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Groundwater Quality Assessment of the Upper Kalumbila Mining Area in North-Western Zambia

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Mining has been the main economic stay of the country since independence and has triggered negative impacts on the environment and groundwater. It has brought about immerse socioeconomic development, but at the same time released the waste effluents and solid wastes, which threaten the quality of groundwater leading to negative effects on animals, human health and may even cause death. This study assesses the quality of groundwater around Upper Kalumbila mining area in North-western Zambia. This research used mixed methods approach with emphasis on concurrent design. Data for the study 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), which were implemented using Excel Spreadsheet Data Analysis Toolkit (ESDAT). Handheld Global Positioning System (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.

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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 area was moderately safe for human consumption. The study recommends strengthening of community participation and installing filters in the water tanks to mitigate Total Suspended Solids (TSS) and to also carefully monitor heavy metals on a regular basis.

Keywords: Groundwater; kalumbila; mining pollution; turbidity; water quality.

1. BACKGROUND

UNESCO [1] observed that, the world is not on track to achieving Targets 6.1 and 6.2 of Sustainable Development Goal (SDG) 6. 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 [2]. This natural resource has often been mismanaged and even abused especially in areas that are surrounded by industrial activities [3]. There is widening gap in water supply between urban and rural dwellers as governments have not expanded appropriate infrastructure to meet growing demand [4-6]. Many countries are facing challenges in extending services to rural areas where there is 60% safely-managed drinking water services as compared to 86% in urban areas [7]. 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 [8].

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 amidst climate change leading to additional stress [9]. According to UNESCO [10], persistent contamination of rural groundwater supplies with pathogens and pollutants is estimated to affect about 30% of the total installations, which usually affects 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 [11]. Southern Africa in general depends 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 [12]. Taonameso et al. [12] acknowledge that the main challenges to groundwater quality includes, but not limited to industrial and agricultural pollutants, as well as poor hygiene around water points especially for shallow wells. The United Nations Environment Programme (UNEP) [13] 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. [12] 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.

Zambia, like many parts of the world has experienced several challenges regarding managing water resources. Pollution, insufficient information for water managers, limited financing of infrastructure development and, inadequate participation of stakeholders are among challenges faced by local authorities in addressing groundwater resources. In most parts of Zambia, groundwater remains the most important resource for water supply (Lusaka Water and Sewerage Company (LWSC), [14]. For example, LWSC [14] 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 [15,3].

Environment Africa (EA) [16] 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 [17] and the British Geological Society [15] 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 [16]. 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 [18]. 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 that is whether it is in rainy season (Summer) or dry season (Winter). The chemical concentration and mixing will vary, consequently affecting the water quality. The topographical orientation and elevation relative to the mining site also influence the water quality depending where the sampling points are located, lower part or higher part in relation to the mining site.

2. DESCRIPTION OF THE STUDY AREA

The study area is located in the North-western Zambia. The First Quantum Mine (FQM) Trident Limited as a reference point to the study area is located specifically on 12°16'25" South and 25° 22' 47" East [18]. The mine is surrounded by villages namely, Musele, Chitungu in the north, Chisasa, Northern Resettlement Northeast, Kanzanji on the East of the mine, Kankonzhi in the Northwest, and Shinengéne is the south of the mine [19]. The visual impression of the study area location is shown in Fig. 1.

