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ASSESSMENT OF GROUNDWATER QUALITY IN RURAL AREAS OF MBALA DISTRICT, ZAMBIA

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Abstract
Access to good quality drinking water still remains a challenge in most rural areas of Zambia, Africa. The aim of this study was to assess the quality of groundwater for human consumption in rural areas of Mbala district in Zambia. A total of fifty nine (59) water samples were collected from fifty nine (59) boreholes in the aforementioned district. The water samples were analysed for physical, chemical and microbiological parameters using standard techniques specific for each parameter. Results were compared to the Zambian Bureau of Standards (ZABS) guideline values for drinking water and in some cases, with WHO guideline values if known. In general, most water parameters in Mbala district complied with ZABS drinking water guideline values. A few chemical parameters which include pH ranging from 5.1 to 6.98, sodium from 0.001mg/L to 49.9mg/L, sulphate from 2mg/L to 18.76mg/L, iron from 0 to 10.22mg/L and manganese from 0 to 0.23mg/L did not meet ZABS drinking water guideline values at a few boreholes. TSS and turbidity ranged from 0 to 133mg/L and 2 to 358NTU respectively. A few exceedances of the aforementioned parameters were recorded at a few boreholes. In contrast, significantly high turbidity levels (>20NTU) were recorded at a few boreholes in the district thus posing a significant threat to the health of the consumers. In terms of microbiological parameters, a few boreholes did not meet the ZABS drinking water guideline values for total coliforms rendering the water supplies from the affected boreholes unfit for human consumption unless boiled or treated with chlorine.

Key Words: *Groundwater, Zambia, rural areas, water quality, Mbala district*

Introduction

In most rural and peri-urban areas of Zambia, groundwater is the main source of water for drinking and other domestic uses (IWMI, 2012). Mbala district in Northern Province of Zambia is no exception as most rural communities in the district rely on groundwater from furrows and hand dug wells (Bury, 1998). In most cases, these water sources are unprotected which puts them under threat of contamination from anthropogenic inputs.

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Although Zambia is endowed with abundant water resources, the majority of the population lack access to good quality drinking water especially in rural communities (IGRAC, 2013). This prompted the Zambian government and its co-operating partners to embark on a countrywide improvement and increasing of access to clean and safe drinking water especially in rural communities. African Development Bank, World Bank and World Vision Zambia are some of the organisations supplementing the government's efforts in the provision of clean and safe drinking water through proper siting and drilling of standard boreholes in rural communities.

It should be noted that although the majority of people in rural communities of Zambia depend on groundwater, there is paucity of information on groundwater quality in the country (ADB, 2013; Norrgren *et. al*., 2000). With limited chemical data on chemical composition of groundwater resources in Zambia, there is need for urgent research in the country to assess the drinking water quality of the available groundwater resources (BGS, 2001; IWMI, 2012; World Bank, 2009). Limited available chemical data however suggest that the Zambian groundwater has generally very low concentrations of dissolved constituents (ADB, 2013; MacDonald, 1990)

According to the Geological Survey of Sweden (2014), the Zambian Department of Water Affairs which is responsible for the overall management of water resources in the country has up until recently mainly focussed on water quantity and not quality. In terms of water quality, the department is less strong in its performance and lack both the capacity and knowledge to survey the major water resources especially groundwater (GSS, 2014; IMWI, 2012). Moreover, groundwater resources in Zambia are less well understood than surface water despite the importance of the resource in social and economic development of the country (UOG, 2010). Against this background, the objective of this study was to assess the quality of groundwater for human consumption in rural areas of Mbala district in Northern Province of Zambia.

Site Location and Description

Mbala district is located in Northern Province of Zambia. It is 1067Km from Lusaka, the capital city of Zambia and shares an international border with Tanzania. The district lies between 9.1570° S and 31.5370° E, and is mostly mountainous with numerous rivers and seasonal streams (Bury, 1998). Mbala has access to two lakes namely lake Chila and Tanganyika. As of the year 2010, the district population was estimated at 213,254 (GEOHIVE, 2015). According to UNICEF (2002), more than 70% of the district population falls in the low socioeconomic status with women being the most affected. Farming in Mbala district is the main source of income and livelihood for the local communities. The district is also rich in precious and semi-precious minerals and has great potential for tourism.

