

Heavy metal levels in drinking water sources of Chingola District, Zambia

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Abstract

Background: One of the factors impeding access to safe water is water pollution. Of particular concern is heavy metal contamination of water bodies. This study was aimed at determining the levels of heavy metals in drinking water sources of Chingola District of Zambia.

Methods: A cross sectional study was employed. A total of 60 water samples were collected. Thirsty (30) samples were collected in the dry season in the month of October 2016 and another 30 in the wet season in the months of February and March, 2017. For each season 10 water samples were collected from each of the three water sources. i.e. Tap water, Urban ground water sources and Rural ground water sources. Heavy metal analysis was done using Atomic Absorption Spectrophotometer (AAS).

Results: This study revealed that the concentrations of Iron, Manganese, Lead, Nickel and Arsenic were beyond maximum permissible levels in various water sources. Combined averages for both dry and wet seasons were as follows: Iron: 2.3, Copper: 0.63, Cobalt: 0.02, Manganese: 0.36, Lead: 0.04, Zinc:3.2, Nickel: 0.03, Arsenic: 0.05. Chromium and Cadmium were below detection limit in all water samples. The median concentrations of iron, arsenic, copper, manganese in drinking water from the Tap, rural and urban ground water sources were different, and this difference was statistically significant ($p < 0.05$). The median concentrations of arsenic, nickel, manganese and cobalt were different between dry and wet season, and this difference was statistically significant ($p < 0.05$).

Conclusions: Sources of heavy metals in water seems to be both natural and from human activities. The concentration of heavy metals in different water sources in this study was found to be above the recommended levels. This calls for improvement in water monitoring to protect the health of the public. Therefore, there is need for continuous monitoring of heavy metals in drinking water sources by regulatory authorities.

Background

Access to safe drinking water across the globe remains a major public health concern. A joint report by World Health Organization and United Nations' Children Fund (WHO/UNICEF) reported that more than 2.1 billion people do not have access to safe water on a global scale. One of the factors impeding access to safe water is water pollution (1). Of particular concern is heavy metal contamination of water bodies. Heavy metals may be introduced into drinking water through runoff or leached from the soil into groundwater (2). Heavy metals also occur naturally in the earth's crust (3). Streams and rivers are mainly contaminated with heavy metals by discharges of effluents from industrial process like mining among others. Some heavy metals maybe eliminated through proper process of water treatment by utility companies. However, some heavy metals still persist past the water treatment stage. Heavy metals persist for a long time in the environment being non degradable and are trans located to different components affecting the biota (4, 5). The persistence of heavy metals can result in bioaccumulation and

biomagnifications causing heavier exposure for some organisms than is present in the environment alone (6).

There have been concerns of water pollution of Kafue River and the soil in Chingola. Mining activities have been ongoing in Chingola district for many years. The Copperbelt Province of Zambia where Chingola District is located is one of the world's largest copper and cobalt ore districts (7, 8). Besides mining, the region is also home to about 40% of the nation's socio-economic activity. More than 93,000 tons of industrial waste is produced annually from various industries ranging from pulp-and-paper mills, fertilizer factories, granulation plants, abattoirs, textile manufacturers among others (9). Most of the effluents from the mining activities and other industrial processes are discharged into Kafue River. The tap water provided by the water utility company is abstracted from the same Kafue River. However, little information is available on levels of heavy metals in tap water and underground sources like boreholes and wells.

This study was conducted to determine the levels of heavy metals in drinking water sources of Chingola District. The study also aimed at assessing variations in concentrations of each heavy metal in water with respect to different sources and season.

Methods

Study Area

This study was conducted in Chingola District situated on the Copper belt Province of the Republic of Zambia. Chingola lies on the following Coordinates: 12° 32' 0" South, 27° 51' 0" East. The district shares boundaries with Chililabombwe at Kafue River in the North, Solwezi at Mushingwe Stream in the Northwest, Lufwanyama to the Southwest and Kalulushi at Musenga to the South. It covers a total surface area of 1,676 square kilometers. At the time of the study in 2016, Chingola had an estimated population projection of 237,816 with an annual growth rate of 2.9% and 60% of the people live in the urban areas that are densely populated (10)

Study Design

Cross-sectional study was carried out.

