Effects of tailings disposal on the environment: A case study of Nampundwe Mine

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Abstract

Globally, the demand for mineral products is ever increasing. Extraction of these mineral resources results in the continuous production of a huge volume of waste material, including tailing dumps. The mass of tailings usually exceeds the actual resource and often contains hazardous contaminants. This study investigated the effects of tailings disposal on soil, water, and air quality in the Nampundwe area. Water, soil, and dust samples were collected from different locations in the surrounding communities. The constituents analysed in the samples included copper, cobalt, iron, sulfate, and silica. According to the results obtained, some seepages occurred from the tailings impoundment to the shallow aquifer in the area. However, the general water quality meets the Zambia Environmental Management Agency (ZEMA) statutory limits. Recorded concentrations of sulfate (1500 mg/l), copper (1.5 mg/l), cobalt (1.0 mg/l), iron (2.0 mg/l), and silica were between 0.003 mg/l and 705 mg/l, which is far below ZEMA's statutory limit. Silica concentration was also evident in the air. The highest concentration recorded was 260 ppcc (particle per cubic centimeter) recorded in July 2019 from the northern direction of the tailings dam. The concentration was below the statutory limit of 350 ppcc. The topsoil from the northern part of the tailings recorded a silica dust concentration of 39.9 ppcc. Iron was evident in the underground soil with a concentration of 8.01 ppcc, cobalt 0.005 ppcc, copper 0.051 ppcc, while sulfate was recorded as 0.41 ppcc.

Keywords

environment, tailings, seepage, disposal, pollution, contaminant

Introduction

To achieve rapid economic growth, the world has resorted to activities such as mining, which leads to the exploitation of natural resources. As we may all be aware, mining is an important economic activity that has the potential to contribute to the development of many countries. In Zambia, the mining sector plays a vital role in the development of the economy. It accounts for 12 percent of the GDP. Over the past 50 years, Zambia has been successful in attracting investors into its mining sector. Despite the benefits from mining activities, mining activities in Zambia have an enormous environmental impact (Muma et al, 2020). This has emanated from mining and processing activities by the mining companies as well as the disposal of mine waste, especially tailings in the environment. This has long-term effects on the natural environment as well as the people in the surrounding communities (Besa et al., 2019). According to Awudi, 2000, despite these positive indicators, the role of the mining industry in the economic development of any country is questionable. The gains from the sector in the form of increased investment are being achieved at a great cost to the environment, health, and social wellbeing of the people in the surrounding communities, recording a series of public complaints against the mining companies operating in Zambia. According to Hudson, 2012, the major environmental problems arising from mining activities are land degradation, soil contamination, air pollution, surface, and groundwater pollution.

Overview of mining activities at Nampundwe Mine

This study was conducted at the Nampundwe mine area in the Central Province of Zambia. The Nampundwe mine is the most southerly of the Konkola Copper Mines (KCM) operations. It is located 48 km to the west of Lusaka (Figure 1). Mine-associated infrastructure occupies an area of approximately 9 ha, while the mining license area covers 950 ha. Nampundwe area was once a forest and agricultural area before mining activities commenced. It is surrounded by communities that consist of approximately four hundred (400) households with roughly eight (8) people per household. Kacheta stream is the main surface water in the area and flows through the mine area, which is the main source of water to the community. The Nampundwe mine township is 2.5 km to the southwest of the mine. The area has a population of about 3500 people.

Figure 1—Location of Nampundwe mine in the Central Province of Zambia

The Nampundwe mine operates an underground pyrite mine and concentrator. The pyrite from the Nampundwe mine is typically used as a blending material with copper concentrate for smelting. The ore from underground is hoisted directly onto the concentrator shaft bin for primary crushing before it is conveyed through the 120-tonnes/hour belt for secondary crushing. The mining method employed at the Nampundwe mine is conventional sublevel open stoping.

Materials and methods

Conceptual framework

The conceptual framework (Figure 2) used for the study illustrates the environmental and health impacts of mine tailings disposal on the environment. It shows the impact of mine tailings disposal on the environment and the health of people, according to the available literature.