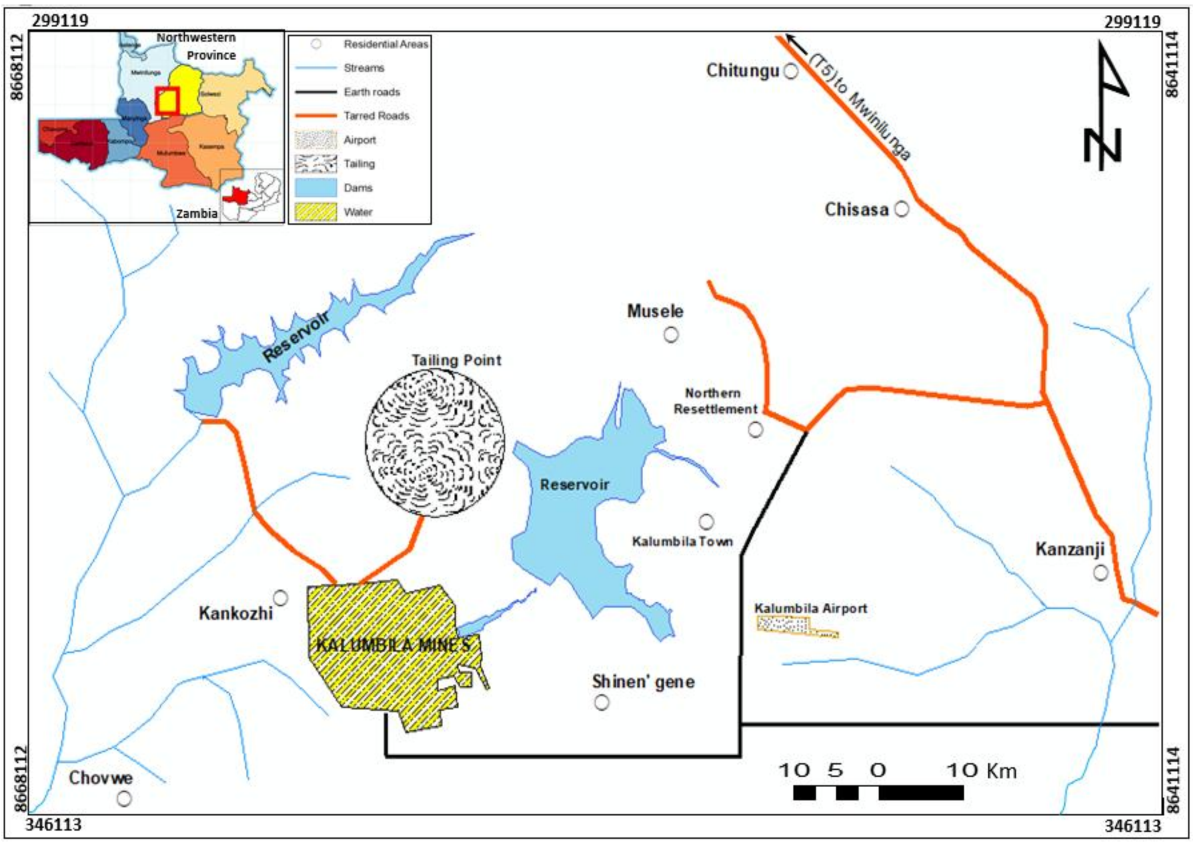

Fig. 1. General location of the study area

The geological structure of the study area is predominantly underlain by the Shale and 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 are severely deformed in the Lufilian Arc, where the basement is exposed in the core of the Kabompo Dome [20]. The study area is made up of largely three distinct soil types Orthic-rudic Ferrasols, Skeletic dystric Leptosols and Acrisols with dystric Leptosols [21]. Due to heavy rains in the area commonly above normal, the soils are heavily leached [22]. Fig. 2a-b shows the geological and soils maps of the study area.