Sample size calculation

Sample size of 30 was derived using STATA software version 13.0 using the mean concentration of arsenic in water samples which had been estimated in a study in Ghana as 0.031 mg/l (Standard deviation = 0.005) (11). Power of the study was estimated at 90% with 95% level of significance. In order to measure seasonal variations in concentrations of heavy metals a total of 60 samples were collected. A total of 30 samples were collected in the dry season and 30 samples were collected in the wet season.

Sampling and data collection

Water samples were collected from the three main sources of drinking water in Chingola (Tap, urban ground and rural ground water sources). Tap water samples were collected from the urban areas supplied by the water utility company, while urban ground water samples were collected from the urban areas within a radius of 10 kilometers from the mining environment. Out of the ten urban ground water samples; three were collected from boreholes while seven were collected from shallow protected wells. The rural ground water samples were collected from rural areas far away from the mining environment. The nearest rural sampling location was about 15 kilometers while the furthest was about 60 kilometers. Rural ground water sources sampled included: five shallow wells, two boreholes and three hand pumps. Simple random sampling was used to select a zone from each area of interest to ensure representation. Selection of a sampling point was done using households as a sampling frame. A total of 60 water samples were collected. Thirty (30) water samples were collected in the dry season in the month of October, 2016 and 30 water samples were collected in the wet season in the months of February and March, 2017. For each season, 10 water samples were collected from each of the three water sources. i.e. Tap water, urban ground and rural ground water sources. The water samples were collected in sterile 1 litre polyethylene bottles according to method of Muhammad et al (12).

Different sampling procedures were employed for different types of water sources and all the precautions were taken. Water from hand pump and tap was allowed to run for a couple of minutes before filling the bottles and then reduced the water flow to permit filling of bottle without splashing. Immediately after collection, 1 mL drop of 5% nitric acid was added to prevent the loss of heavy metals. Then the water sample was placed in a cool box (about 4⁰C) and transported to the laboratory.

Sample digestion and analysis

Sample digestion was done to ensure the removal of organic impurities from the samples and thus prevent interference in analysis. Digestion of the sample is one of the storage steps taken to preserve the samples from bacterial activities and to release metals into the analytical solution. Digestion of the samples was done using concentrated nitric acid according to the method of Zhang (13). Water was filtered using whatman paper before digestion. Concentrated nitric acid (5 ml) was added to 100 ml of sample of water in a beaker. This was heated on a hot plate to boil for about 40 minutes until its volume reduced to 10 ml and afterwards allowed to cool.

After cooling, the sample was filtered using whatman paper. Afterwards, 100 ml of distilled water was added to the filtered sample. For the different element's determination, standards of known concentration were prepared for each element, followed by calibration of the wave longitude, plasma position, gas flux and sensibility for each element. Heavy metal analysis was done using Atomic Absorption Spectrophotometer version Perkin Elmer, A-Analyst 2000, 2007 model. Calibration curves were drawn for each metal by running suitable concentrations of their standard solutions, from which the concentrations of the elements was obtained by extrapolation.

In view of data quality assurance; average values of three replicates were taken for each determination and after every 10 samples, one blank sample using distilled water was analyzed. Strict quality assurance and quality control measures were adopted to ensure reliability of the results. All reagents and chemicals which were used were of analytical grade. Blinding was applied to the Laboratory Technicians as they did not know the sources of water. Sampling IDs which were only known by the principal Investigator were used to label each sample. Glasswares used during laboratory analysis were thoroughly cleaned with detergent and rinsed several times with deionized water. Dilutions were done using deionized water. The heavy metal analysis was carried out at the Environmental Engineering Laboratory of the School of Mines, Copperbelt University. The following heavy metals were analyzed: Arsenic (As), Copper (Cu), Iron (Fe), Zinc (Zn), Cobalt (Co), Cadmium (Cd), Chromium (Cr), Manganese (Mn) and Lead (Pb).

Data analysis

Non parametric statistical tests were used since heavy metal concentrations were skewed. Heavy metal concentrations were summarized using median and interquartile ranges. Kruskal Wallis test was used to compare metal concentrations between the three sources of water (Tap, urban and rural ground water sources). Wilcoxon rank-sum test was used to compare metal concentrations between dry and wet season. All the analysis was done using STATA software Version 13.0 at 95% confidence level.

