

GROUNDWATER QUALITY ASSESSMENT AROUND THE UPPER KALUMBILA MINING AREA IN NORTH-WESTERN ZAMBIA

Abstract

In Zambia, mining has been the main economic stay of the country since independence. On the other hand, mining activities also trigger negative impacts on various aspects of the environment and groundwater. Mining operations in Kalumbila area have brought socioeconomic development, but at the same time, the waste effluents, solid waste such as tailings threaten the quality of groundwater. If not effectively addressed this may affect human health even cause death. Hence the aim of the study was to assess the quality of groundwater around Upper Kalumbila mining area in north-western Zambia. Pragmatic paradigm philosophically informed the study whose main research approach was mixed methodology with emphasis on a concurrent design. Data on the study Objective was collected using a digital portable multiparameter, which enabled insitu measurement of concentration of selected parameters in real time. The data was analysed using descriptive statistics and this included standard deviation and Coefficient of Variation (CV) aided by Excel Spreadsheet data Analysis Toolkit. Handheld GPS was used for geocoding of groundwater access points. A Student T-test was used to determine how statistically significant the difference in means for 30 paired samples was between the measured turbidity and the WHO ideal standard for groundwater. The reason for isolating out this parameter was because it was a major source of concern from the water users, and it was visibly above the ideal standard. The study found that almost all chemical parameters were well within Maximum Permissible Limits (MPLs). However, one of the heavy metals, namely, Cobalt was above normal. Turbidity was above WHO's prescribed ideal standard. From the analysed data, it was concluded that although some isolated parameters were above their MPLs, groundwater around the target areas in the upper part of Kalumbila mining was moderately safe for human consumption. The study recommends strengthening of community participation and installing filters in the water tanks to mitigate TSS and to also carefully monitor heavy metals on a regular basis.

Key words: *Groundwater, Water quality, Turbidity, Kalumbila, Mining pollution*

BACKGROUND

As of 2009, almost 50% of the global urban population was estimated to be supplied from groundwater sources including the domestic water of the rural population who had no access to water supplied by local authorities through taps (Das and Saikia, 2009). About 3 billion people across the world barely know the quality of water they drink because of poor investment in constant monitoring of water quality in general (United Nations (UN), 2023). However, this natural resource has often been mismanaged and even abused especially in areas that are surrounded by industrial activities. Groundwater provides the only feasible and affordable way to extend basic water access to unserved rural populations in much of the world. This is especially the case in Sub-Saharan Africa where the rural population is large, but dispersed (UNESCO, 2022).

While the pressure on groundwater has been steadily increasing, there has not been a complementary effort to address the potential risks to groundwater resource, such that groundwater quality is becoming an overarching concern for groundwater amidst climate change leading to additional stress (Baumle *et al.*, 2007). According to UNESCO (2022), persistent contamination of rural groundwater supplies with pathogens and pollutants is estimated to affect about 30% of the total installations, which usually affected the marginalized. Amidst climatic changes that affect the whole world, the pollutants are expected to reach high concentrations rendering groundwater unsuitable for domestic purposes, especially in places with high pollution risks such as mining areas (Foteinis, 2021) says that Southern Africa in general depended on groundwater for domestic, industrial, and agricultural use and therefore the protection of groundwater resources should have been imperative in many of the countries that were found in this part of Africa. They acknowledged that the main challenges to groundwater quality were industrial and agricultural pollutants, as well as poor hygiene around water points especially for shallow wells. The United Nations Environment Programme (UNEP) (2006) also earlier indicated that, although groundwater could be a safe source of water supply for many urban and rural people in Africa, most of them were vulnerable to pollution. Taonameso *et al.* (2019) indicated that 1.1 billion people drank water that was of moderate level of safety and quality adding and further arguing that, even those boreholes that were well protected, 10% of them were at high risk of pollution due to multiple sources of pollution.

Just like many parts of the world, Zambia has experienced several challenges with regard to managing water resources. Pollution, insufficient information for decision-making, limited financing to develop the resources and inadequate participation of stakeholders are among some challenges faced by local authorities in addressing groundwater resources challenges. In most parts of Zambia, groundwater was the most important resource for water supply (Lusaka Water and Sewerage Company (LWSC), 2014). For example, LWSC (2014) noted that, more than 52% of the urban areas in Zambia depended on groundwater, which was unfortunately under threat of pollution due to excessive human encroachment in the form of construction of settlements, industries, and other social amenities (British Geological Society, 2001; Monde *et al.*, 2023).

Environment Africa (EA) (2021) further confirmed that mining pollution had been threatening the quality of groundwater in various parts of the country and such a scenario had

been affecting many people especially children who could not easily discriminate poor quality from good quality groundwater. Smedley (2001) and the British Geological Society (2001) also showed that metal mining was one of the main sources of pollution for groundwater in many parts of the country where mining had been happening. The vulnerability of groundwater to contamination has been a serious concern in Zambia because of public health issues associated with it such as respiratory problems, digestive problems, and urinary system infections (EA, 2021). Hence, regular monitoring of groundwater is essential to prevent potential public health problems as those mentioned above, especially since the whole world has been pressing towards meeting the targets for Sustainable Development Goal number 6. Given the stochastic nature of the mineralogical and chemical concentration in water, all quality monitoring of groundwater, in general, add value to broadening the understanding of the nature of the problem and strengthens quality decision-making over time and space. It is generally said that water quality is highly compromised in most, if not all mining areas, but this study partly disputes this claim and says that, water quality could be suitable in some selected mining areas depending on the time of sampling, topographical orientation and elevation relative to the mining site.

DESCRIPTION OF THE STUDY AREA

The physical characteristics of the study area is described in terms of location, soils, vegetation, climate, topography, drainage, and geology. The study area is located generally in North-western Zambia. The First Quantum Mine (FQM) Trident Limited as a reference point to the study area is located specifically in UTM terms between Latitudes 299119-346113 m South and Longitudes 8668112-8641114 m East (Magdalena, 2015). The mine is surrounded by villages – Musele, Chitungu in the north, Chisasa, Northern Resettlement Northeast, Kanzanji on the East of the mine while Kankonzhi in the North West, Shinengéne is South of the mine, 18 km from their original village (Magdalena, 2015). The visual impression of the study area location is shown in Figure 1.

