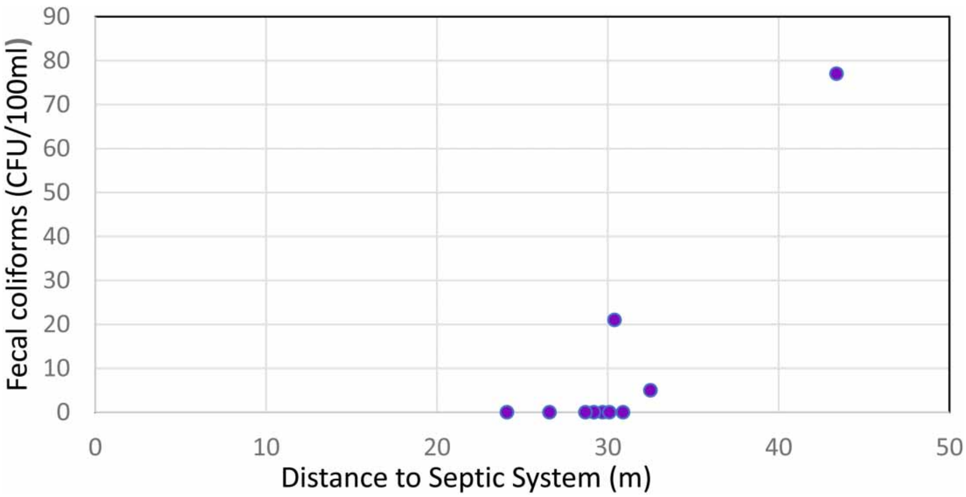

Figure 5 | *Fecal coliforms* against mean distance of boreholes to septic systems.

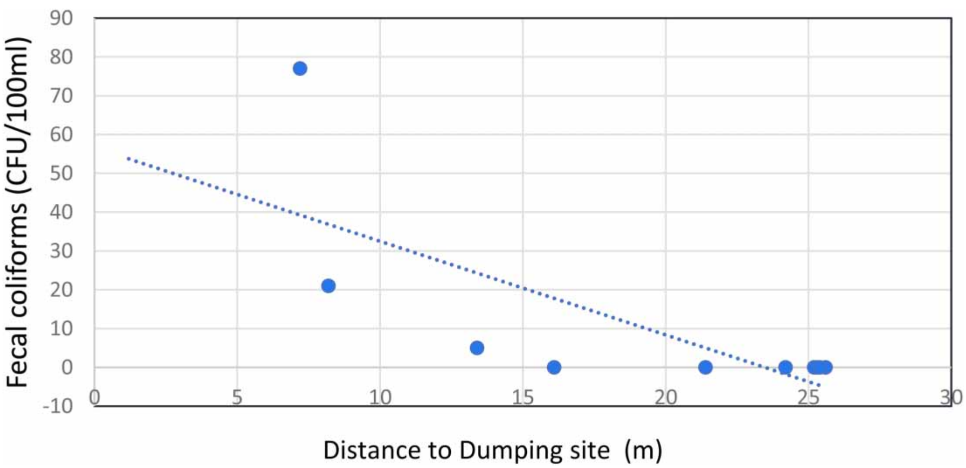

Figure 6 | *Fecal coliforms* against distance to dumping site with trend line.

The presence of individual residential dumpsites (identified as potential contamination sources) located near the boreholes may have contributed to the presence of *fecal coliform* bacteria detected in the respective sampled boreholes. The observed dump sites contained a variety of wastes which included: baby diapers, chicken manure and fecal matter from domesticated animals such as dogs. During the rainy season, the moisture content of wastes increases, making them soggy and hard to burn. This results in the accumulation of wastes on the dump sites thereby increasing the amount of effluent that leaches and eventually percolates into groundwater.

Analysis of contamination levels with the distance between groundwater sources and the individual plot dump sites showed an increase in the amount of contamination as the distance between boreholes and respective dump sites decreased. This relationship is shown in Figure 6.

CONCLUSION AND RECOMMENDATIONS

This study revealed that 70 percent of the sampled boreholes were free from fecal contamination and 30 percent of the sampled boreholes were contaminated with *fecal coliforms* rendering the water unsafe for domestic consumption. However, 90% of the sampled boreholes contained *total coliforms*. The study revealed that there was no distinct relationship between distance from borehole to septic systems and the quality of groundwater. The study however indicated some form of relationship between distance from boreholes to individual residential dump sites and the amount of *fecal coliforms* detected. It was surprisingly observed that for boreholes within a 15 m proximity to solid waste dump sites the level of contamination increased as the distance from the boreholes to the dump sites decreased. This may suggest a possible contribution of dumpsites to the fecal contamination of the respective boreholes.

The study has vividly shown that the location of boreholes and septic tank systems in the same plot of land exacerbated by the presence of solid waste dump sites in a residential plot that depends on groundwater is not correct. This is because the safety of groundwater cannot be guaranteed even if technical specifications are followed for boreholes and septic tank systems.

Providing solid waste services in the study area is highly recommended. Residents should additionally be informed on the dangers of indiscriminate disposal of solid wastes. Furthermore, the responsible Water and Sanitation Company should consider providing piped water supply and sanitation services in Kitwe West Township so as to prevent the increase of septic systems, thereby protecting the community from potential outbreaks of waterborne diseases.

It is also proposed that future studies in the study area should also collect samples from the septic systems and dumpsites in order to establish any possible correlation between the septic systems, dumpsites and boreholes. It is further recommended that any future studies should be done in the rain season and/or over the whole hydrological year to conclusively ascertain the impact of contamination from septic systems and boreholes in the study area. Additionally, if resources allow, future studies in the area should also collect data on the occurrence of waterborne diseases from respective health centers to correlate the findings with waterborne disease records.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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