Tailings production and disposal at Nampundwe Mine

According to Ritcey (2005), tailings are the major mine solid waste produced in the process of mineral beneficiation. With the development and utilization of mineral resources, the production and disposal of tailings have become an important factor in the sustainable development of the mining industry and endangering mining and the surrounding area's ecological environment. Tailings are a waste product that has no financial gain to a mineral operator at that point in time. Not surprisingly, it is usually stored in the most cost-effective way possible to meet regulations and site-specific factors. They often consist of chemicals from processing plants as well as fine particles suspended in water. These have the potential to damage the environment by releasing toxic metals into the environment through erosion and surface runoff from the tailings into nearby water bodies (Blight, 1998).

In the past, when mines just started to operate in Zambia around the 1930s, river dumping was the most convenient way of disposing of tailings. This disposal system led to widespread environmental impacts in mining areas. This was nominally acceptable in earlier eras, but human production of mine tailings has increased by several orders of magnitude in the modern age, making such methods unacceptable to many societies (Blight,

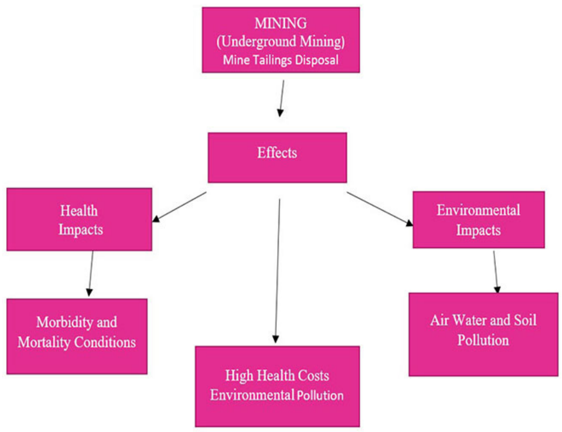


Figure 2—Conceptual framework illustrating mine tailings disposal, environmental, and health impacts

1998). At Nampundwe mine, the tailings are pumped as slurry to the tailings dam situated 700 metres to the south of the plant. The slurry is discharged from a spigot that is moved around the perimeter of the facility and the walls are raised using the tailings.

Disposal of tailings

According to Vick, (1983), the disposal of tailings is commonly identified as the single most important source of environmental damage by any mining operations. This is not surprising when considering that the volume of tailings requiring storage can often exceed the in-situ total volume of the ore being mined and processed. Over the last century, the volumes of tailings being generated at Nampundwe mine have increased dramatically as the demand for minerals and metals has enlarged. Nampundwe mine tailings are frequently stored in tailings dams, also known as tailings storage facilities, indicated in Figure 3.

Dust minimization

Prevention and control of surface runoff from the plant area to the surrounding environment and minimizing dust generation are important considerations for the receiving environment illustrated at Nampundwe mine in Figure 4.

Figure 3—The tailings dam storage facility at Nampundwe mine

Figure 4—Trees planted around the tailings dam for dust minimization

Sampling

The study involved the collection of water, air, and soil samples from various points of the study area following the specific objectives. Soil, water, and air samples were collected randomly (to eliminate systematic bias and for equal opportunity of being chosen as a part of the sampling process) over time from the direction of the prevailing up-winds at the time of sampling, as there were more particles blown due to the wind direction. The Toxicity Characteristic Leaching Procedure (TCLP) was used to determine the elements that were present in the samples collected.

Water sampling

Twenty (20) water samples were collected randomly (to eliminate systematic bias and for equal opportunity of being chosen as a part of the sampling process) from Nampundwe township, Kacheta stream, village boreholes, village wells, monitoring boreholes near the tailings dam, and the tailings dam overflow. Figure 5 indicates the location of water sampling points in the Nampundwe area. All samples were collected and stored in 750ml sampling bottles before testing and analysis.

Water samples were collected from the upper, middle, and lower streams of the Kacheta stream (Figure 6). The upper stream provides the level of concentration before the stream passes through the mine area while the samples from the middle and lower stream will provide the level of concentration from the mine and after the mine respectively.