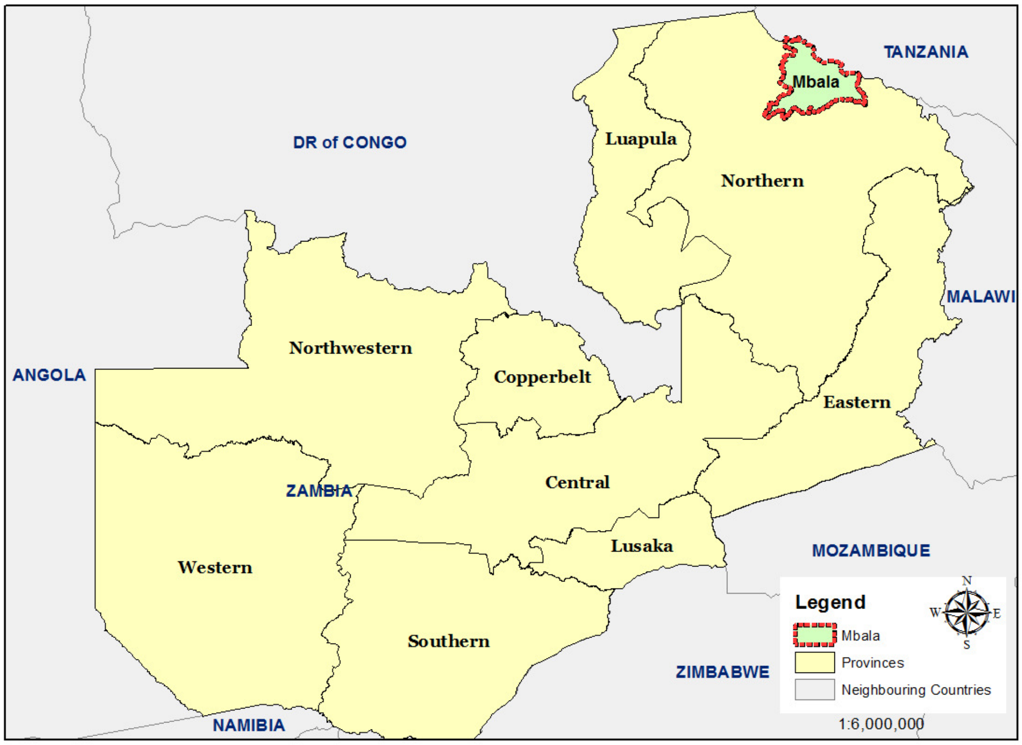

Figure1: Map showing the location of the study area

Geology and Hydrogeology of the Study Area

Most parts of Northern Province of Zambia where the study area lies are underlain by the rocks of the Basement Complex including granites, meta-igneous and meta-volcanic rocks (JICA, 1995; SRK, 2002). In some parts of the Province, the Basement Complex is unconformably overlain by sedimentary rocks of the Katangan Supergroup. Borehole logging from the drilling programme carried out by World Vision Zambia shows that most areas in Mbala district are underlain by granites from the Basement Complex. However, in some areas, the granites are overlain by the sediments (feldspar rich sandstones) from the Katangan Supergroup.

The Basement Complex forms the major aquifer units in Northern Province of Zambia. According to JICA (1995), groundwater in the Basement Complex rocks occur within joints, faults and weathered zones. The report further states that fracture zones in the Basement Complex rocks usually extend to depths of between 30 to 40m and in some cases up to 90m. The weathered Basement Complex rocks form the shallow aquifer system in the Province. The fractured and weathered Basement Complex aquifers in Northern Province are categorized as locally productive as shown below (Figure 2). In certain areas of Northern Province, low yielding aquifers with limited potential are known to occur within meta-igneous and meta-volcanic units of the older Basement Complex (JICA, 1995).