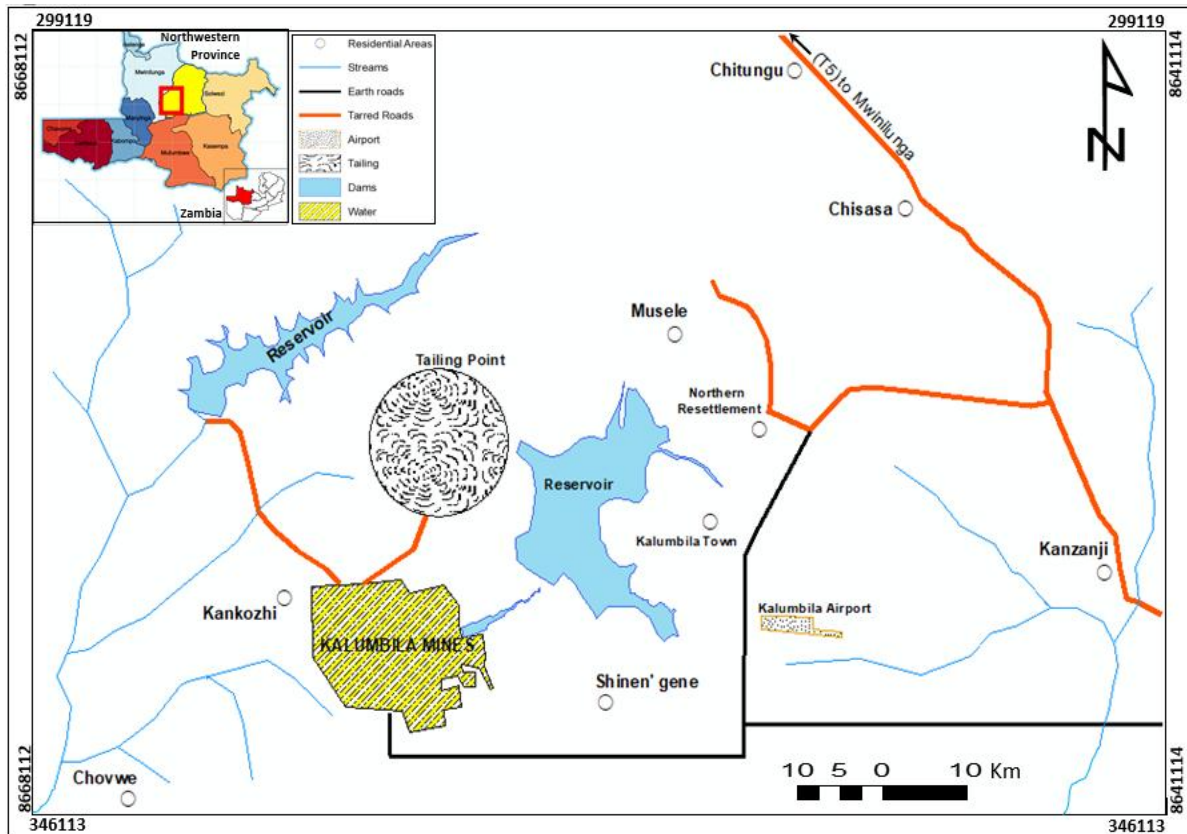


Figure 1: General location of the study area

The general geological structure of the study area is predominantly underlain by the Shale silt Sandstone which is half of the area laid in southward part. Largely, the northern part has a mixture of several rock types. The main ones include – Carbonate rocks, Basal conglomerate, Dolomite. The area is also endowed with a mixture of Granite, igneous-meta-igneous, Meta Carbonate rocks. The area is covered by the Kasai Shield comprising of metamorphic and igneous rocks. The Katanga strata is severely deformed in the Lufilian Arc, where the basement is exposed in the core of the Kapompo Dome (Young, 2001). The study area is made up of largely three distinct soil types – orthic-rudic Ferrasols, skeletal dystric Leptosols and Acrisols with dystric Leptosols (Kribek *et al.*, 2010). Due to heavy rains in the area commonly above normal, the soils are heavily leached (Godfrey, 1982). Figure 2a-b shows the Geological and soils maps of the study area.