There are four (4) monitoring boreholes around the tailings dam, which are used by the company to monitor the level of contamination from the tailings dam. The water quality monitoring data collected indicated that the pH level was between 7 and 8, sulfate presented an average of 445–505 mg/l, iron 0.8, and other dissolved metals were present at low concentrations. Water samples were also collected from the monitoring boreholes around the Nampundwe mine (Figure 7).

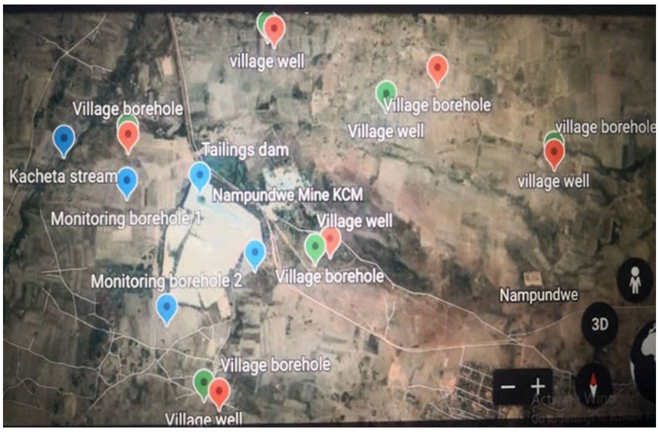


Figure 5—Satellite map indicating the water sampling locations

Figure 6—Sampling points from the Kacheta stream

Figure 7—Water sample being collected from one of the monitoring boreholes

Water sampling from tailings dam overflow

Figure 8 shows the over-flow water from the tailings dam at Nampundwe mine. The overflow water is released into the Kacheta stream through the toe drain. There are filter drains installed in the dam walls, which also flow to the decant drain. One (1) water sample was collected from the tailings dam overflow/decant drain to determine the quality of water discharged into the water system from the tailings dam. The water quality monitoring data collected indicated that the pH level was between 7 and 8, sulfate exhibited an average of 1011 mg/l, iron 0.1, and other dissolved metals were present at low concentrations.

Figure 8—The decant or the overflow from the mine tailings storage at Nampundwe mine

Soil sampling

Twenty-one (21) soil samples were collected from different locations according to the direction of the prevailing up-winds in August 2019 during the dry season. The soil was sampled from Shanide village, ranging between 0.5 km and1.5 km from the mine, Shamoonga village, which is situated between 1.5 km to 3 km from the mine, Sichobo village ranging between 0.5 km and 1.5 km from the mine, and Shakemba village being situated 1.5 km to 3 km away from the mine area. Other soil samples were collected during the rainy season in December 2019 from Shakainge village, which is situated 0.5 km to 1.5 km away from the mine, Northern Mwanachindalo, situated 1.5 km to 3 km away, and Nampundwe township, approximately 1.5 km to 3 km away from the mine. Kombo and Tromp (2006) state that random sampling is a part of the sampling technique in which each sample has an equal probability of being chosen. A sample chosen randomly is meant to be an unbiased representation of the total population. Soil samples were collected from the depth of 30 cm (topsoil), 60 cm (middle soil), and 90 cm (ground soil), culminating in a total depth of 90 cm. The samples were collected by using a standard auger and were stored in sample bags. The sample bags were tied using a string to avoid cross-contamination and were labeled according to the sampling points, whereafter the samples were taken to the lab for testing. Figure 9 shows a satellite map demonstrating the soil sampling locations. The mine commenced operations in 1913 and, at the time, was known as the King Edward mine. At that stage there was no pollution, hence no background data was obtained for soil contamination.

Air sampling

The dust samples were collected from the northern, southern, eastern, and western parts of the tailings dam. The samples were collected using dust samplers from January 2019 to December 2019. This was done to determine the amount of silica dust from the tailings that were present in the air.