Results

A total of sixty (60) water samples were analyzed. Thirty (30) samples were analyzed in the dry season and another 30 in the wet season. Zambia Bureau of Standards (ZABS) 2010 standards for drinking water including World Health Organization (WHO) and United States Environmental Protection Agency (US EPA) water standards for drinking water were used to compare the levels of drinking water.

Concentrations of heavy metals in water sources

Median concentrations of heavy metals according to wet and dry season

Table 1 shows the median and IQR of heavy metal for the dry and wet season from all the sources. In both dry and wet season chromium and cadmium levels were below detectable limit. Arsenic concentrations were below detectable limits in the dry season but were detected during the wet season.

Table 1
Median concentrations of Heavy metals according to dry and wet season

Heavy metal	Water standards			Dry season		Wet season	
	WHO	US EPA	ZABS	Median	(IQR)	Median	(IQR)
Iron	1.0	0.3	0.3	0.16	(0.06, 0.46)	0.14	(0.01, 0.59)
Copper	2.0	1.3	1.0	0.06	(0.03, 0.27)	0.064	(0.01, 0.17)
Cobalt	n.d	0.1	0.5	0.01	(0.01, 0.02)	0.001	(0.001, 0.01)
Manganese	0.4	0.3	0.1	0.06	(0.03, 0.15)	0.56	(0.18, 0.96)
Lead	0.01	0.015	0.01	0.01	(0.01, 0.03)	0.01	(0.001, 0.02)
Zinc	3.0	5.0	3.0	0.32	(0.11, 0.52)	0.22	(0.17, 0.52)
Nickel	0.02	0.1	n.d	0.04	(0.02, 0.06)	0.01	(0.001, 0.01)
Arsenic	0.01	0.01	0.01	b.d.l	b.d.l	0.115	(0.03, 0.13)
Chromium	0.05	0.1	0.05	b.d.l	b.d.l	b.d.l	b.d.l
Cadmium	0.003	0.005	0.03	b.d.l	b.d.l	b.d.l	b.d.l
KEY							
b.d.l: Below detection limit (< 0.001 mg/l).							
n.d: not determined							

Table 2 shows median concentrations of heavy metals for dry and wet season from various sources compared to various standards of drinking water. Concentrations of Arsenic in wet season from urban and rural ground sources exceeded the permissible levels for drinking water for all the standards. Median concentrations of Nickel for dry season and from all the sources exceeded the permissible levels as provided by the World Health Organization (WHO). Median Concentrations of lead from rural ground water sources during the dry season exceeded the permissible levels as provided by WHO, ZABS and United States Environmental Protection Agency (US EPA). Median concentrations of Manganese in Tap water for both dry and wet season, and urban ground water in wet season exceeded the permissible levels as provided by ZABS. The median concentrations of iron in rural ground water sources for both dry and wet season exceeded permissible levels as provided by USEPA and ZABS.

Table 2:
Median concentrations of Heavy metals in dry and wet season according to source of Water compared to the various standards of drinking water

	Water standards			Dry Season			Wet season		
	WHO	US EPA	ZABS	Tap	Urban ground water sources	Rural ground water sources	Tap water	Urban ground water sources	Rural ground water sources
Iron	1.0	0.3	0.3	0.16	0.13	1.04	0.12	0.02	1.02
Lead	2.0	1.3	1.0	0.74	0.035	0.035	0.24	0.05	0.001
Copper	n.d	0.1	0.5	0.015	0.01	0.01	0.005	0.001	0.001
Manganese	0.4	0.3	0.1	0.21	0.04	0.06	0.58	1.0	0.04
Nickel	0.01	0.015	0.01	0.01	0.01	0.025	0.01	0.01	0.001
Chromium	3.0	5.0	3.0	0.30	0.30	0.38	0.32	0.2	0.3
Cadmium	0.02	0.1	n.d	0.045	0.04	0.035	0.02	0.01	0.006
Cobalt	0.01	0.01	0.01	b.d.l	b.d.l	b.d.l	0.001	0.13	0.13
Vanadium	0.05	0.1	0.05	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l
Barium	0.003	0.005	0.03	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l

KEY

b.d.l: below detection limit (<0.0001 mg/l)

n.d: not determined

Comparison of heavy metal concentrations according to source of water

Comparison of levels of heavy metals according to the various sources was done using the Kruskal–Wallis one-way analysis-of-variance test. The three sources were tap water, rural ground water and urban ground water sources.