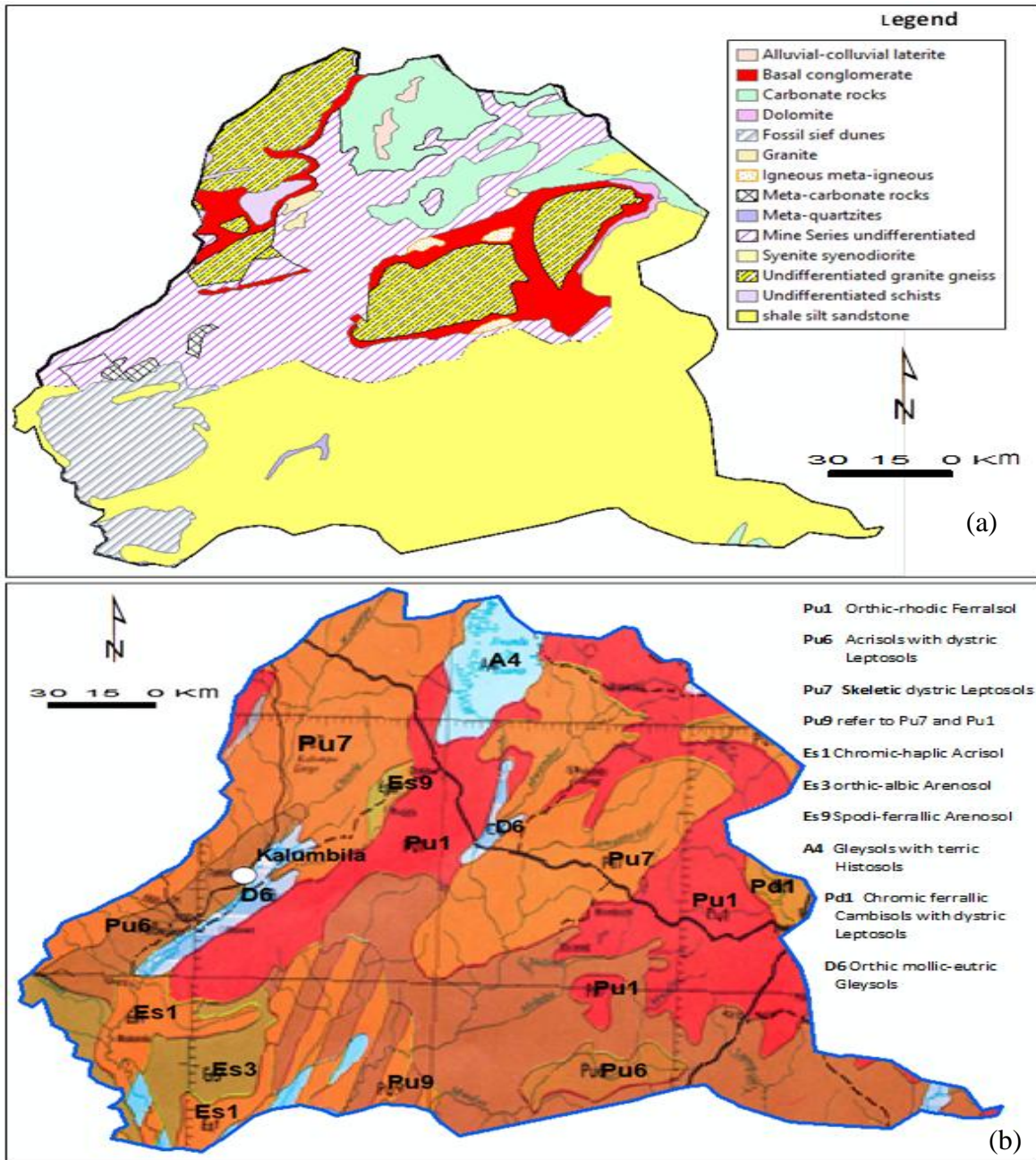


Figure 2: (a) Map showing geological orientation (b) Soils cover of the study area, Extracted from the Geological Map of Zambia, and Soils Map of Zambia

The study area is covered mainly by the native vegetation with closed-open broadleaved semi-deciduous forests (Fanshawe, 2010). It is side by side mixed and interwoven with the open broadleaved deciduous forests. It is endowed with Zambezian *Cryptosepalum* dry forests and Central Zambesian Miombo woodlands. The tree species consist generally of *Brachystegia longifolia* (Figure 3) (Byers, 2001)

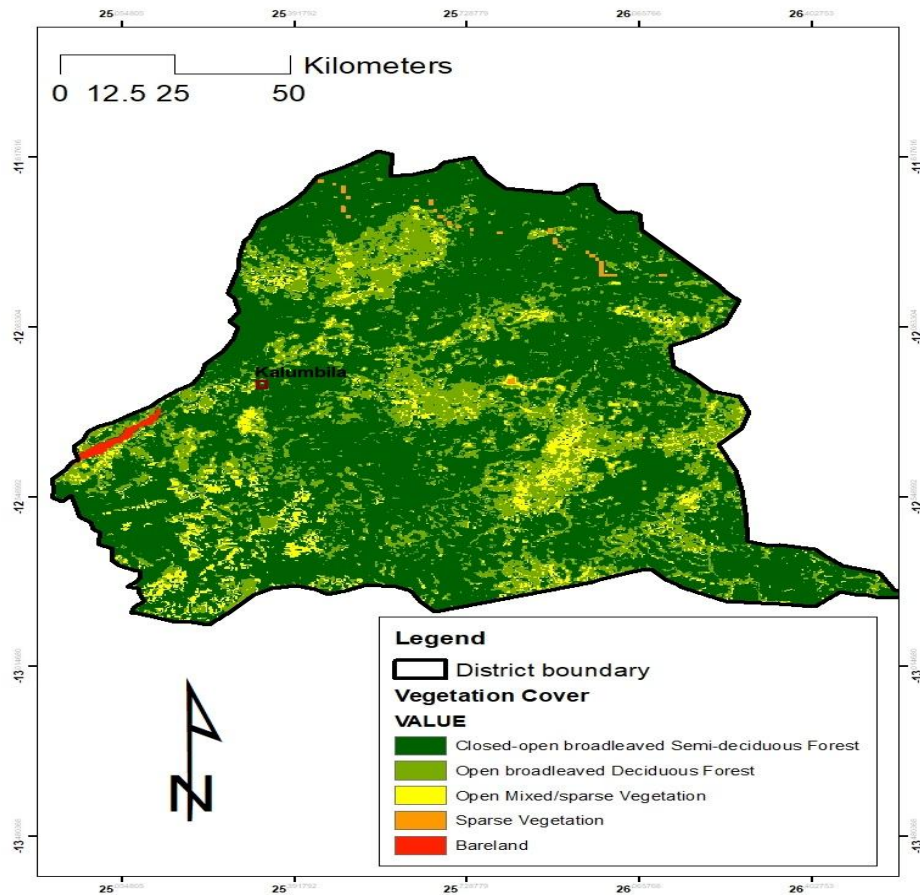


Figure 3: Vegetation of the study area (Extracted from Vegetation cover Map of Zambia)

The terrain of the study area is a rugged landscape with gentle to steep slope contouring. The relief ranges from a maximum elevation of 1354m and a minimum elevation of 1227m. The average elevation is about 1290m. The area is found in the watershed between D.R. Congo and Zambezi River systems. It falls within the Kabompo Sub-basin of the Zambezi basin drainage system. The Mumbezhi and Jiwundu Rivers from northeast of the study area meander smoothly on a gentle landscape before draining into the Kabompo River, which is a huge tributary of the Zambezi River (Knoblauch *et al.*, 2020). Figure 4 shows the Digital Elevation Model (DEM), drainage of the entire study area and water sampling points.