Data analysis

Water and soil samples were analysed by means of the Atomic Absorption Spectrometer (AAS) at the University of Zambia, School of Mines Geo-Chemical Analytical Laboratory (Figure 10). The AAS is a tool that was used to analyse the metal concentration in the samples. The elements that were analysed included cobalt (Co), copper (Cu), iron (Fe), silica, and sulfur (S). Air samples were collected over a period of one (1) year to obtain representative samples from all three (3) main seasons of the year (cold, hot, and rain). Air samples were also analysed at the University of Zambia, School of Mines Geo-Chemical Analytical Laboratory.

Results and discussions

The results from the study indicate that the soil, water and air samples obtained from the study area indicated the presence of sulfate, copper, cobalt, iron and silica, of which the recorded concentrations were below the ZEMA's statutory limit, being: Sulfate (1500 mg/l), copper (1.5 mg/l), cobalt (1.0 mg/l), and iron (2.0 mg/l). The statutory limits exist to determine whether the elements tested exceed the allowable standard or limit for polluting. The results from the study indicate that all element concentrations were below the statutory limits, except for iron, which recorded higher concentrations in the water, i.e. between 4.05 mg/l and 5.18 mg/l in some areas. However, background levels of iron in the water of the area were between 0.3 mg/l and 1.9 mg/l. Hence, it is worth noting that the higher concentration of iron in the samples tested and analysed should not only be attributed to the mining activities, but also as a naturally occurring element most likely to be present in all the soil, as it is an essential element for plant growth.

Water sampling results

It was observed that there were significant differences in the concentrations of elements contained in the water according to the

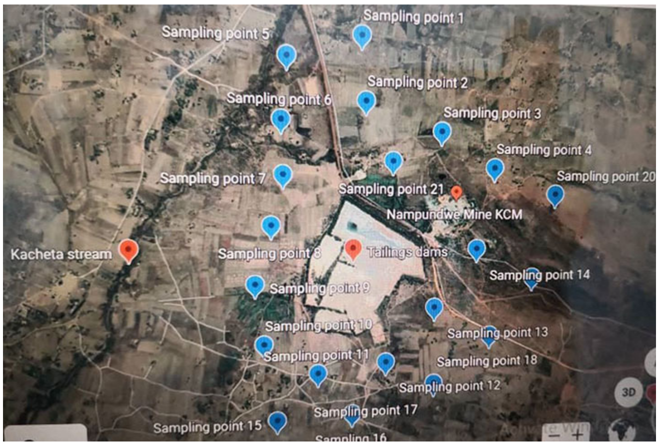


Figure 9—Satellite map showing the soil sampling locations

Figure 10—Sample analysis

sampling points. All the water samples tested and analysed were compared to the Zambia Environmental Management Agency (ZEMA) statutory limits as indicated in Table I. This was done to give a clear picture of how the actual findings compare with the ZEMA statutory limits. ZEMA ensures that mining companies undertake their operations in line with the laws. The agency monitors the element concentration within the Nampundwe area from time to time. Table I, includes the information for the ZEMA statutory limits.

According to water sampling results (Figure 11), it is evident that all element concentration levels from all the samples tested and analysed were below the ZEMA statutory limits. However, iron was recorded at 4.38 mg/l in the middle of the Kacheta stream. The iron concentration exceeded the statutory limit of 2.0 mg/l. The pH level ranged between 5.5 to 6.8, whilst the TDS levels were between 1300 mg/l to 1500 mg/l. The water quality monitoring data collected indicated that the pH level was between 7 and 8, Sulfate exhibited an average of 445-505 mg/l, whilst other dissolved metals were present in low concentrations.

It is also evident from the results of water sampling from the village boreholes (Figure 12) that the concentration of all elements in the water obtained from all the village boreholes was below the ZEMA statutory limits. Furthermore, the depth of the boreholes was in the range of 30 metres to 90 metres, where the land had a slight slope and the distance ranged between 0.5 km to 3 km far from the tailings storage facility (TSF) respectively.

