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Environmental and social risks associated with small scale mining in Kabwe and mitigation measures

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Studies on environmental and social risks associated with artisanal and small-scale mining (ASM) activities around Sable Zinc mine, Kabwe, Zambia in 2023 were investigated and mitigation measures suggested. ASM operations were noticed to pose significant threats to land degradation as evidenced by the presence of dungeons and valleys which later became sources of air and water pollution. Increased dust-fallout up to 5000 mg/m^3 per day from May-November and a decrease to 2500 mg/m^3 per day in December was observed against 500 mg/m^3 Zambia Environmental Management Agency (ZEMA) set limit. The increase and decrease in aforementioned periods could have been due to increase and decrease of mining operations in the period underreview. Though detected Pb and Zn concentrations at pH 7 in almost all areas were below the set limit of 0.5 mg/L and 1 mg/L by ZEMA, respectively, soil contamination was inevitable and this was due to complexation of Pb and Zn nuclear hydroxylate species and quicklime used as a pH modifier resulting from molecular electrostatic potential variations. To mitigate this challenge, interactions of metal species complexes with eco-friendly polysaccharides such as xanthan and guar gums would aid to further cushion this contamination before discharging water into the environment. Further, though the noise pollution was also below 85 dB from various sections, further decrease in noise pollution could be achieved by setting the speed limit for the earth moving machinery and promoting the usage of ear plugs among mining actors. In general, in order to fully mitigate these challenges, strong policies need to be implemented by the government that would while allowing legit operations by these miners, deter anything that would facilitate the aforementioned challenges.

Keywords: Pollution, Land, Mining, Mitigation measures, Concentration

INTRODUCTION

Not all mining is carried out by large global mining companies such as First Quantum Minerals, Rio Tinto, Glencore PLC, Vale SA and China Shenhua Energy Co Ltd, which are the major players in the mining market with extensive machinery in open or underground mines yielding colossal productions (Z. Yanfei et al., 2019). Globally, other mining activities such as Artisanal and small-scale mining (ASM) are also carried out by various groups (Ofosu et al., 2020). ASM is defined as any single mining operation with minimal capital measured at the mine entrance with minimal capital investment (Aryee et al., 2003). Despite the minimal production of ASM compared to the global mining companies, owing to the increase in global demand of critical elements such as Pb and Zn owing to their increase in medical therapies (Collin et al., 2022), alloy formation used in aerospace (McCormack et al., 1993; Rettenmayr et al., 2002), electronics (Menon et al., 2015), military equipment manufacture (Lima et al., 2011), electric vehicles (Cairns and Albertus, 2010) and batteries (Shivkumar et al., 1998), ASM plays a significant role in cushioning this global demand. For instance, in 2017, ASM contributed 20 % of the global production of gold amounting to 630 tons (Statistica, 2022), whereas ASM in Peru produced approximately 4900 tons of copper amounting to 0.2 % of the national production (Egunyu and Boakye-Danquah). Hence ASM is a double-edged sword that could aid in promoting the country's economic growth or invoke social and environmental challenges if not properly handled. Further, due to the above-mentioned increase in global demand of the critical minerals, increased ASM have been reported to consist of more than 150 million workforce dotted across the globe, thereby making them the largest employer in mining fraternity (Statistica, 2024). India, China, DR. Congo, Ethiopia, Ghana and Burkina Faso consist of the largest ASM workforce amounting to more than 15, 9, 1.8, 1.2, 0.8 and 0.4 million, respectively. These higher numbers arise from unemployment in the formal sector, lack of alternative ways of livelihood, and political leniency especially for members of the ruling political party resulting from corrupt law enforcement (Arthur-Holmes and Ofosu, 2024; Bansah et al., 2024; Fisher et al., 2009; Teschner, 2012). Despite these benefits, the environmental and social risks due to ASMs require urgent attention (Bansah et al., 2024; Genetu and Kebede, 2024; Ghose, 2003; Mohanty et al., 2023; Sayapathi et al., 2014b; Schreuder et al., 2001; Vandana et al., 2024). A lot of investigations on the benefits, negative impact and mitigation measures depending on the targeted mineral/metal have been conducted in several countries such as Ghana (Aryee et al., 2003; Bansah et al., 2018; Bansah et al., 2016; Hilson, 2001; Teschner, 2012; Wireko-Gyebi et al., 2020; Yankson and Gough, 2019), Burkina Faso (Andriamasinoro and Angel, 2012; Drechsel et al., 2019; Gueye, 2001; Hein and Funyufunyu, 2014; Ouoba, 2017; Pokorny et al., 2019), South Africa (Dreschler, 2001; Ledwaba and Mutemeri, 2018; Ledwaba and Nhlengetwa, 2016; Mkubukeli and Tengeh, 2015; Mutemeri and Petersen, 2002), China (Andrews-Speed et al., 2005; Andrews-Speed et al., 2002; Shen et al., 2009; Shen and Gunson, 2006), to mention but a few.