According to Table 3 the median concentrations of iron, arsenic, copper, manganese in drinking water from the tap, rural and urban ground water sources were different, and this difference was statistically significant ($p < 0.05$). However, levels of cobalt and nickel showed no significant difference in terms of source of water. Rural ground water had significant amount of Iron, while Tap water had significant levels of Copper and urban ground water had higher amounts of Manganese.

Table 3
Kruskal–Wallis comparison
of heavy metals between
Tap, rural ground water and
urban ground water
sources

Heavy metal	P- Value
Iron	0.008
Copper	0.0001
Cobalt	0.17
Manganese	0.002
Nickel	0.21
Arsenic	0.0006
Lead	0.42

Comparing seasonal variations of heavy metals

Seasonal variation of heavy metal was done using Two-sample Wilcoxon rank-sum

Table 4 shows that the median concentrations of arsenic, nickel, manganese and cobalt were different between dry and wet season, and this difference was statistically significant ($p < 0.05$).

Table 4
Two-sample Wilcoxon rank-sum
seasonal variations of
heavy metals

Heavy metal	P- Value
Iron	0.3073
Copper	0.7899
Cobalt	0.0004
Manganese	0.0004
Lead	0.0928
Zinc	0.3911
Nickel	0.0001
Arsenic	0.0001

However, zinc, lead, copper and iron showed no significant difference between dry and wet season. Significant levels of manganese were reported during the wet season while significant levels of cobalt

were reported in the dry season.

Discussion

This study was conducted to determine the levels of heavy metals in drinking water sources of Chingola District. The study also aimed at assessing variations in concentrations of each heavy metal in water with respect to different sources and season.

Arsenic levels were found to be beyond permissible levels in all ground water sources during the wet season both rural and urban. For Tap water, only three (3) sampling locations out of ten (10) had arsenic levels beyond permissible levels. UNICEF reported that the primary source of arsenic contamination in the populace is ground water sources (14). Reported elevated levels of arsenic during the wet season in this study agree with a number of studies conducted in other settings. However, very little information is available on heavy metal levels in drinking water sources in Zambia. Most available information on heavy metals in Zambia has to do with water samples collected from the soils and rivers especially Kafue River. Previous studies reported that Sediments Arsenic levels surpassed United States Environmental Protection Agency (USEPA) along Kafue River (15). Other studies also reported high levels of Arsenic groundwater and well water in the Mekong River basin of Cambodia (16). Similar to findings in this study; other studies also reported higher levels of arsenic during the wet season (17). This suggests that arsenic might be desorbed and leached from contaminated soils into shallow groundwater (18).

Observed fluctuations of arsenic are primarily induced by seasonally occurring groundwater movement (19). Elevated levels of arsenic may also be influenced by the weathering/erosion of minerals as well as application of various agricultural fertilizers (20, 21). Other studies reported that the presence of arsenic may also be attributed to anthropogenic activities, such as the use of herbicides (22). This means that water may get contaminated through improperly disposed arsenical chemicals and use of arsenical pesticides (23). It's probable that apart from the natural and weathering processes of arsenic, use of agricultural pesticides/herbicides might contribute to the high levels of arsenic in ground water sources since small scale farming is the predominant activity in Chingola district especially rural communities.

Elevated lead beyond permissible levels was detected in a number of water samples in both dry and wet season. The highest median value was 0.025 for rural ground water sources during dry season. Previous studies in Nigeria revealed elevated levels of lead above permissible levels in various water samples (24, 25, 26). This study however, reported relatively higher concentrations of lead in the dry season than wet season contrary to findings by other studies which reported relatively higher concentrations of lead in the wet season compared to the dry season in ground water sources (27). Various factors are associated with increased levels of lead in drinking water sources. In this study, rural ground water samples reported relatively higher concentrations of lead compared to urban ground water sources and Tap water especially in the dry season. Khan et al. (28) identified improper disposal of sewage and solid wastes, over application of agrochemicals (pesticides and fertilizers), deteriorating condition of piping network and transportation as the major sources responsible for contamination of drinking water with lead.