In addition, it was found out that all element concentrations recorded from all the village wells sampled, were below the ZEMA statutory limits (Figure 13). However, iron exhibited a higher concentration of 5.18 mg/l, which was in excess of the ZEMA statutory limit of 2.0 mg/l. The higher concentration was also attributed to the natural formation of iron within the Nampundwe area, and the depth of the wells being in a range of 10 metres to 25 metres, where the land has a slight slope and the distance is 0.5 km to 3 km far from the tailings storage facility (TSF) respectively.

All element concentrations recorded from the township boreholes (Figure 14) were also below the ZEMA statutory limit and the depth of the boreholes were in a range of 30 metres to 90 metres, where the land has a slight slope. There the distance was 0.5 km to 3 km far from the tailings storage facility (TSF), respectively.

Additional findings indicated that the concentration of all the elements recorded (Figure 15) was below the ZEMA statutory limits, except for iron, which recorded 4.05 mg/l from the sampling borehole 1. The concentration recorded was higher than the ZEMA statutory limit of 2.0 mg/l, but it was also attributed to the naturally

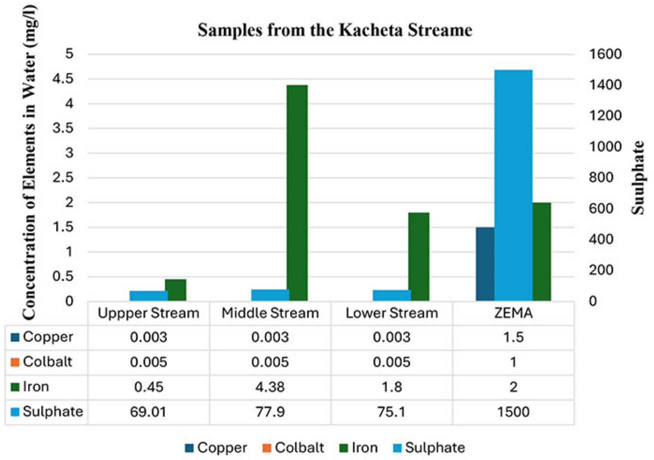


Figure 11—Concentration of elements from the Kacheta stream

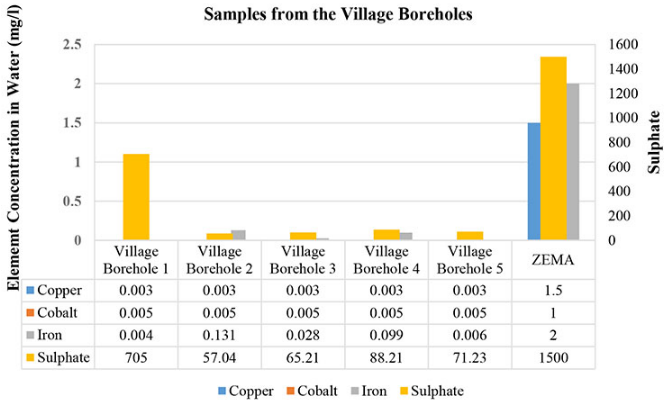


Figure 12—Concentration of elements from the village boreholes

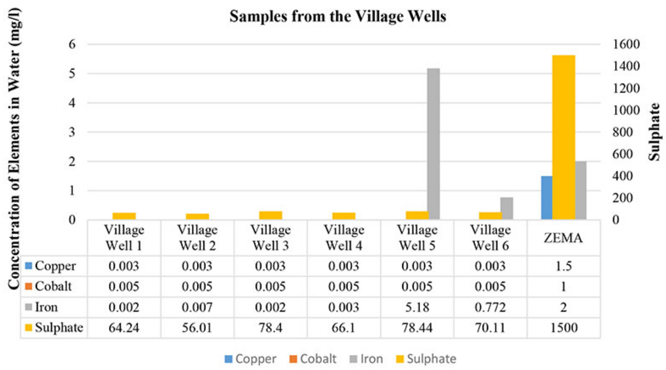


Figure 13—Concentration of elements from the village wells

Table I

Zambia Environmental Management Agency (ZEMA) and Zambia Bureau of Standards (ZABS) statutory limits