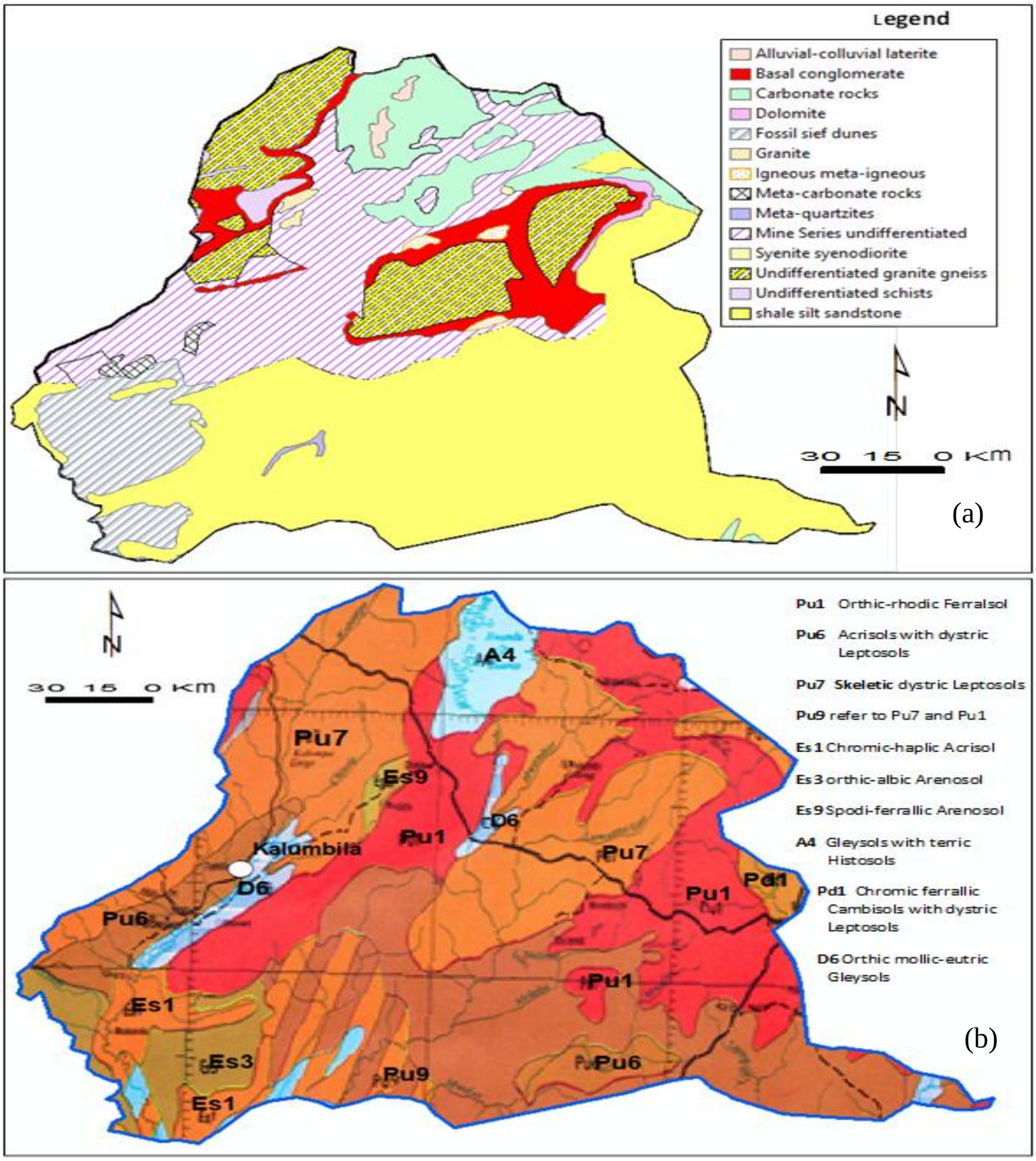

Fig. 2. (a) Map showing geological orientation (b) Soils cover of the study area, Extracted from the Geological Map of Zambia, and Soils Map of Zambia (1990)

The study area is covered mainly by the native vegetation with closed-open broadleaved semi-deciduous forests [23]. It is side by side mixed and interwoven with the open broadleaved deciduous forests. It is endowed with Zambezian *Crytosepalum* dry forests and Central Zambesian Miombo woodlands. The tree species consist generally of Brachystegia longifolia (Fig. 3) [24].

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 [25]. Fig. 4 shows the Digital Elevation Model (DEM), drainage of the entire study area and water sampling points.

The study area experiences at least 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) is generally received during December and January [26].