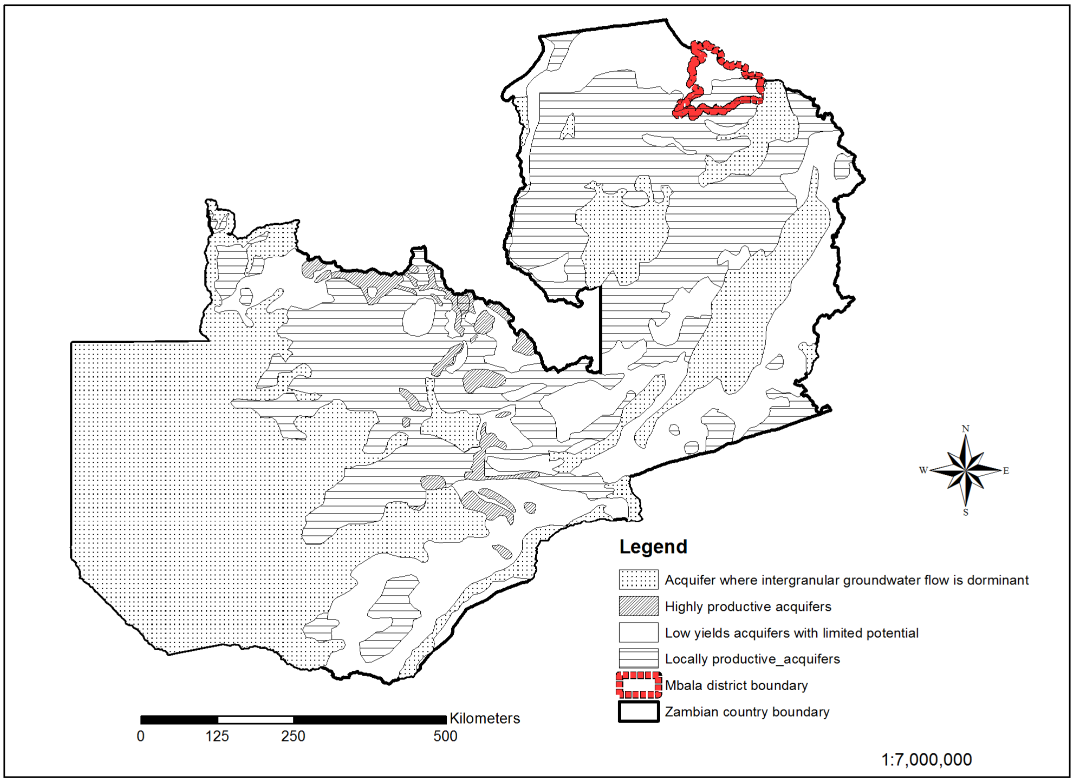

Figure 2: Map of Zambia showing the Distribution of the Aquifer Units (modified after JICA, 1995)

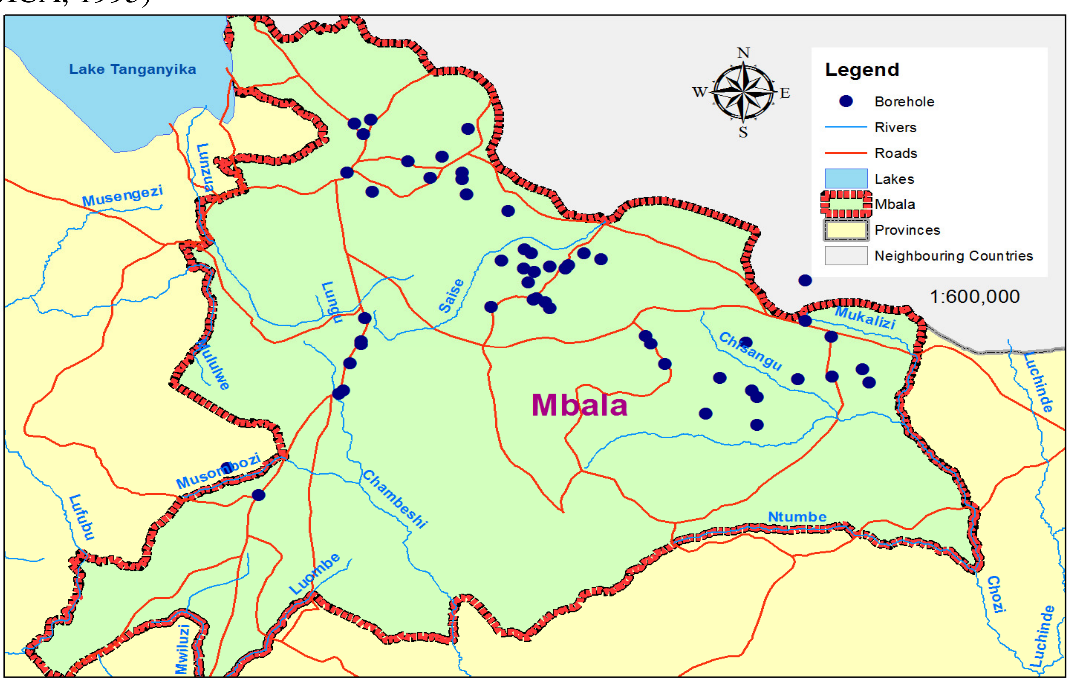

Figure 3: Map showing the distribution of boreholes in the study area

Methodology

Sample Collection Framework, Handling and Preservation

A total of 59 borehole water samples were collected from October, 2013 to September, 2014 from boreholes drilled by World Vision Zambia. Borehole water samples were collected after conducting a pumping test for about 4 to 6 hours to ensure that the water is visibly clear and clean. After the pumping test, one litre of water sample from each borehole was collected in a cleansed polythene bottle after 20 minutes of continuous pumping. At least 5 to 15 samples were collected from boreholes in a day. In each water bottle, some space was left in order to prolong the life of microbiological organisms.

Once the borehole water samples were collected, they were immediately placed in a cool box and transported by road to the laboratory within 24 to 48 hours. For sample preservation, ice blocks were put in cool boxes during transportation to keep them cool as the laboratory was situated about 1000 km from the site.

Laboratory Sample Analysis

The collected borehole samples were immediately analysed for physical, microbiological and chemical parameters at the Environmental laboratory under the Copperbelt University in Zambia. pH measurements were done with a Hanna pH 213 microprocessor pH meter and electrical conductivity (EC) was measured using an Accumet AP75 electrical conductivity meter. Nitrates were analysed using the calorimetric cadmium reduction method (AWWA, 1995) and the test for the presence of total and faecal coliforms were done using membrane filtration method (UNEP/WHO, 1996). Turbidity was measured using the nephelometer or turbidimeter (AWWA, 1995). In general, all water samples were analysed using standard technique specific for each parameter (AWWA, 1995; UNEP/WHO, 1996).