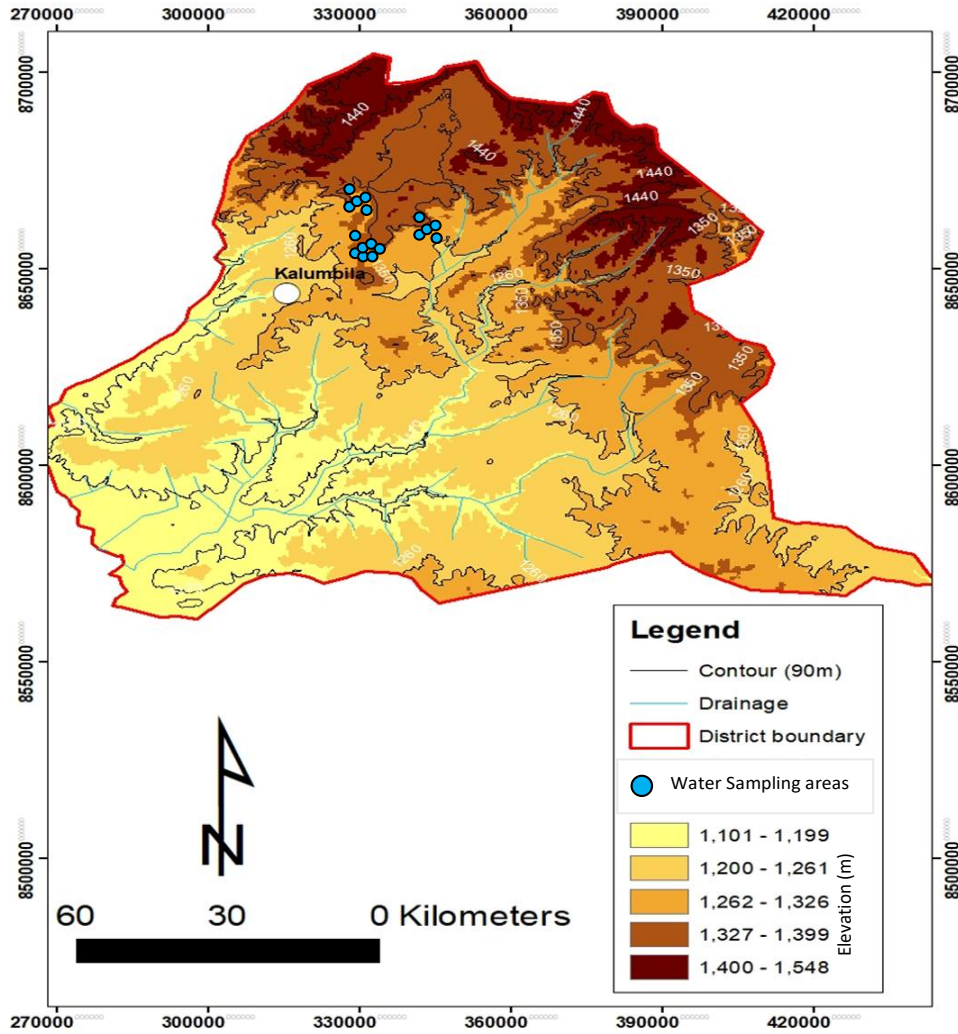


Figure 4: Digital Elevation Model and Water Sampling points

The study area experiences the latest three major seasons: cool dry season from April to August, a hot dry season from August to November and a warm wet season from November to April. The maximum heat is experienced during October reaching slightly above 30°C, while the lowest temperature is recorded in June and July reaching around 6°C. The maximum rainfall (>1200mm) received is generally during December and January (ZMD, 2022).

METHODOLOGY

The philosophical perspective that guided the research study was a pragmatic approach. Pragmatism as a research paradigm finds its philosophical foundation in its stance to embrace a plurality of methods and realities (Creswell and Clark, 2011). The ontological position is based on both subjective and objective realities where both value-ridden and value-free

realities were allowed to emerge in the study. The reality of the knowledge generated in this study can be experienced. Depending on the timing of collection of data, the findings may show a range of variations in concentrations of selected chemical parameters. Epistemologically, understanding such realities require the use of mixed methods techniques in both transgressive and non-transgressive ways (Saunders *et al*, 2007). By transgressive method, it means methods and tools that would allow diverse perspectives to emerge on selected thematic areas of the study whereas non-transgressive ways mean scientifically restrictive methods were used to understand some value-free phenomena such as mineralogical and chemical concentration in the 30 samples of water.

Data were collected using a digital portable multiparameter meter, which enabled insitu measurement of the concentration of selected parameters. This was able to measure parameters such as Chloride, Lead, Cobalt, Iron, pH, and turbidity, among others. Handheld GPS was also useful in geocoding of groundwater access points. Collected data and assessing the quality of groundwater was in line with WHO-prescribed standards for domestic consumption. This data was analysed using descriptive statistics specifically standard deviation and Coefficient of Variation (CV) implemented in Excel Spreadsheet data Analysis Toolkit. The data which was captured onsite was entered into the Excel spreadsheets and averages were computed for each parameter. These were, thereafter, analysed based on how close or far they were from the WHO-prescribed standards. Based on Jhunjhunwala's (2008) criteria, all CVs which were above 5% or 0.05 were classified as widely variant from the WHO standards.

The study assessed the chemical concentration of selected parameters in the groundwater samples around the upper part of Kalumbila Mining area. The results in Table 1 and Figure 5 show that, all analysed parameters such as pH and Magnesium (Mg) were outrightly within very acceptable limits as they were perfectly within WHO's prescribed Maximum Permissible Limits (MPLs) for domestic use as demonstrated by high CVs and Standard deviations of mean concentrations from the MPLs. From a hydrochemistry context, the study generally found that groundwater around Kalumbila mining area was safe for human consumption.

Table 1: Mean concentration of selected chemical parameters in the Groundwater around Kalumbila mining area

Groundwater Parameter	Average Across Target Area in Kalumbila	WHO Standard for human consumption	Standard Deviation	Coefficient of Variation
pH	6.8	9.2	1.70	0.21
Alkalinity (CaCO ₃ /l)	33.2	200	117.95	1.01
Ca (mg/l)	3.7	100	68.09	1.31
Mg (mg/l)	8.2	50	29.56	1.01
K (mg/l)	5.2	20	10.47	0.83
Na (mg/l)	2.4	50	33.66	1.28
Cl ⁻ (mg/l)	4.8	250	173.38	1.36
SO ₄ ²⁻ (mg/l)	1.7	400	281.64	1.40
HCO ₃ (mg/l)	1	8.3	5.16	1.11
NO ₃ (mg/l)	0.2	10	6.93	1.35

Source: Field data (2022).