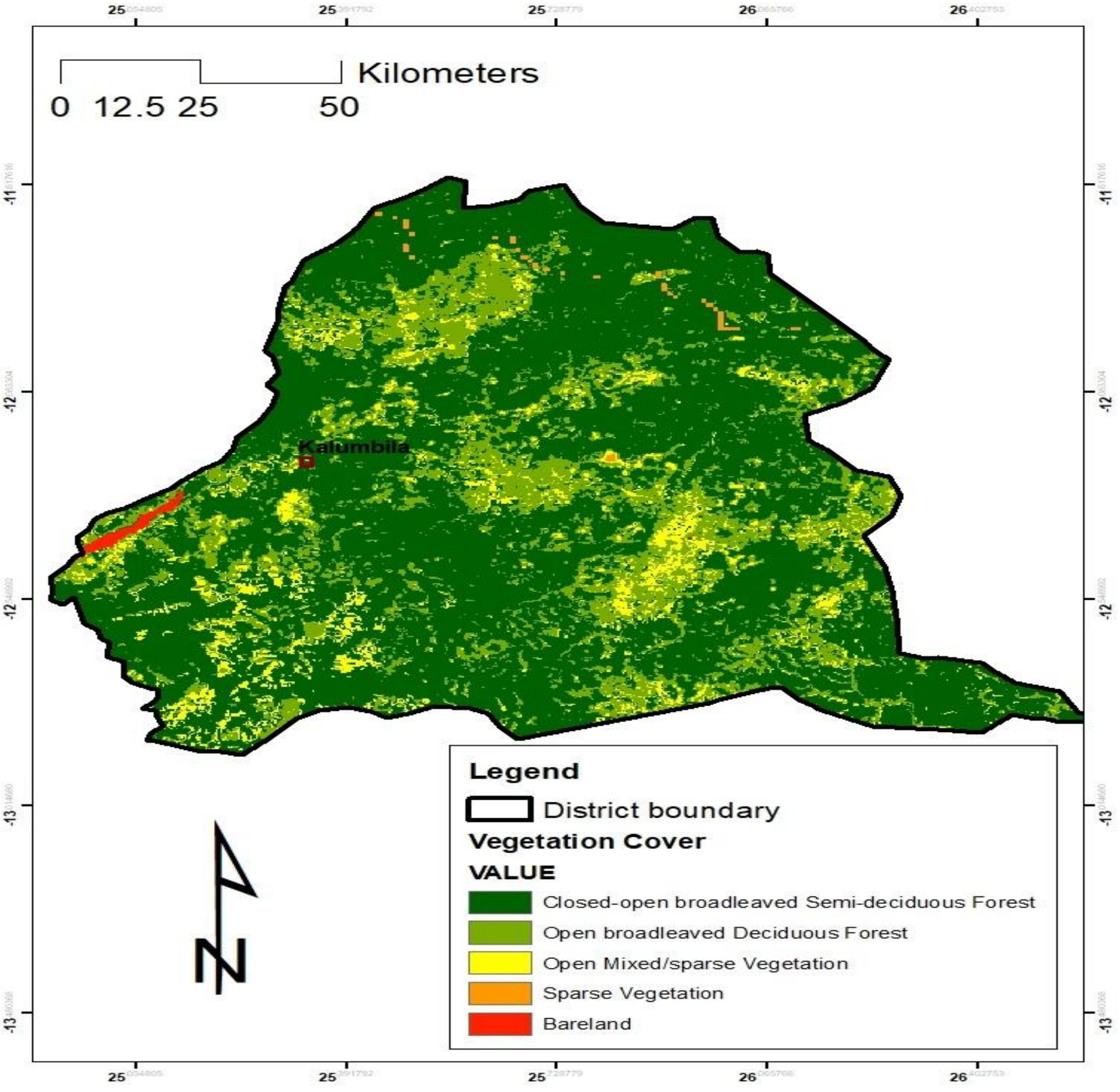

Fig. 3. Vegetation of the study area (Extracted from Vegetation cover Map of Zambia)