Data Analysis

To assess the drinking water quality, various physical, chemical and microbiological parameters were compared to their permissible value(s) set by the Zambia Bureau of Standards (ZABS) for drinking water (Table 1 and 2) and in some cases to World Health Organisation guideline values if known.

Table 1: Zambia Bureau of Standards Permissible Levels and World Health Organisation Guideline Values for Parameters of Concern in this Study

Parameter	ZABS Permissible Value	WHO (2008) Drinking Water Guide Values
EC	1500µS/cm	Not stated
TDS	800mg/l	No stated
Hardness	250mg/l	Not stated
TSS	100mg/l	Not stated
Turbidity	5 NTU	Not stated
pH	6.5-8.0	Not stated
Alkalinity	500mg/l	Not stated
Nitrates	10mg/l	50mg/l
Mn	0.1mg/l	0.4 mg/l
Fe	0.3mg/l	Not stated
Ca	100mg/l	Not stated
Mg	250mg/l	Not stated
Na	1.5mg/l	Not stated
Fluorine	1.0mg/l	1.5mg/l
Chlorine	250mg/l	Not stated
Phosphate	0.1mg/l	Not stated
Sulphate	1mg/l	Not stated
Total Coliform	0 tc/100ml	Not stated
Faecal Coliform	0 cfu/100ml	Not stated

Table 2 below shows the summary of physical and chemical parameters for the 59 borehole water samples analysed from various villages in Mbala district. For each physical and chemical parameter, the minimum, maximum and average values were determined coupled with the percentage of boreholes that did not comply with the ZABS permissible values for drinking water. In terms of microbiological parameters, only 22% of the borehole water samples tested positive for total coliforms.

Table 2: Summary of Physical and Chemical Data on Groundwater Quality in Mbala District

Parameter	Min	Max	Average	ZABS Permissible Value (PV)	Percentage of Water Samples not in compliance with the PV
EC	43	511	132.62	1500(μS/cm)	0
TSS	0	133	41.35	100 mg/L	17
TDS	0.001	358	70.28	8000 mg/L	0
Turbidity	2	358	19.71	5 NTU	49.1
Hardness	0.001	330	28.54	250 mg/L	0
pH	5.1	6.98	6.3	6.5-8.0	47.5
Alkalinity	0	312	29.9	500 mg/L	0
Ca	0.001	41.6	6.21	100 mg/L	0
Mg	0	57.2	3.69	250 mg/L	0
Cl	1	43.99	14.26	250 mg/L	0
Fl	0	0.16	0.02	1 mg/L	0
Fe	0	10.22	0.49	0.3 mg/L	22
Sulphate	2	18.76	2	1 mg/L	37
Nitrate	0	3.98	0.09	10 mg/L	0
Phosphate	0	0.6	0.03	1 mg/L	5
Mn	0	0.23	0.04	0.1 mg/L	14

Results and Discussion

The results of various water parameters analysed from the collected water samples in various villages in Mbala district as tabulated in Table 2 above. A total of fifty nine (59) borehole water samples were analysed for nineteen (19) parameters as shown in Table 1 and 2.

Physical Characteristics of Analysed Borehole Water Samples

Physical parameters for the borehole water samples are presented in Tables 2 and 3. The values for electrical conductivity (EC) and total dissolved solids (TDS) complied with the Zambia Bureau of Standards (ZABS) drinking water guideline values except for turbidity and total suspended solids.

Turbidity values in borehole water samples ranged from 2NTU to 358NTU with about 49% of these samples recording turbidity levels greater than ZABS drinking water guideline value of 5NTU. High turbidity levels (>5NTU) recorded in some borehole water samples could be attributed the improper selection of the borehole screens or damaged casing pipes. The aforementioned factors can allow fine particles to enter the borehole during pumping. Furthermore, the nature of the underlying aquifer may also contribute to high turbidity levels in some boreholes. During flushing period, it was observed that groundwater in areas where the aquifer is highly fractured and less competent sandstone formation took longer to become visibly clear and clean than in areas underlain by the crystalline basement aquifer (granite). Fine particles from the fractured sandstone aquifer may easily be drawn to the borehole especially during high pumping rates. According to World Health Organisation (2008), high turbidity levels can seriously interfere with the disinfection process of the water as the particulate matter tend to protect the pathogens.