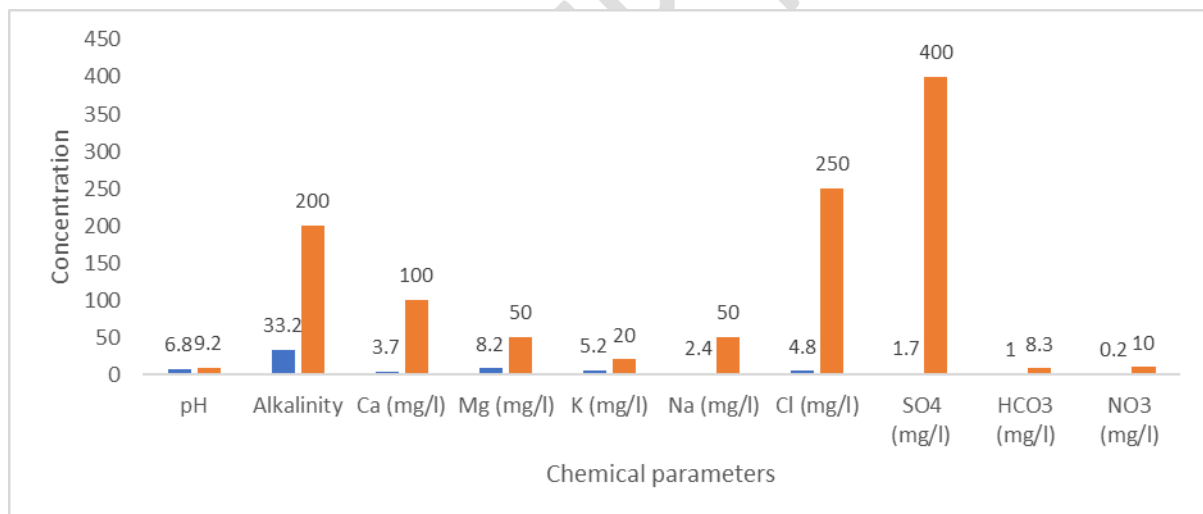


Figure 5: Chemical concentration of selected parameters compared to respective WHO's MPLs in Kalumbila mine area Source: Field Data (2022)

The geospatial analysis of the variability of chemical concentrations across the target area indicated that chemical concentrations of all assessed chemical parameters were generally highly variable from one point to the other. This was especially very evident for Magnesium and Potassium (Figure 6). This means that, even though the concentration of studied parameters were all within MPLs, they were not necessarily homogeneous across the space

and, this implies that with changes in seasons, the water quality may not necessarily be the same.

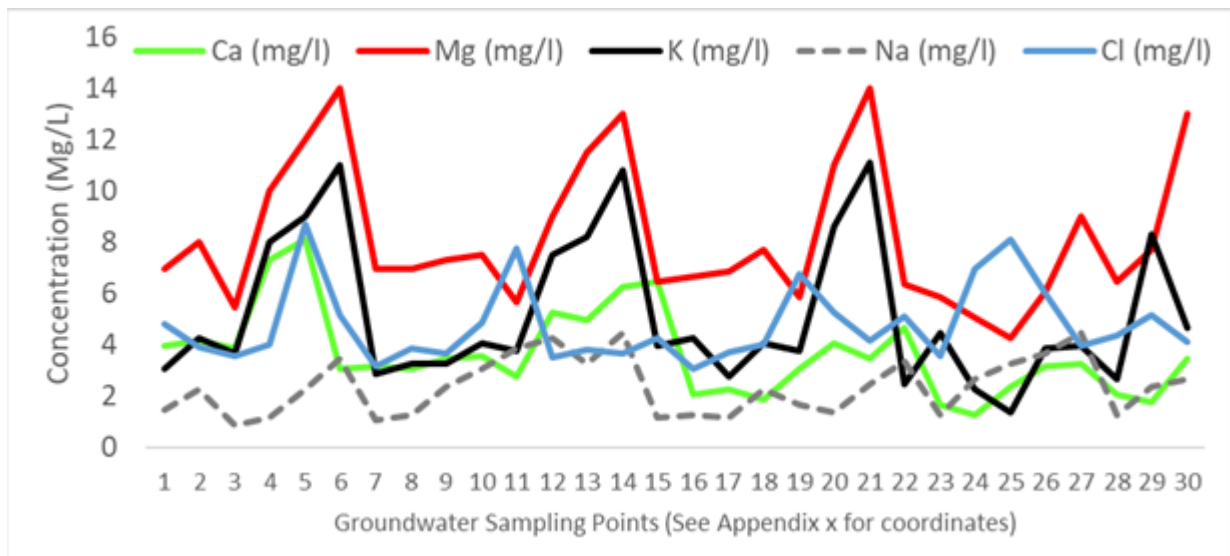


Figure 6: Chemical concentration dynamics for selected parameters in the groundwater around Kalumbila mining area. Source: Field data (2022).

Heavy metals concentration compared to WHO Standards

The study also examined the presence of heavy metals in the groundwater with reference to the WHO MPLs. Compared to respective MPLs, almost all assessed heavy metals were within very acceptable limits, this was especially the case for Copper (Cu) and Iron (Fe). However, Cobalt (Co) was found to be high at over 100% compared to the WHO's MPL for Cobalt, with CV at 0.52 above the normal concentration (Figure 7a). Iron was found to be the most geospatially variable, whereas Copper was fairly the most stable compared to other assessed heavy metals.