Environmental risks

Mining activities especially ASMs have been reported to pose numerous challenges including environmental protection (Aryee et al., 2003; Huang et al., 2021; Ofosu et al., 2020) resulting from the modification of the functioning ecosystem. This results in significant changes in both landscape and ecology viz., deforestation (**Figure 1(a)**), soil and water pollution (**Figure 1(b)**), land degradation (**Figure 1(c)**) coupled with land shaping, and loss of biodiversity. Further, another risk involved is acid mine drainage resulting from the oxidation of the sulphide minerals after processing also as shown in **Figure 1(e)**. These deteriorations are mainly caused by unprofessional and unethical working practices, mitigation measures coupled with weak policies and corrupt enforcing institutions (Ofosu et al., 2020; Singh et al., 2023; Szczerski et al., 2013). Apart from poor environmental governance, most third world countries (Blanche et al., 2024) such as Zambia do not carry out correct impact assessment on the inactive, abandoned, and active ASMs. This was in consonance with the studies conducted by other earlier workers in DR. Congo, Otamonga and Poté (Otamonga and Poté, 2020).

Social risks

Apart from environmental risks, other workers have also reported on the promoted social risks due to ASMs (Ali, 2014; Lei et al., 2013; Shen et al., 2009). One common risk is child labor (Hilson, 2008). According to research, child labor in ASMs is a common and contentious topic that has led to various interpretations of the practice and rising cost of living has too contributed to an increase in child labor. Child labor is still a growing and common practice notwithstanding overall economic progress. ASM exposes children to risks that can seriously affect their health and safety, including spinning machinery and equipment, falling objects and earth, heat and stress, hazardous chemicals, and contaminated waterways (Hilson, 2008); Other prevalent risks include health hazards (Arthur-Holmes and Busia, 2022), exploitation (Rushemuka and Côte, 2024), community displacement (Wilson, 2019)and conflict (Andrew, 2003). Poverty, coupled with unemployment, economic stagnation, rural migration, and urbanization. In addition a few studies on the same have been performed in Zambia (Banda and Chanda, 2021; Hilson, 2020; Kambani, 2000; Kambani, 2003; Siwale and Siwale, 2017)

Figure 1: Environmental risks of artisanal and small scale mining (ASMs) resulting from (a) deforestation (b) water pollution (c) land degradation (d) air pollution (e) Acid mine drainage

Close analysis of the articles revealed that Kambani proposed that since the benefits of ASMs are immense, there is need of establishing sound policy on the environment that should be enforced without exceptions(Kambani, 2000; Kambani, 2003). Siwale and Siwale carried out an investigation on whether ASMs can be formalized; and they insinuated that there was need of not only a strong political will but also robust implementing institutions (Siwale and Siwale, 2017) and this was also confirmed by Hilson (Hilson, 2020). Banda and Chanda conducted studies on the proportion of the tax imposed on ASMs and reported that fiscal regimes imposed were excessively higher promoting the failure of miners to positively contribute to the economy. Despite, hitherto nil studies on the environmental and social risks associated with ASMs at Sable Zinc Mine, Kabwe, Zambia and the surrounding areas have been performed. Therefore, this study aims to investigate the environmental and social risks resulting from ASMs around Sable Zinc Mine and the surrounding locations coupled with the required mitigation measures.