Total suspended solids (TSS) recorded in borehole water samples in this study ranged from 0 to 266mg/l. However, the majority (about 84%) of the borehole water samples recorded the levels of total suspended solids (TSS) less than the permissible limit of 100mg/l set by the ZABS for drinking water. A few borehole water samples (about 16%) slightly exceed the TSS maximum permissible value of 100mg/l set by ZABS. This could also be attributed to the damaged casing pipes or improper selection of borehole screens by the drilling contractor. High levels of total suspended solids in drinking water can also have profound effects on human health as they tend to inhibit pathogens and other toxic chemicals.

Chemical Characteristics of Borehole Water Samples

Results of all the analysed chemical parameters from the collected borehole water samples in Mbala district are presented in Tables 2 and 4. From these results, almost all borehole water samples recorded concentrations of nitrate, phosphate, hardness, alkalinity, fluorine, chlorine, magnesium and calcium complied with the Zambia Bureau of Standards guideline values for drinking water with the exception of sodium, iron, manganese, sulphate and pH.

The pH of the borehole water samples were slightly acid and ranged from 5.1 to 6.98. About 48% of water samples did not comply with ZABS permissible pH range of 6.5-8.0 for drinking water. According to Giovanoli (*et al*., 1988), the hydrolysis of feldspars from granitic rocks produces silicic acid which may affect the pH of groundwater. Therefore, the weak acidic nature of groundwater in Mbala district could be attributed to the weathering of feldspars from the granite and sandstone formations which makeup the major aquifers units in the area. Although the pH of groundwater in Mbala district is slightly acid, it has no direct health effects to the consumers. It is however advisable to treat slightly acidic water (pH<6) with hydrated lime to ensure that the pH falls within the permissible range for drinking water.

Concentrations of manganese from the majority (about 86%) of the borehole water samples complied with ZABS permissible value of 0.1mg/l of manganese in drinking water. However, about 14% of the borehole water samples recorded manganese levels slightly greater than the permissible value of 0.1mg/l. It should be noted that concentrations of manganese recorded from borehole water samples ranged from 0.0mg/l to 0.23mg/l. This concentration range is within the expected range of Mn (0.01mg/l to slightly greater than 10mg/l) in natural waters free from anthropogenic inputs (WRA, 2013). Concentrations of manganese in all the borehole water samples complied with WHO health guideline value of 0.4mg/l hence will not likely affect the health of the consumers. However, water supplies from a few boreholes which exceeded manganese concentration of 0.1mg/l will likely impart undesirable taste to drinking water.

Iron concentrations in borehole water samples ranged from 0 to 10.22mg/l. The majority (about 78%) of water samples complied with ZABS permissible value of 0.3mg/l for drinking water. Only a few water samples (about 22%) slightly exceeded ZABS permissible value of

0.3mg/l of iron in drinking water. According USEPA (2015), excessive amounts of iron are known to occur in many places especially where the water is acidic. In this regard, concentrations of iron which exceeded the permissible value of 0.3mg/l at a few boreholes in the district could result from the leaching of iron bearing minerals from the local geology due to the presence of slightly acidified groundwater. Water supplies from the boreholes which exceeded ZABS permissible value of 0.3mg/l of iron may impart a metallic taste to drinking water.

Furthermore, about 49% of the borehole water samples recorded concentrations of sodium greater than the accepted limit of 1.5mg/l set by the ZABS for drinking water. According to World Health Organisation (2003), most water supplies contain sodium levels less than 20mg/l although some countries can exceed 250mg/l. In this study, almost (about 95%) all the water samples were found to be far less than 20mg/l recommended by Environmental Protection Agency for drinking water.

Concentrations of sulphate in borehole water samples ranged from 0.0mg/l to 18.76mg/l. About 37% of these samples recorded concentrations of sulphate greater than the permissible value of 1.0mg/l set by the ZABS for drinking water. However, UNEP (1990) cited in (WHO, 2004) reports that typical concentrations of sulphate in fresh water are within 20mg/l and can range from 0 to 230mg/l in groundwater. In this study, concentrations of all borehole water samples were within the range of fresh water hence may not affect the health of the consumers. However, the presence of sulphate in drinking water can impart a noticeable taste and high concentrations may cause a laxative effect in unaccustomed consumers (WHO, 2008). In Mbala district, sulphate concentrations in all the water samples were less than 250mg/l hence will likely cause minimal taste impairment.

Microbiological Characteristics of the Borehole Water Samples

The results for microbiological parameters of borehole water samples are presented in Table 5. It is observed that approximately 78% of borehole water samples complied with ZABS drinking water guideline values of 0TC/100ml of water sample. The presence of total coliforms in a few water samples (22%) indicates the potential of pathogenic organisms in water. The presence of total coliforms at a few boreholes in Mbala district could be attributed to the movement of microbial contaminants from waste dumps and pit latrines that are situated in close proximity to the affected boreholes.