Agricultural activities may be implicated as the main source of elevated levels of heavy metals in water. Previous use of lead paints and leaded fuel may also be implicated since heavy metals are non-biodegradable and remain in the environment for a long time.

Manganese was detected from almost all the sampling locations in both dry and wet season. Only two sampling locations in the wet season reported concentrations below detection limit. The median concentration for Tap water and urban ground water sources during wet season exceeded ZABS permissible values of drinking water. Median concentrations for Tap water sources during dry season exceeded ZABS permissible values of drinking water. Similar study in past studies in groundwater and well water in the Mekong River basin of Cambodia reported high levels of Manganese (29). Equally, Buschmann et al. (30) reported higher concentrations of Manganese in wells. Manganese naturally occurs in many surface and ground water sources and in soils that may erode into these waters (31) however, past mining activities has been implicated to be responsible for elevated levels in drinking water sources in some studies (32).

Nickel concentrations exceeded WHO permissible levels in dry season in all water sources. The highest median concentration was 0.045 mg/l in Tap water during the dry season while the lowest median concentration was 0.006 mg/l in rural ground water sources during the wet season. Little information is available in Zambia on nickel levels in drinking water sources. Most information available is on studies which focused on river and soil samples. All studies on Zambia reviewed by the researcher did not report any significant amount of Nickel in water. However, studies in other settings have reported elevated nickel levels in drinking water sources. A study in Nigeria reported elevated nickel concentrations among other heavy metals in Bore-hole water from Kebbi state (33). Another study in Izmir, Turkey reported high levels of nickel beyond their safe limits in drinking water (34). Equally, a study in Greece, revealed high levels of nickel in drinking water from various regions of Greece (35). The European Food Safety Authority (EFSA) reported that nickel is a widespread component of Earth's surface found in all environmental compartments and is ubiquitous in the biosphere (36). Weathering of rocks and soils has been identified as one of the main natural sources of nickel (37).

The median concentrations of iron in rural ground water sources for both dry and wet season exceeded permissible levels as provided by US EPA and EU. Previous studies elsewhere also reported that iron exceeded their respective permissible limits set by different organizations in some locations (38). Iron is frequently found in groundwater due to large deposits in the earth's surface (39). The levels of iron in groundwater can be increased by dissolution of ferrous borehole and hand pump components (40). The use of groundwater for drinking is in many cases limited by the presence of dissolved iron. Iron gives the water an unpleasant metallic taste, and stain food, sanitary wares and laundry.

Median concentrations for the other heavy metals were below their respective permissible values. However, some of the sampling points reported values beyond permissible values for copper, cobalt and zinc. Concentrations of chromium and cadmium were below detection limits

A study by Ndilila et al revealed significantly higher Toenail concentrations of cobalt, copper, lead and zinc in the mining area compared to non-mining areas in Zambia (41). Others reported elevated cobalt and copper levels along Kafue River in Chingola district which he attributed to mining activities (42). Other past findings further found out that areas geographically distant from mining beds had only moderate or low heavy metal concentrations. Sampling locations with higher levels of zinc were rural ground water sources. Anthropogenic activities may be responsible for these elevated of zinc in some rural ground sources (43).

Cadmium and chromium were all below detection limit in the water sources for both wet and dry season of the study area. This implies that the study area had no traces of the metal ions being mentioned, or that their concentrations were just too low to be detected by the instrument of analysis. This is good news, since cadmium and chromium might be considered a threat according World Health Organization (44). The non-detect result for chromium in this study is an indication and likely confirmation of the absence of industrial activities which involves chromium and cadmium in its operations.

In this study; iron, arsenic, copper manganese showed a significant difference ($P < 0.05$) with respect to the three different sources of drinking water. Levels of arsenic, nickel, manganese and cobalt differed significantly between dry and wet season. Previous studies in Nigeria and Jordan also revealed significant ($p < 0.05$) heavy metal variation in terms of water source (45, 46).