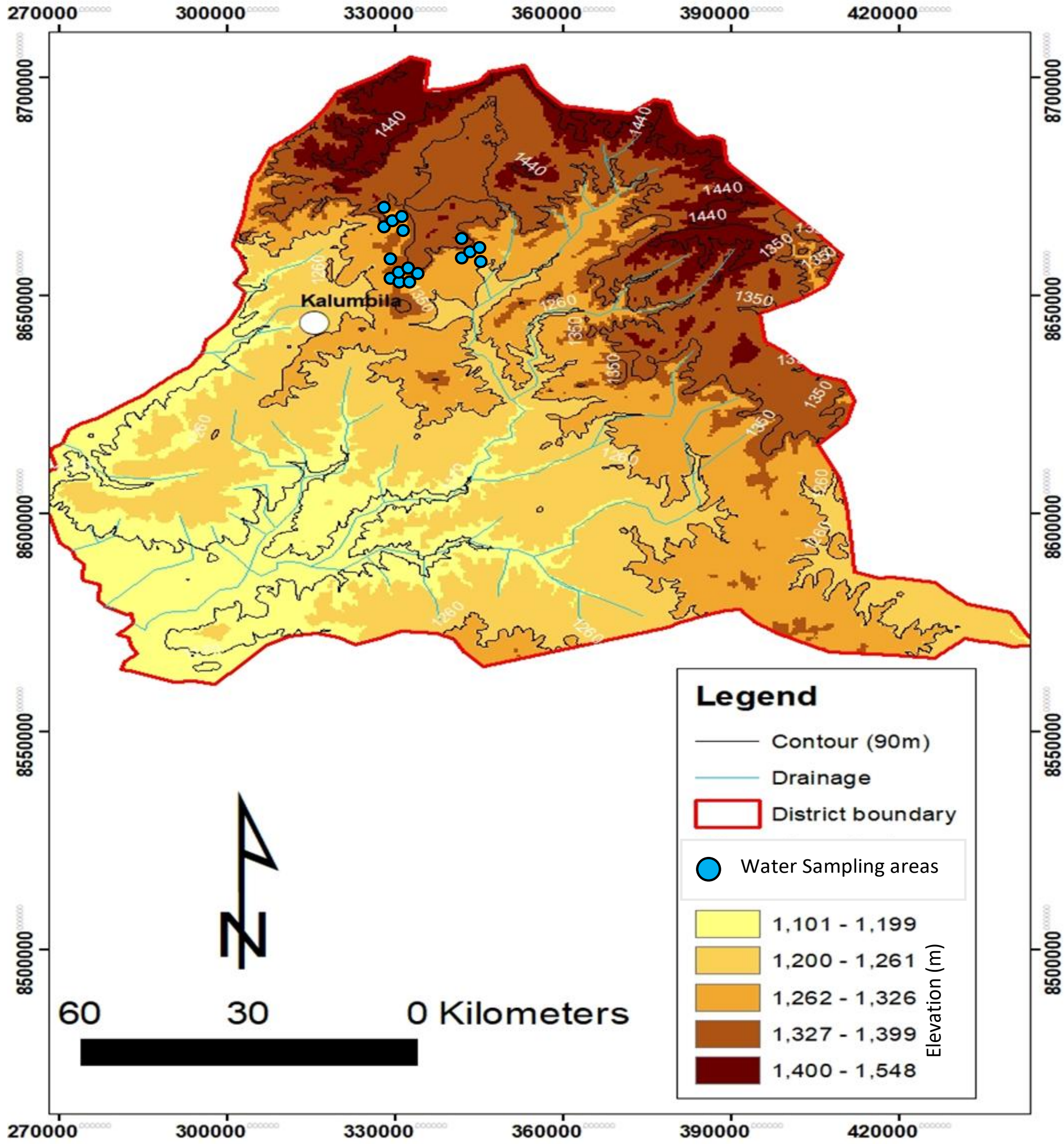

Fig. 4. Digital elevation model and water sampling points

3. 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 [27]. 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. 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 [28]. 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. This basically provided the conceptual lens through which this study could be comprehended [29].

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 [30] criteria, all CVs which were above 5% or 0.05 were classified as widely variant from the WHO standards.

4. RESULTS

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 Fig. 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.

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 (Fig. 5). 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.

4.1 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 (Fig. 6a). Iron was found to be the most geospatially variable, whereas Copper was fairly the most stable compared to other assessed heavy metals.