Table 3: Physical Parameters of Borehole Water Samples collected in Mbala District

BH	Village Located	Electrical conductivity (µS/cm)	Turbidity NTU	Total Dissolve Solids (mg/L)	Total suspended solids (mg/L)	Hardness (mg/L)
		1500	5	800	100	250
1	Kombe School	110	57	77	36	46
2	Senga North	95.7	2	67	0.001	30
3	Chambezi Village	74.29	3	52	0.001	18
4	Manyika Village	132.86	2	93	0.001	66
5	Musatwe Village	80	4	56	3	20
6	Iyanda B Village	124	17	0.001	104	30
7	Iyanda Co school	68.57	2	48	0.001	20
8	Kampandila Village	111.43	56	78	31	16
9	Chitimbiti Village	82.86	16	58	9	14
10	Ngelesani Village	80	49	56	44	12
11	Mayanga Village	51.43	11	36	9	10
12	Chiwindi Village	56	8.5	42	7	18
13	Mwembe P School	80	20	56	11	10
14	Chele Village	181.43	16	127	110	60
15	Landula P School	112	4	34	13	32
16	Chalunga/Kakozya	88	3	102	26	22
17	Ntapita Vullage	143	6	51	38	14
18	Chaya/ Ntondokoso	102	2	27	42	32
19	Mulalo	76	3	66	76	26
20	Kacheche Com. School	67	4.2	33	38	0.001
21	Ngombezo Village	221	8.8	111	107	0.001
22	Beni Village	109	3.2	54	15	0.001
23	Saulo kela (chilyango	242	12.2	121	125	0.001
24	Namatemba village	191	4.9	95	32	0.001
25	Nsindano village	52	6.3	26	46	0.001
26	Mulenga village	43	6.3	21	28	0.001
27	Mwesela village	67	5.1	23	20	0.001
28	Jeremia village	73	10.3	37	105	0.001
29	Mpanga village	203	12.8	102	128	0.001
30	Owen village	147	3.9	74	14	0.001
31	Katambalile village	159	11.2	80	108	0.001
32	Teya village	121	10.7	61	102	0.001
33	Kasanga village	47	2.9	23	17	0.001
34	Mwesela B village	120	3.7	60	27	0.001
35	Kayawala Vlge	156	2.7	78	17	0.001
36	Mwambala P. School	120	2.1	60	18	0.001
37	Mbulauyo village	144	7.2	72	33	0.001
38	Ng'ombe Village	86	4	43	12	0.001
39	Seven Village	222	4.2	111	45	0.001
40	Katuna Village	76	4.5	38	13	0.001
41	Chisama Village	68	3.5	34	17	0.001
42	Chikusela Village	157	5	78	23	0.001
43	Maliko Village	207	4.2	104	47	0.001
44	Sampatika Village	69	4.2	35	10	0.001
45	Lwanda Village	152	3.8	76	27	0.001
46	Sikalembe village	148	4.2	74	37	0.001
47	Chilundumunsi vlg	168	4	84	43	0.001
48	Tomo Village	77	5	39	16	0.001
49	Siolwe Village	149	4.7	75	27	0.001
50	Philimoni	97	37.5	49	8	56
51	Susuntila	159	26.2	80	6.9	92
52	Tomo	244	11.3	122	4.6	142
53	Ali Chikoti	150	3.84	76	<1.0	82
54	Zukuza	310	8.72	155	<1.0	188
55	Nyenye	334	48.6	167	<1.0	330
56	Matelo	46	171.6	24	<1.0	58
57	Chilundumusi	190	35	17	133	120
58	Mweembe Village	511	358	358	266	100
59	Chela	72.86	11	51	0	20

Table 4: Chemical parameters of borehole water samples collected in Mbala District