Analytes	pH	Electrical Conductivity (µS/cm)	Copper (mg/l)	Iron (mg/l)	Manganese (mg/l)	Cobalt (mg/l)	Cal-cium (mg/l)	Magnesium (mg/l)	Sulfates (mg/l)	TDS (mg/l)	TSS (mg/l)
ZABS Max Limits	6.5–8.0	1500	1.0	0.3	0.1	0.5	200	150	400	1000	100
ZEMA Statutory Limits	6.0–9.0	4300	1.5	2.0	1.0	1.0	100	500	1500	3000	100

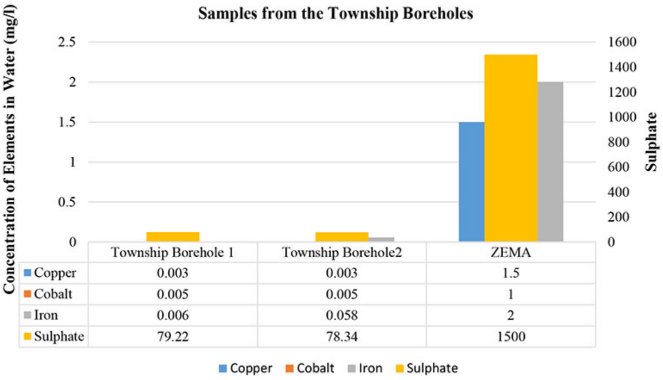


Figure 14—Concentration of elements from the township boreholes

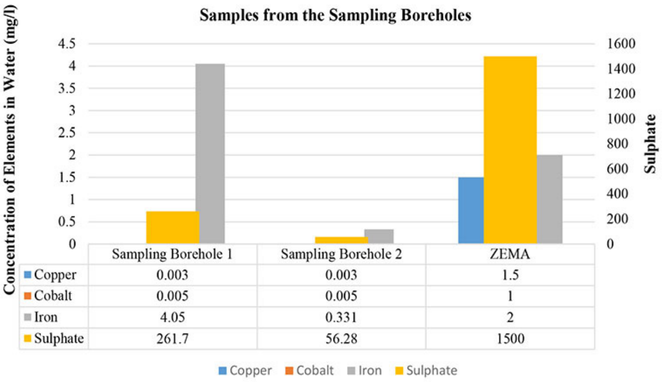


Figure 15—Concentration of elements from the sampling boreholes

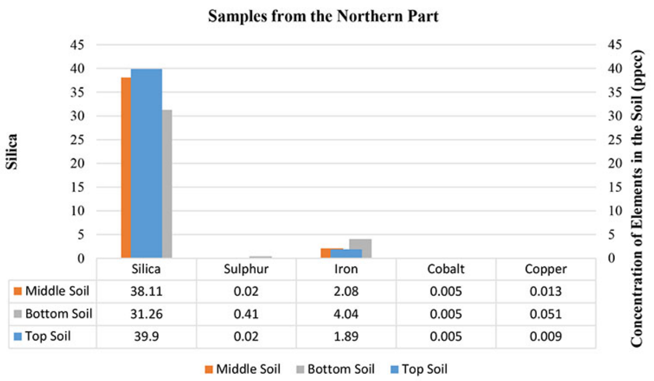


Figure 16—Concentration of elements in the soil from the northern part

occurring element present in the Nampundwe area. The depth of the boreholes was in a range of 30 metres to 90 metres, where the land has a slight slope. There are monitoring boreholes around the tailings storage facility (TSF) to monitor the amount of element concentration that could be present within a distance of 0.5 km to1.5 km far from the TSF, respectively.

Soil sampling results

Sampling results revealed that the soils in the Nampundwe area exhibited the presence of Sulfur, iron, and silica. In relation to Figure 16, silica represented the highest concentration as compared to other metals because the wind was blowing in the northern direction of the tailings at the time of sampling. In addition, the particles were being moved in a northern direction by the running water resulting from the rains. All the levels of soil from the northern part of the tailings recorded the presence of silica, Sulfur, and iron as shown in Figure 16.