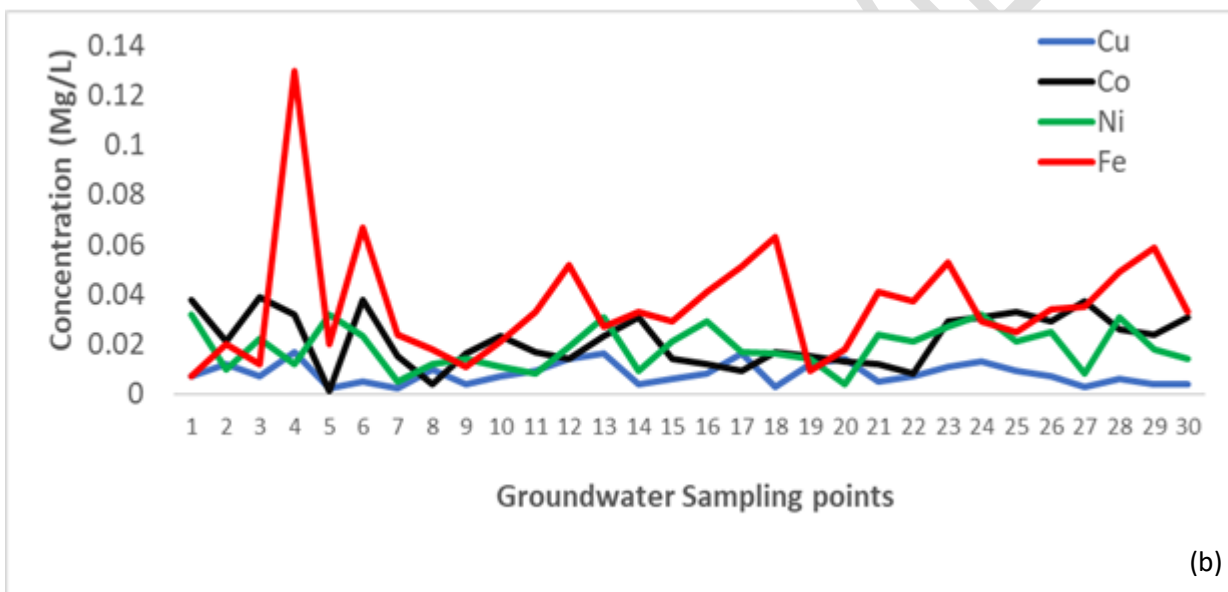
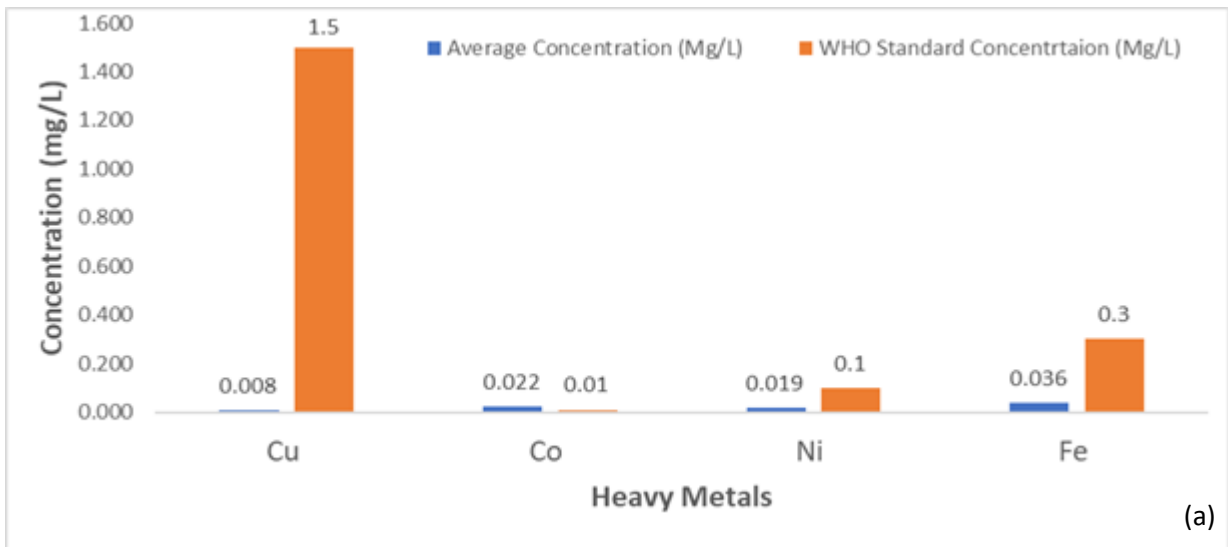


Figure 7: (a) Concentration of heavy metals compared to their respective MPLs and (b) dynamics of heavy metal concentration in the groundwater around Kalumbila mining area. Source: Field data (2022)

Turbidity trends across the sampled area

While chemical concentrations were all within permissible limits, it was noted that turbidity was above the ideal standard for human consumption as prescribed by WHO (1.8). The study generally found that, groundwater around the upper part of Kalumbila Area was acceptable for human consumption, but not necessarily ideal. T-test statistics confirmed a significantly higher measured mean turbidity compared to the mean ideal standard by WHO, $p= 0.003$ (Table 2).

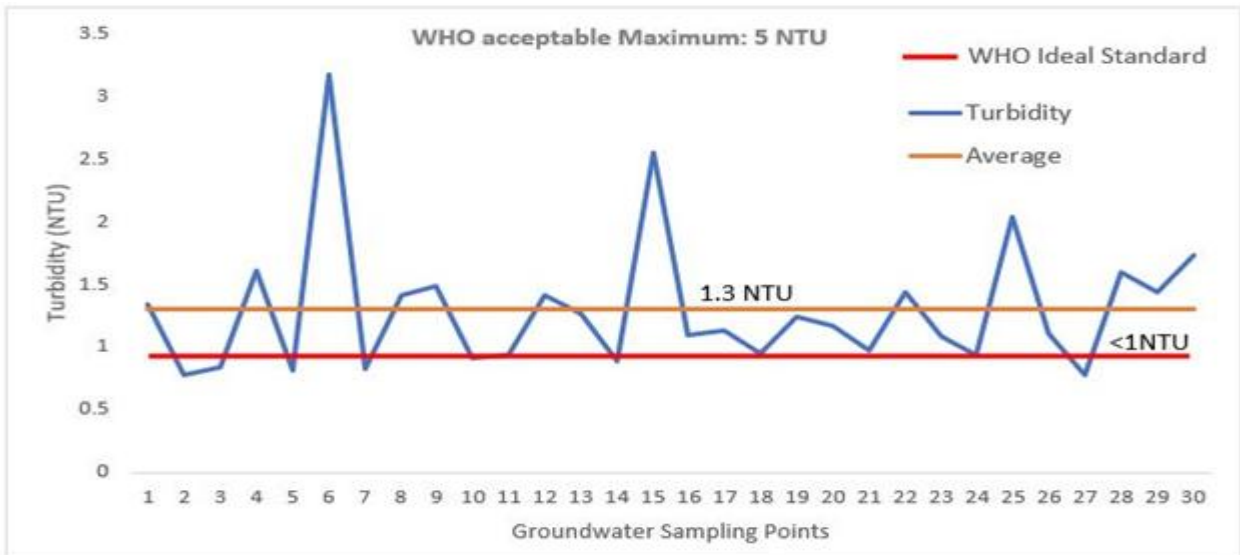


Figure 8: Geospatial dynamics of Turbidity in groundwater compared to WHO’s standards around Kalumbila area. Source: Feld Data (2022).