This shows that different sampling locations contribute differently to the median heavy metal concentrations from various sources. This means that heavy metal contamination is likely to be anthropogenic. This result may be explained by the fact that such heavy metals which arise from anthropogenic sources are collected and concentrated during no-rain months, and then washed at the beginning of rainfall with the rain runoff and leached to the ground- water through soil (47). Variations in this regard may probably arise from changes along the groundwater flow path, and slight variations in net effect of the pH dependent processes of minerals dissolution and precipitations (hydrogeology) (48, 49).

Conclusions

This study revealed that concentrations of Iron, Manganese, Lead, Nickel and Arsenic were beyond maximum permissible levels in various water sources. Chromium and Cadmium was below detection limit in all water samples. Levels of arsenic, nickel, manganese and cobalt differed significantly between dry and wet season. Levels of iron, arsenic, copper and manganese showed a significant difference with respect to the three different sources of drinking water. Highest levels of copper, nickel and cobalt were reported from tap water sampling locations.

In view of the above; the water utility company should improve its water treatment methods so as to reduce levels of heavy metals in water supplied to their customers. Further, Government should consider providing household water filters to those who use underground water sources so as to reduce levels of arsenic in water.

List Of Abbreviations

WHO: World Health Organization.

ZABS: Zambia Bureau of Standards.

US EPA: United States Environmental Protection Agency.

NWSCO: National Water Supply and Sanitation Council.

ERES: Excellence in research ethics and science.

UNICEF: United Nations International Children's Emergency Fund

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from Excellence in research ethics and science (ERES) Coverage Research Ethics Committee (Protocol reference number: 2017-June-006). Permission was obtained from Chingola District Director of Health before commencement of data collection. During water sample collection, permission was obtained from the head of the household or any adult who was present and was above the age of 18 years. No force or coercion was applied. In this study, no personal and demographic information was required from householders apart for the plot number. ID numbers were used to label the sampling bottles at each sampling location. There were no foreseeable physical risks to humans involved in this study though it may have invoked some anxiety. However, the participants were assured that the findings of this study would be availed to the relevant authorities for appropriate action. The records of this study have been kept strictly confidential. All electronic information has been coded and secured using a password protected file.

Consent for publication

Not applicable.

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

FH conceived and designed the study, collected the data, contributed to the analysis of the data and prepared drafts of the manuscript. CDM, PM & HH contributed to the design of the study, provided oversight on data collection, contributed to the analysis of the data and conducted critical reviews and revisions of drafts of the manuscript. All the authors reviewed and approved the final version of the manuscript.

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Ethics approval and consent to participate

Not applicable.