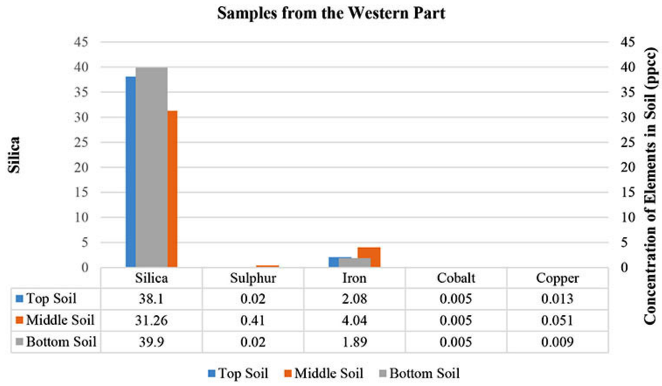


Figure 17—Concentration of elements in the soil from the western part

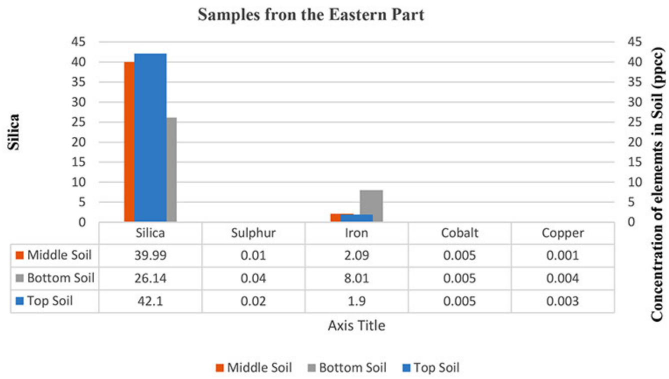


Figure 18—Concentration of elements in the soil from the eastern part

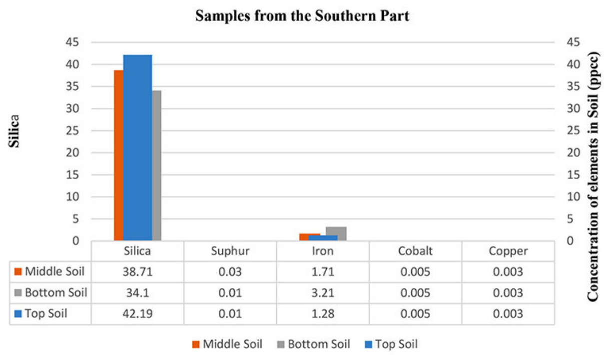


Figure 19—Concentration of elements in the soil from the southern part

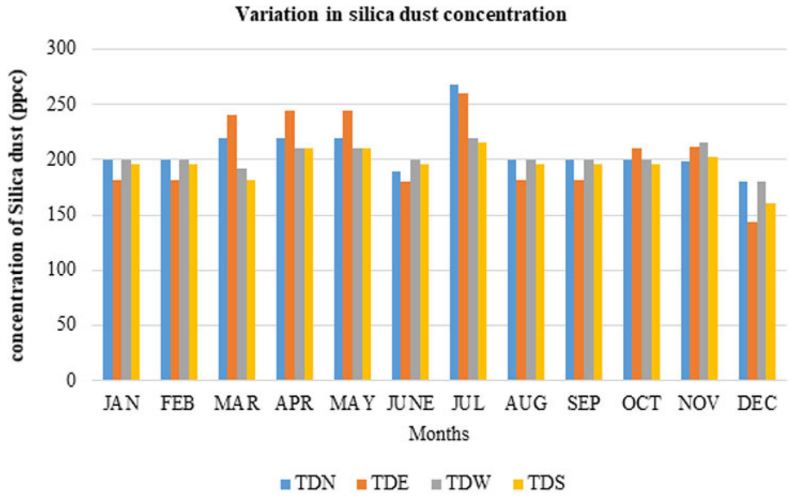
In the western part of the tailings, results in Figure 17 show that silica and iron were present in all the levels of soil.

The eastern part of the tailings also recorded the presence of iron and silica (Figure 18) in all the levels of the soil.