BH	Village Located	PH	Alkalinity (mg/L)	Calcium (mg/L)	Magnesium(mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Iron (mg/L)	Sulphate (mg/L)	Nitrate (mg/L)	Phosphates (mg/l)	Manganese (mg/l)	Sodium (mg/l)
		6.5-8.0	500	100	250	250	1.0	0.3	1.0	10	0.1	0.3	1.5
1	Kombe School	5.37	36	11.2	0.23	25	<0.01	0.54	2	0.001	<0.01	0.23	14.71
2	Senga North	5.24	48	7.2	2.9	15	<0.01	0.94	4	0.001	<0.01	0.22	14.7
3	Chambezi Village	5.14	24	3.2	2.43	17	<0.01	0.47	1	0.001	<0.01	0.22	18.58
4	Manyika Village	5.44	86	1.6	15.07	20	<0.01	0.42	4	0.001	<0.01	0.05	19.23
5	Musatwe Village	5.1	16	1.6	14.82	16	<0.01	0.57	2	0.001	<0.01	0.05	12.69
6	Iyanda B Village	5.36	0.001	6.4	3.4	27	<0.01	1.44	2	0.001	<0.01	0.2	13.58
7	Iyanda Co school	5.3	18	1.6	0.92	20	<0.01	0.3	2	0.001	<0.01	0.03	10.08
8	Kampandila Village	6.1	30	4	1.46	43.99	<0.01	0.14	8	0.001	<0.01	0.15	12.72
9	Chitimbiti Village	5.76	34	3.21	1.46	28.99	<0.01	0.09	6	0.001	<0.01	0.07	13.12
10	Ngelesani Village	5.94	0.001	0.97	0.97	9.11	<0.01	0.01	5	0.001	<0.01	0.02	7.73
11	Mayanga Village	6.77	0.001	2.81	0.73	11.36	<0.01	0.01	1	0.001	<0.01	0.06	8.19
12	Chiwindi Village	6.1	22	1.72	0.88	17.23	<0.01	0.02	4	0.001	<0.01	0.04	10.2
13	Mwembe P School	5.77	34	4	0.001	32.49	<0.01	0.23	6	0.001	<0.01	0.07	14.7
14	Chele Village	6.75	12	18.44	3.4	19.49	<0.01	0.09	8	0.001	<0.01	0.12	18.33
15	Landula P School	6.6	0.001	4.3	2.3	11.2	<0.01	0.02	0.08	0.001	<0.01	0.16	4.6
16	Chalunga/Kakozya	6.8	0.001	1.8	4.6	5.7	<0.01	0.03	0.01	0.001	<0.01	0.11	6.7
17	Ntapita Vullage	6	15	1.3	6.2	23	<0.01	0.01	2	0.001	<0.01	0.04	13.5
18	Chaya/ Ntondokoso	5.9	9	2.4	4.5	19	<0.01	0.02	3	0.001	<0.01	0.03	9
19	Mulalo	6.2	11	6.3	5.9	37	<0.01	0.4	2	0.001	<0.01	0.02	6.8
20	Kacheche Com. School	6.3	0.001	0.001	0	4.7	0	0.02	0	0.03	<0.01	0	0.001
21	Ngombezo Village	6.8	0.001	0.001	0	1.56	0	0.06	0.01	0.03	<0.01	0.01	0.001
22	Beni Village	6.6	0.001	0.001	0	2.1	0	0.04	0	0.02	<0.01	0	0.001
23	Saulo kela (chilyango	6.9	0.001	0.001	0	3.72	0.01	0.08	0	0.03	<0.01	0	0.001
24	Namatemba village	6.5	0.001	0.001	0	2.82	0	0.01	0	0.01	<0.01	0	0.001
25	Nsindano village	5.8	0.001	0.001	0.001	1	0	0.04	0	0.03	<0.01	0	0.001
26	Mulenga village	5.8	0.001	0.001	0.001	2.2	0	0.02	0	0.01	<0.01	0	0.001
27	Mwesela village	6	0.001	0.001	0.001	3	0	0.04	0	0	<0.01	0	0.001
28	Jeremia village	6.2	0.001	0.001	0.001	3.5	0	0.02	0	0.01	<0.01	0	0.001
29	Mpanga village	6.7	0.001	0.001	0.001	4.8	0	0.07	0	0.02	<0.01	0.01	0.001
30	Owen village	6.5	0.001	0.001	0.001	3.8	0	0	0	0.01	<0.01	0	0.001
31	Katambalile village	6.5	0.001	0.001	0.001	4.5	0	0.13	0	0.01	<0.01	0.01	0.001
32	Teya village	6.7	0.001	0.001	0.001	2.5	0	0.04	0	0.02	<0.01	0	0.001
33	Kasanga village	6.5	0.001	0.001	0.001	3.2	0	0.01	0	0	<0.01	0	0.001
34	Mwesela B village	6.5	0.001	0.001	0.001	3.75	0	0	0	0.03	<0.01	0	0.001
35	Kayawala Vlge	6.7	0.001	0.001	0.001	5.2	0	0	0	0.01	<0.01	0	0.001
36	Mwambala P.	6.5	0.001	0.001	0.001	3.2	0	0.01	0	0.001	<0.01	0	0.001