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)

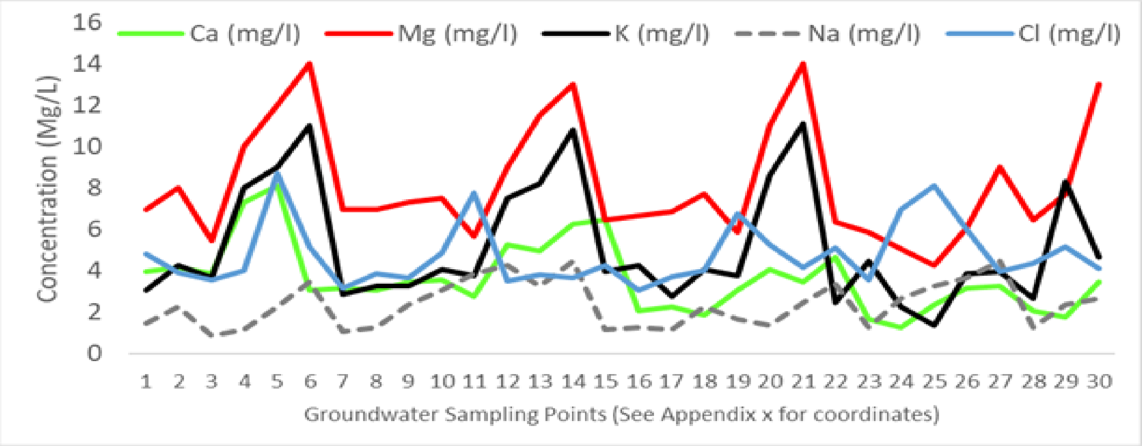

Fig. 5. Chemical concentration dynamics for selected parameters in the groundwater around Kalumbila mining area
Source: Field data (2022)