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Figures

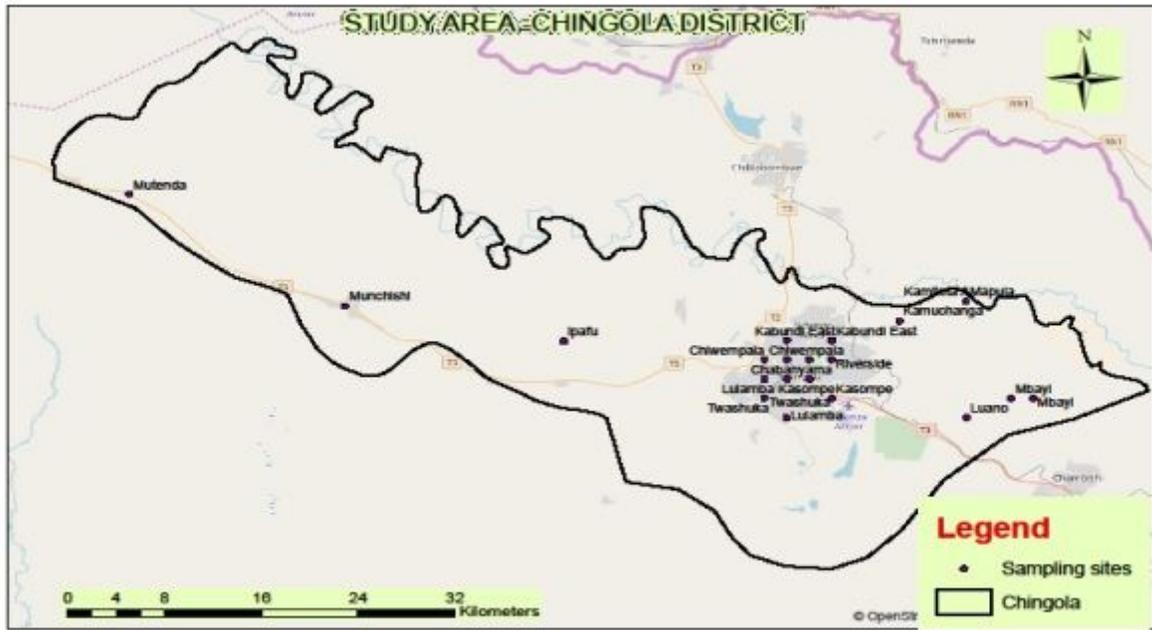


Figure 1

Map of Chingola District showing names of water sampling locations

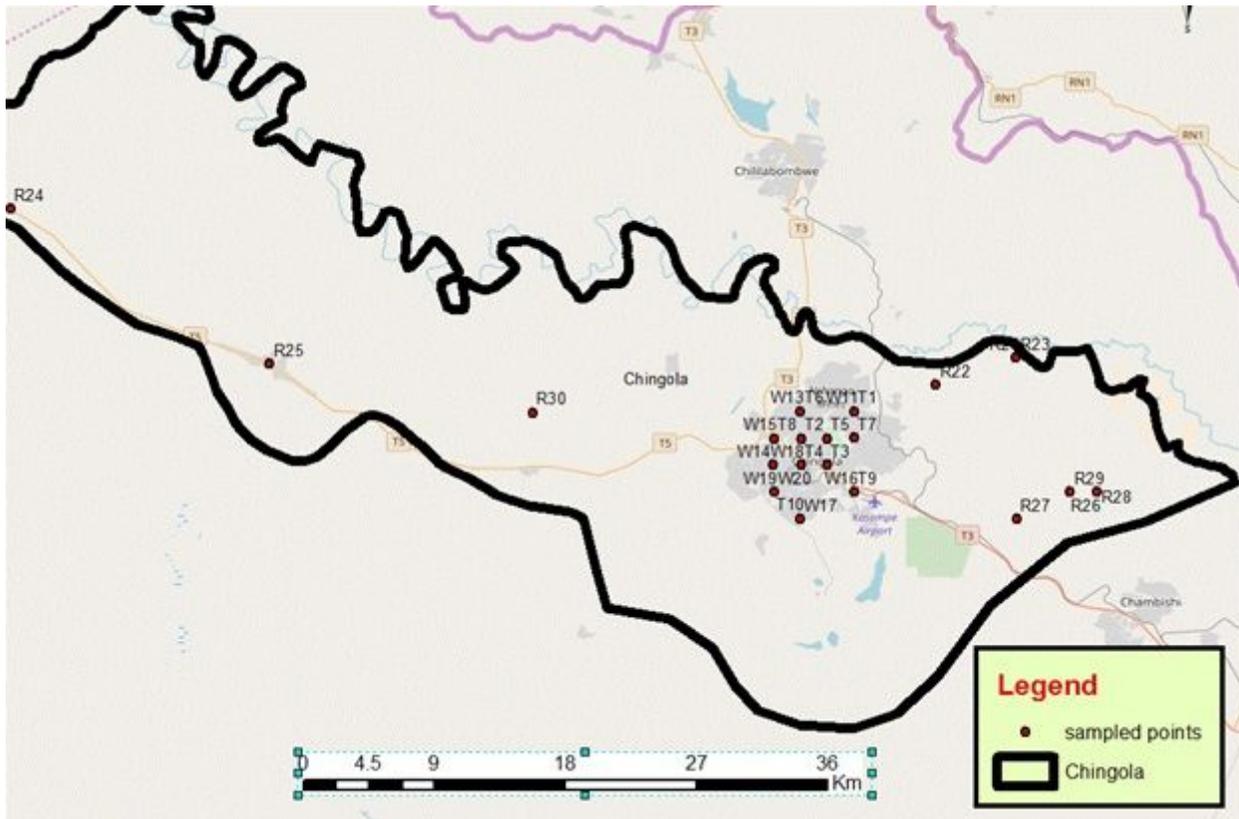


Figure 2

Map of Chingola District showing sampling locations for various water sources