Table 2 : Paired two sample T-text for measured and WHO’s ideal standard for turbidity

	Measured Turbidity	WHO ideal Standard
Mean	1.29	1
Variance	0.29	0
Observations	30	30
Df	29	
<i>t Stat</i>	3.03	
<i>P(T<=t) one-tail</i>	0.003	
<i>t Critical one-tail</i>	1.70	

Source: Field Data (2022). Turbidity significantly higher than the WHO standard

DISCUSSION

According to World Health Organisation (2020), knowing the chemical concentration of water is critical for a better understanding of its quality and safety for domestic use. The analysed results for the upper part of Kalumbila mining area for all selected parameters such as pH, Sulphate (SO_4^{2-}) were outrightly within very acceptable limits as they were significantly below WHO’s prescribed MPLs for domestic use as demonstrated by high CVs and Standard Deviations of mean concentrations from the MPLs. This implies that the water was chemically safe for human consumption at the time of measurement and for the targeted variables. Although Alkalinity was also way within the MPL, the WHO (2009) earlier noted that water with alkalinity below 50mg CaCO_3 (Calcium Carbonate) per litre may be

vulnerable to chemical corrosion of piping and fixtures that could increase the metal content of the water resulting in aesthetic problems, or health problems if the level heavy metals such as lead, and copper were too high. The average alkalinity was around 33 mg/l, which cause some corrosion for metal piped water lines.

The geospatial analysis of the variability of chemical concentrations across the target area of Kalumbila mine showed that chemical concentrations of all dissolved chemical parameters were generally highly variable from one point to the other meaning that, they were not necessarily uniformly distributed at different sampling points. Such findings were also noted in earlier studies by Davis *et al.* (1994) and Obiri (2007). As opposed to an earlier study by Environment Africa (EA) (2021) around the Kansanshi mining area, which found excessive heavy metals in groundwater, this study found that almost all assessed heavy metals such as Copper (Cu) and Iron (Fe) were within very acceptable limits. This could perhaps be one of the few studies with such a revelation because most of the studies abnormally show high chemical composition of groundwater in the mining environments. The possible explanations could be that this study was done in the upper Kalumbila mining area with higher elevation compared to the location of the mine which is located on the downside. This perhaps reduced subsurface leakages of effluents into the groundwater. Moreover, the period during which the sampling was done was at peak of rainy season such that, the rise in water table could have diluted high concentrations. Asthana and Asthana (2001) earlier noted some of these variables to have a profound influence on the concentration dynamics of chemicals in fluid.

Nevertheless, Cobalt was excessively above WHO standard for human consumption. This could be associated with mining activities which typically contribute to high concentrations of such heavy metals (Environmental Protection Agency, 2000). Such spatially distributed high concentrations of cobalt raise some public health concerns as EPA (2000) states that, acute exposure to high levels of cobalt by inhalation in humans and animals' results in respiratory effects, such as a significant decrease in ventilatory function, congestion, and haemorrhaging lungs. An earlier study by (ICCIDD, 2012) confirmed high incidences of goitre rates more than 50% suggesting high concentrations of heavy metals such as cobalt in groundwater in these areas. Another study by Farjana (2019) indicates similar health risks for end users of water that is highly concentrated with cobalt.

The fact that most of the selected chemical parameters and heavy metals were lowly concentrated simply confirms earlier studies, which generally indicated that, groundwater quality in Zambia usually has very low concentrations of dissolved constituents (total dissolved solids concentrations are typically less than 200 mg/l) (Smedley, 2001; British Geological Society, 2001; Cheng *et al.*, 2009). These authorities unanimously point out that, the main expected source of concern is with metal mining as was the case for North-western Zambia where the study was conducted, hence, explaining why the concentration of trace metals as cobalt was high across almost all access points.

Whilst turbidity levels in the groundwater samples were generally within the acceptable maximum prescribed by WHO, the study noted that the water was typically not ideal for human consumption under ideal circumstances because most sampled points (81%) were high and, even on average. The turbidity levels were above ideal standard for groundwater. The study showed that most of the complaints on the physical quality of water were revolving around turbidity. The T-test statistics confirmed a statistically significant and higher turbidity levels compared to the ideal standard prescribed by WHO ($p=0.003$). Regarding turbidity, the study notes that it is possible for water to be within acceptable prescribed limits in terms of chemistry, yet without being ideal for human consumption due to overshoots for selected parameters. Muchanga (2020), Muchanga & Sichingabula (2022) and FAO (2013) earlier noted that chlorine-resistant pathogens such as *Cryptosporidium* are likely to be present in turbid water thereby threatening human health. The study found that groundwater around upper part of Kalumbila Mining Area was acceptable for human consumption, but not necessarily ideal for selected parameters, especially Cobalt.

CONCLUSION

The study concluded that, the chemical concentrations of all measured parameters were generally highly variable from one point to the other. The parameters were within the MPLs, but not homogeneous across the space. Although most heavy metals such as copper and iron were within permissible limits, cobalt was high and, this needs immediate attention in order to curtail potential health challenges. While chemical concentrations were all within permissible limits, the turbidity trends across the sampled areas showed that it was above the ideal standard for human consumption as prescribed by the WHO. The t-test statistics confirmed a significantly higher measured mean turbidity (1.3 NTU) compared to the WHO ideal mean standard of less than 1 NTU, which was high. When integral measures are

applied, mining firms are poised to operate within the common framework of social harmony. As much as mining environments are so destructive to all environmental components such as groundwater, the study concluded that seasonality, place or location relative to the mining sites as well as topographic conditions could potentially moderate the negative effects as also noted by the study where most chemical parameters were within safe ranges probably due to being located on the upper side of the mine site such that, the pressure gradient of the effluents were in the opposite direction than in the direction where boreholes were located.