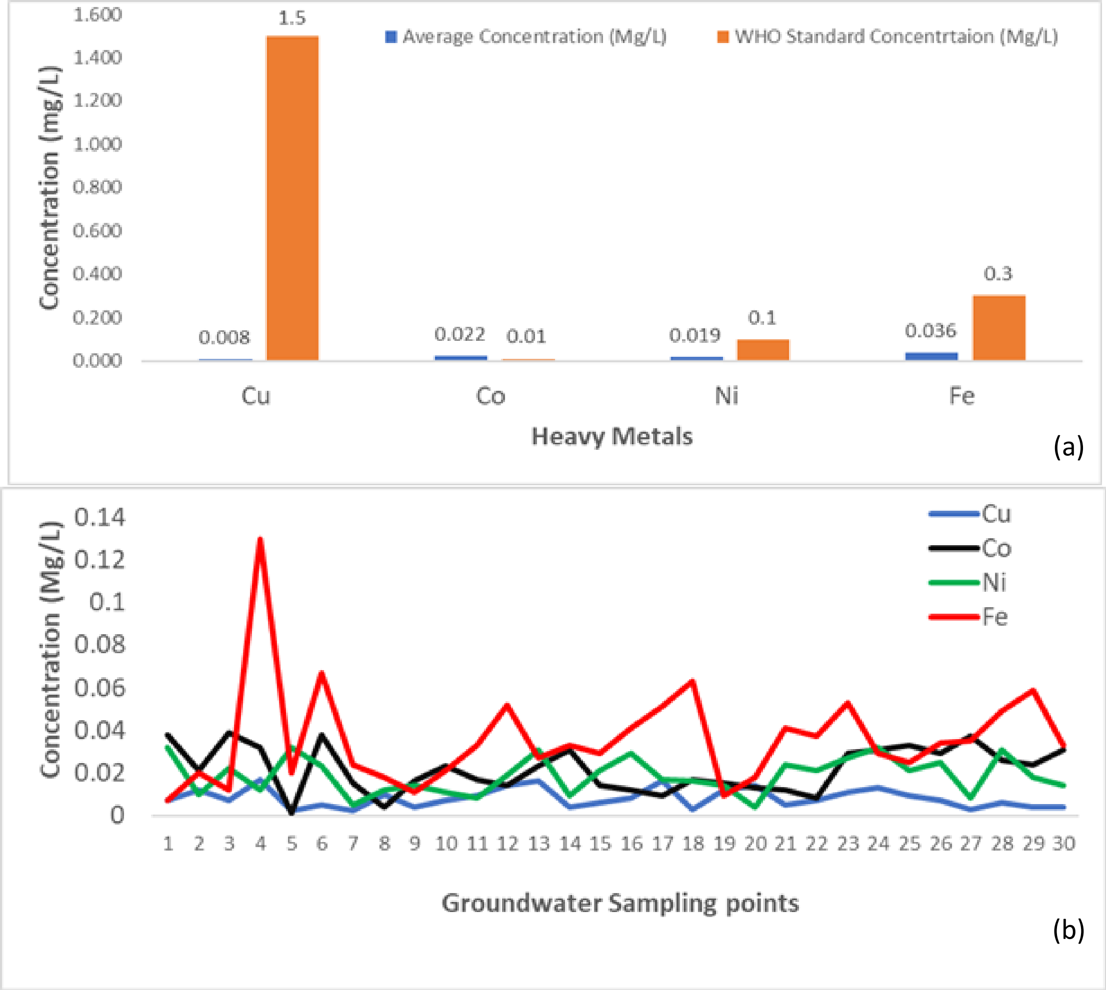

Fig. 6. (a) Concentration of heavy metals compared to their respective MPLs and (b) dynamics of heavy metal concentration in the groundwater around Kalumbila mining area.
Source: Field data (2022)

4.2 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).

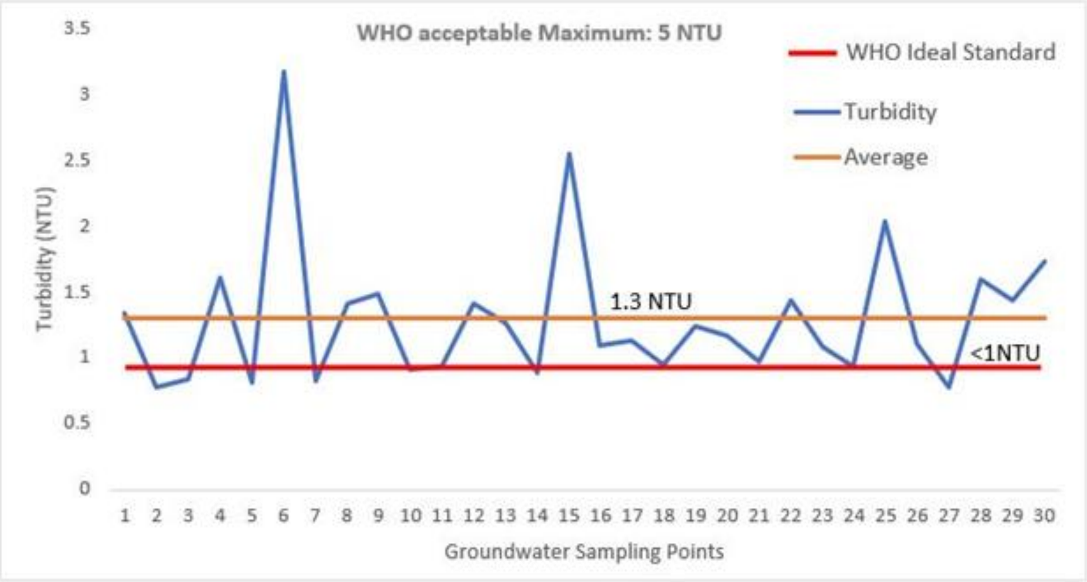

Fig. 7. Geospatial dynamics of Turbidity in groundwater compared to WHO's standards around Kalumbila area

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	
t Stat	3.03	
P(T<=t) one-tail	0.003	
t Critical one-tail	1.70	

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

5. 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 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 [7] 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 levels of heavy metals such as lead, and copper were too high. The average Alkalinity was around 33 mg/l, which probably caused some corrosion in 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. [31] and Obiri [32]. As opposed to an earlier study by Environment Africa (EA) [16] 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 [33] 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 [34]. Such spatially distributed high concentrations of Cobalt raise some public health concerns as EPA [34] states that, acute exposure to high levels of Cobalt by inhalation in humans and animals' results in respiratory problems, such as a significant decrease in ventilatory function, congestion, and haemorrhaging lungs. An earlier study by ICCIDD [35] confirmed high incidences of goitre rates more than 50% suggesting lack of iodine in groundwater in these areas. Another study by Farjana [36] 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) [17,15,37]. 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 such as Cobalt were 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 normal 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 [38], Muchanga & Sichingabula [39] and FAO [40] 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 [41,42].