The southern part of the tailings recorded concentrations of silica and iron in all the levels of the soil as can be seen in Figure 19.

Air pollution

According to the results (Figure 20) the concentration of silica dust was recorded in July 2019 with 260 ppcc as the highest recording in the northern direction of the tailings. This was the direction of the prevailing up-winds at the time of air sampling and was closer to the tailings compared to the eastern, western, and southern directions. During this period, it is usually dry and windy, and this results in high emissions of silica dust. The highest recorded concentration of 260 ppcc did not however, exceed the statutory acceptable standard of 350 ppcc. From the dust sampling results recorded during the month of December, it can be seen that concentration decreased to



TDN – Tailings Dam North, TDE – Tailings Dam East, TDW – Tailings Dam West, TDS – Tailings Dam South

Figure 20—Variation in silica dust concentration at different directions for the year 2019

180 ppcc in the northern direction. During this period there was very little silica dust concentration as it was during the wet season of the year.

Conclusion

In as much as we acknowledge the economic benefits of mining activities in Zambia, there is a need to recognize the environmental impacts that are associated with it to find ways to mitigate and manage them. After an investigation into the problem as it pertains to the Nampundwe mine and the surrounding community, it has come to light that, despite the mining activities, the general water, soil, and air quality meets the statutory limit requirements. Kacheta, which is the major stream in the area, recorded concentrations of all the tested elements. It was observed that all the elements, except for iron, which was recorded at 4.38 mg/l in the middle stream (situated adjacent to the tailings dam), were below the statutory limit. This concentration of iron exceeded the statutory limit of 2.0 mg/l. Results from the village wells indicated a low concentration of the elements, except at village well 5, which recorded the highest iron concentration i.e., 5.18 mg/l. The concentration of iron at village well 5 exceeded the ZEMA statutory limit of 2.0 mg/l. All elements from the township boreholes showed low concentrations that were below the ZEMA statutory limit. As mentioned earlier, it is worth noting that the higher concentration of iron in the samples tested and analysed may not only be attributed to the mining activities, but also as a naturally occurring element most likely to be present in all the soil as it is an essential element for plant growth. Soil sampling results revealed that there was a presence of Sulfur, iron, and silica in the Nampundwe area. Furthermore, it was observed that the concentration of iron, silica, and Sulfur had no major effect on the soils in the Nampundwe area. According to the results, the concentration of dust was recorded as being higher in July 2019 with 260 ppcc in the northern direction. However, the recorded concentration of 260 ppcc did not exceed the statutory acceptable standard of 350 ppcc. The dust sampling results recorded during the month of December, revealed that the concentration decreased to 180 ppcc in the northern direction as this was during the wet season of the year.

Furthermore, in the event where the element concentration exceeded the statutory limit, Nampundwe mine sought to institute certain measures to curtail and mitigate the environmental, health, and other effects on people. Measures that have been put in place include reforestation of degraded lands, reviewing the operation methods, establishment of a health facility within the area for the benefit of both workers and residents within the communities, and the institution of health education programmes for the benefit of the people. Furthermore, the mine is working hand in hand with the ZEMA, which ensures that mining companies undertake their operations in line with the laws. The agency monitors the element concentration within the area from time to time.

Recommendations

(i) Stringent and rigorous efforts to bring about reforestation and other measures aimed at restoring degraded lands to their original state after mining activities, should be intensified by the company. The land would be available especially to farmers for cultivation purposes. Also, employment opportunities will receive a significant boost to reduce the high rate of unemployment in the region.

(ii) Nampundwe mine should provide alternative sources of potable drinking water, such as from boreholes. However, in support of this exercise, there should be intensive education of the people in the surrounding areas to comprehend the need for them to utilize the potable water rather than the poor-quality surface water sources.

Water from Several dug wells are excessively consumed by local villages and are potentially at risk. It seems reasonable, therefore, to initiate regular monitoring of these sources. Monitoring data may support mine-community initiatives towards improved water supply for the local communities. Therefore, it is recommended that some of the existing shallow village wells, if retained for local use, should be monitored for water level, and organic and inorganic water quality.

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