REFERENCES

- Asthana, D. K., and Asthana, W. (2001). Environmental: Problems and Solutions. Second. Revised Edition. S Chand and Company Ltd, New Delhi: ISBN:18 – 219.
- Baumle, R., Neukum, C., Nkhoma, J., and Silembo, O. (2007). The groundwater resources Southern Province, Zambia. Ministry of Energy and Water Development – Department of Water Affairs and federal and Federal Institute Geosciences and Natural Sciences; Phase 1 Technical Report, Vol. 1: Lusaka, MWDS.
- British Geological Society, (2001). Engineering Geological Society mapping. J. Griffiths publication, London.
- Byers, A. B. (2001). Conserving the Miombo Ecoregion, Reconnaissance Summary office, p.24, Harare.
- Cheng, H., Hu, Y., Luo, J., Xu, B., Zhao, J., 2009. Geochemical processes controlling fate and transport of arsenic in acid mine drainage (AMD) and natural systems. *J. Hazard Mater.* 165: 13 – 26. [Httpps://doi.org/10.1016/j.jhazmat.2008.10.070](https://doi.org/10.1016/j.jhazmat.2008.10.070).
- Creswell, J. W., Clark, V. L. P., (2011). Designing and Conducting Mixed Methods Research, 2nd ed. Thousand Oaks: Sage.
- Das, M. M., and Saikia, M. D. (2009). Hydrology. New Delhi: PHI Learning Private Limited.
- Davis, D. W., Hirdes, W., Schaltegger, U., and Nunoo, E. A. (1994). U-Pb age constraints on deposition and provenance of Birimian and gold-bearing Tarkwaian sediments in Ghana, West Africa, *Precambrian Research* 67: 89 – 107.
- Environment Africa (2021). Impact of Mining on Ecological Rights of Youth and Children in Solwezi District. Technical Report. 1. Environment Africa, Kabwe.

- Environmental Protection Agency (2000). Environmental Issues, The New York Times, New York.
- FAO (2013). Food Security Indicators. Development Economics Division (ESA) of FAO publication, Rome.
- Fanshawe, D. B., 2010. Vegetation Descriptions of the Upper Districts of Zambia. Biodiversity Foundation of Africa, Famera, Bulawayo, Zimbabwe.
- Farjana, S. H., Huda, N., Mahmud, M. A., Saidur, R. (2019). A review on the impact of mining and mineral processing industries through life cycle assessment. *Journal of cleaner production*, p. 1200 – 1217, Elsevier.
- Foteinis, S. (2021). Environmental Impacts. Research Centre for Carbon solutions. School of Engineering, University of Edinburgh.
- Godfrey, M. P., 1982. Collection and Evaluation of information on soil fertility and structure in high rainfall areas of Zambia. AGG 400 report. School of Agricultural Sciences, University of Zambia, Lusaka. 23 ppr.
- GRZ (2016). Monitoring and Evaluation in the Health sector in Zambia. Ministry of Health, Lusaka.
- ICCIDD. 2012. Zambia zeroes in on IDD elimination. IDD Newsletter, International Council for Control of Iodine Deficiency Disorders
https://www.iccid.org/newsletter/idd_aug12_zambia.pdf in May 2015.
- Jhunjhunwala, J. B. (2008). Business Statistics. New Delhi: Chand Publisher.
- Knoblauch, A. M., Farnham, A., Zabre, H. R., Owuor, M., Archer, C., Nduna, K., Chisanga, M., Zulu, L., Musunka, G., Utzinger, J., Divall, M. J., Fink, G., and Winker, M. S. (2020). Community Health Impacts of the Trident Copper mine project in Northwestern Zambia: Results from Repeated Cross-Sectional Surveys. *International Journal of Environmental Research and Public Health*. Doi:10.3390/ijerph 17103633
- Kribek, B., Sracek, O., Mihaljevic, M., Majer, V. (2010). Geochemistry and mineralogy of Cu and Co in mine tailings at the Copperbelt, Zambia. *Journal of African Earth Sciences* 57(1): 14 - 30
- LWSC (2014). A Master Plan for Improving water and sanitation services, Lusaka.
- Magdalena, M. (2015). Global Charity ActionAid, Thomson Reuters Foundation.
- Muchanga, M. (2020). Determination of Sediment, Water quantity and Quality for SWAT Modelling of Sedimentation in the Magoye Reservoir, Southern Zambia. Lusaka: UNZA.

- Muchanga, M., and Sichingabula, H.M. (2022). Spatial and Seasonal Dynamics of Total Suspended Sediment, Total Dissolved Solids and Turbidity of a Lacustrine Reservoir in the Magoye Catchment, Southern Zambia. *European Journal of Environment and Earth Sciences* 2 (6), 43-48.
- NRFA (2021). Strategic Plan – Road Management Initiative, Edition No. 012, NRFA publication, Lusaka.
- Obiri, S. (2007). Determination of heavy metals in boreholes in Dumasi in the Wassa West District of West Region of the Republic of Ghana, Environmental monitoring and assessment 130: 455 – 465
- Saunders, M., Lewis, P. and Thornhill, A (2007). Research Methods for Business Students.
- Smedley PL. 2001. *Groundwater Quality: Zambia*. British Geological Survey.
- SGAB, SWECO, THOMRO & UNZA, 2005: Preparation of Phase 2 of the Consolidated Environmental Management Plan – Project Summary Report. ZCCM Investment Holdings, Copperbelt Environment Project.
- Taunameso, S., Mudau, L. S., Traore, A. N. and Potgieter, N. (2019). Borehole water: A potential risk to rural communities in South Africa. *Water Science & Technology* Water supply 19(1): ws2018030.
- The First Quantum Minerals Limited, (2017) Inside Kalumbila – News, Volume 3.
- UN (2022). SDG Action Zone. United Nations General Assembly, New York.
- UN (2023). Water Conference – Sustainable Development Goals, New York,
- UNEP (2006). Climate Action Disasters and Conflicts. UNEP Publication.
- UNESCO (2022). World Higher Education Conference. The UNESCO Courier issue 2022.
- WHO (2009). Calcium and Magnesium in drinking water, public health significance, Geneva, World Health Organisation
(http://whqlibdoc.who.int/publication/2009/9789241563550_eng.pdf)
- WHO (2020). Guidelines updates on previous recommendations, Geneva, Switzerland.
- Young, G. M., (2001). *Journal of Africa Earth Sciences*, Elsevier, volume 33, Issues 3 – 4, 2001, pages 503 – 528.
- ZamStats (2023). Quality Statistics for Development. Agriculture and Environment. The 2022-Livestock Survey, Lusaka.
- ZMD (2022). Projects and Meteorology. SMART Zambia Institute.