6. 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. The study further concluded that, as much as mining environments are so destructive to all environmental components such as groundwater, it may not always be the case in all geographical areas given that seasonality, place or location relative to the mining sites as well as topographic conditions could potentially moderate the negative effects as also noted in this 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 the sampled boreholes were located.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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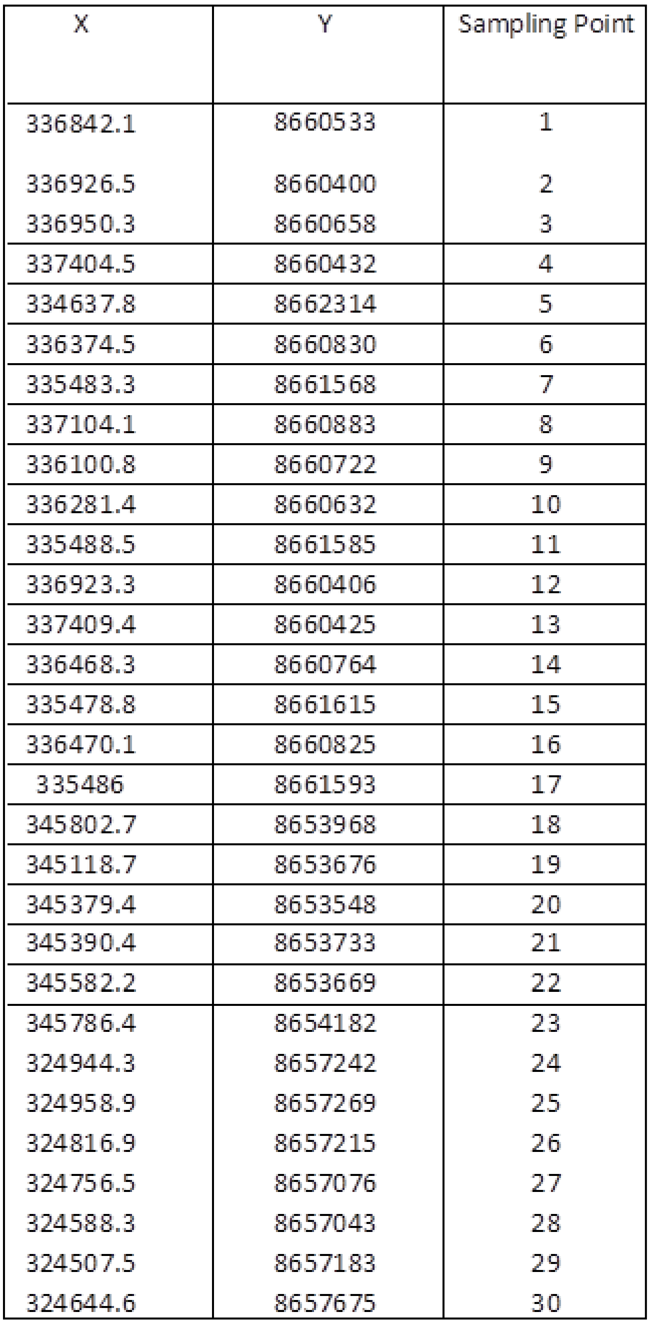
APPENDIX X. Coordinates of water access points – Upper Kalumbila mining area



X	Y	Sampling Point
336842.1	8660533	1
336926.5	8660400	2
336950.3	8660658	3
337404.5	8660432	4
334637.8	8662314	5
336374.5	8660830	6
335483.3	8661568	7
337104.1	8660883	8
336100.8	8660722	9
336281.4	8660632	10
335488.5	8661585	11
336923.3	8660406	12
337409.4	8660425	13
336468.3	8660764	14
335478.8	8661615	15
336470.1	8660825	16
335486	8661593	17
345802.7	8653968	18
345118.7	8653676	19
345379.4	8653548	20
345390.4	8653733	21
345582.2	8653669	22
345786.4	8654182	23
324944.3	8657242	24
324958.9	8657269	25
324816.9	8657215	26
324756.5	8657076	27
324588.3	8657043	28
324507.5	8657183	29
324644.6	8657675	30

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