	School												
37	Mbulauyo village	6.9	0	0.001	0.001	17	0	0.09	0	0.04	<0.01	0.01	0.001
38	Ng'ombe Village	6.1	0	0.001	0.001	6	0	0.04	0	0	<0.01	0	0.001
39	Seven Village	6.6	0	0.001	0.001	7.1	0	0.05	0.03	0.04	<0.01	0	0.001
40	Katuna Village	6.5	0	0.001	0.001	8	0	0.03	0	0.02	<0.01	0	0.001
41	Chisama Village	6.6	0	0.001	0.001	7.5	0	0.04	0	0.02	<0.01	0	0.001
42	Chikusela Village	6.5	0	0.001	0.001	9.2	0	0.07	0	0.06	<0.01	0	0.001
43	Maliko Village	6.6	0	0.001	0.001	10.2	0	0.09	0	0.04	<0.01	0.01	0.001
44	Sampatika Village	6	0	0.001	0.001	3	0	0.02	0	0	<0.01	0	0.001
45	Lwanda Village	6.2	0.001	0.001	0.001	5.5	0	0.03	0	0.08	<0.01	0	0.001
46	Sikalembe village	6.6	0.001	0.001	0.001	15	0	0.07	0	0.06	<0.01	0	0.001
47	Chilundumunsi vlg	6.4	0.001	0.001	0.001	18	0	0.03	0	0.03	<0.01	0	0.001
48	Tomo Village	5.9	0.001	0.001	0.001	10	0	0.05	0	0.04	<0.01	0	0.001
49	Siolwe Village	6.4	0.001	0.001	0.001	14	0	0.04	0	0.01	<0.01	0	0.001
50	Philimoni	6.56	50	15.2	4.32	15	0.09	2.84	1.56	<0.01	<0.01	0.02	9.02
51	Susuntila	6.66	88	18.4	11.04	17	0.11	1.96	18.76	3.93	<0.01	<0.01	12.22
52	Tomo	6.62	140	40	10.8	32	0.14	0.88	1.59	<0.01	<0.01	<0.01	22.04
53	Ali Chikoti	6.94	80	21.6	6.72	17	0.13	<0.01	<0.01	<0.01	<0.01	<0.01	13.11
54	Zukuza	6.94	182	41.6	20.16	25	0.16	0.8	<0.01	<0.01	<0.01	<0.01	36.11
55	Nyenye	6.88	312	36.8	57.12	36	0.16	3.13	3.53	<0.01	<0.01	0.04	49.9
56	Matelo	5.84	50	5.6	10.56	5.65	0.09	10.22	<0.01	<0.01	<0.01	0.05	15.01
57	Chilundumusi	6.73	160	35.3	7.8	20	0.01	0.01	2	0	0.3	0.012	2.13
58	Mweembe Village	6.98	40	38.5	0.97	20	0.01	0.18	18	0	0.3	0.012	7.45
59	Chela	6.49	150	4.8	1.9	20	0.01	0.04	3	0	0.6	0.02	5.36

Table 5: Microbiological parameters of borehole water samples collected in Mbala District

BH	Village Located	Total coliforms #/100ml	Faecal coliforms #/100ml
		0	**0**
1	Kombe School	0	0
2	Senga North	0	0
3	Chambezi Village	0	0
4	Manyika Village	0	0
5	Musatwe Village	0	0
6	Iyanda B Village	0	0
7	Iyanda Co school	0	0
8	Kampandila Village	0	0
9	Chitimbiti Village	0	0
10	Ngelesani Village	0	0
11	Mayanga Village	0	0
12	Chiwindi Village	0	0
13	Mwembe P School	0	0
14	Chele Village	0	0
15	Landula P School	0	0
16	Chalunga/Kakozya	0	0
17	Ntapita Vullage	0	0
18	Chaya/ Ntondokoso	0	0
19	Mulalo	0	0
20	Kacheche Com. School	0	0
21	Ngombezo Village	0	0
22	Beni Village	0	0
23	Saulo kela (chilyango	0	0
24	Namatemba village	6	0
25	Nsindano village	0	0
26	Mulenga village	0	0
27	Mwesela village	0	0
28	Jeremia village	0	0
29	Mpanga village	0	0
30	Owen village	0	0
31	Katambalile village	28	0
32	Teya village	0	0
33	Kasanga village	7	0
34	Mwesela B village	8	0
35	Kayawala Vlge	20	0
36	Mwambala P. School	0	0
37	Mbulauyo village	0	0
38	Ng'ombe Village	7	0
39	Seven Village	8	0
40	Katuna Village	0	0
41	Chisama Village	0	0
42	Chikusela Village	3	0
43	Maliko Village	0	0
44	Sampatika Village	16	0
45	Lwanda Village	0	0
46	Sikalembe village	3	0
47	Chilundumunsi vlg	0	0
48	Tomo Village	8	0
49	Siolwe Village	1	0
50	Philimoni	0	0
51	Susuntila	0	0
52	Tomo	0	0

53	Ali Chikoti	0	0
54	Zukuza	0	0
55	Nyenye	0	0
56	Matelo	0	0
57	Chilundumusi	0	0
58	Mweembe Village	17	68
59	Chela	0	0

Conclusion

Results from this study generally indicate that most water parameters complied with the Zambian Bureau of Standards (ZABS) drinking water guideline values. A few chemical parameters which include pH, Na, Fe, Mn and sulphate did not meet ZABS guideline values for drinking water at a few boreholes although water supplies from these boreholes will not affect the health of the consumers. Physical parameters which include electrical conductivity (EC) and hardness complied with ZABS drinking water guideline values except for total suspended solids (TSS) and turbidity. TSS and turbidity levels from a few borehole water samples exceeded ZABS permissible values for drinking water. In contrast, significantly high turbidity levels were recorded in a few water samples in Mbala district thus posing a significant threat to the health of the consumers.

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