LITERATURE REVIEW

Zambia well known to be endowed with a lot of minerals resources such as copper, cobalt, gold, lead and zinc, nickel sulphides and oxides, tin, manganese, iron ores, emerald, aquamarine and amethyst to mention but a few (Siwale and Siwale, 2017). Though Zambia has main mining companies with huge capital investment such as Konkola Copper Mine in Chingola, Lubambe Copper Mine in Chililabombwe, First Quantum Minerals and Lumwana Mine in Solwezi including Sable Zinc Mine in Kabwe, a higher number of ASM has been reported. For instance, in the early 2000s, Kambani (Kambani, 2000) reported the total number of licenses issued to ASM was slightly more than 460. Therefore, whether some of the ASMs have been closed or not, the possibility of a higher number of these mines compared to the main ones is high. Owing to a number of ASM, various investigations were conducted and reported by several workers including the involved environmental complications and the required mining environmental legislations to mitigate the environmental challenges (Kambani, 2003). At another period, Kambani noted that stopping ASM operations would cause a moral breakdown in society since these activities are a source of livelihood to many community members (Kambani, 2000). Therefore, the implementation of policies and strategic ways to enforces them (Kambani, 2003). Banda and Chanda (Banda and Chanda, 2021) conducted an extensive investigation on the co-operative strategy for ASMs by focusing on three ways viz., formalization of the ASM, the government buying the mined material especially gold in older to promote avoidance of exploitation of locals and also to alleviate poverty in communities and also for macroeconomic stability. Furthermore, in order to promote the sustenance of ASM operations, the researchers also conducted a comparative analysis between the tax policy and the current fiscal regime using three small-scale mining projects. Interestingly, they observed that the current average current tax rates of 52-55 % and marginal effective tax rates of 43-45 % were too high relative to analyzed values of 7 % and 6-7 %, respectively. Others reported on the tried formalization of ASM by the government in the 1980s and observed that contrary to helping the miners to harness the needed benefits, this process was used by the government to gain control of the sector and hence displace the miners to regions without proper economic viability (Siwale and Siwale, 2017). Hilson also reported on the formalization of ASM thereby centralizing taxation and hence aiding in boosting the economy. From the review, observed, none of the researchers reported on the effect of noise, water and air pollution coupled with the required mitigation measures to cushion the negative impact of the aforementioned challenges on operators and the community at large. While the aforementioned workers seemed to focus on formalization of the ASM, the others missed out on reporting negative impact of these activities not only on the environment but also on the social circles of society. Further, while it is well known that different metals and their concentrations affect the environment differently, investigations into the effect of poisonous metallic ions even in small concentrations such as Pb in, Zambia, Kabwe and around Sable Zinc Mine in particular, becomes relevant.

In this article, the environmental and social impacts of ASM including noise, air and water pollution coupled with soil contamination was studied. Furthermore, the required mitigation strategies in order to cushion the damage of the above-stated risks were proposed.

METHODOLOGY

The focus of the study is to investigate the main environmental and social risks involved in ASMs including the mitigation measures. In order to achieve this, the following protocols were followed.

Research design.

To conduct a thorough investigation, a mixed approach method that integrates both quantitative and qualitative data (Creswell, 1999) was adopted. Additionally, a case study was used too, this design allowed the researcher to focus much on a single entity which is the impact of artisanal mining activities on the aspect of the physical environment and the social domain. The researcher believed that by using a case study design, he would get detailed and in-depth information to the topic from respondents. Also, this study design ensured the reliability of the research findings, as each component which was involved in the study, would be studied closely so as to get a clear picture of the problem from each respondent in a sample. Moreover, the case study provides insights into other, similar situations and cases (Msabila and Nalaila, 2013).

Target population and sample size

Target population

A population in a study is the group that has the common characteristics which are of interest to the researcher, and it should be that group from whom the researcher would be able to draw conclusions from. The target population of this case study was the cooperatives members themselves, whose total membership according to their profile was 300 from all corners of Kabwe town, local residents within Kabwe Mine Area and local municipality.

Sample size

According to Frances and co-workers (Francis et al., 2010), a sample size is the number of individuals or things collected from the actual population for the purpose of investigation. With reference to this, and considering that this was a case study, the researcher sampled out 75 cooperative members from Kabwe Kamukuba cooperative whose total membership was 300 representing a 15% sample size as respondents from the target population who were granted consent to mine and reclaim Zinc materials from EPL tailings facilities, in order to generalize the findings. 70 local members from nearby communities, 2 environmental technologists and 3 local municipality leadership giving a total of 150 respondents.

Sampling methods and procedure

Both probability and non-probability sampling were used. Etikan and Bala defined that the probability sampling is a sampling technique in which a sample from a larger population is chosen using a method based on the theory of probability (Etikan and Bala, 2017). This meant that for a participant to be chosen using this technique, a principle called 'randomness' was employed. Non probability sampling was also defined by as a sampling technique where the sample is chosen by a method which does not involve random selection of individuals (Schreuder et al., 2001). Moreover, under probability sampling, simple random sampling method was employed. Propp and collaborators (Propp and Wilson, 1996) defined a simple random as a subset of statistical population in which each member of the subset has an equal probability or chance of being chosen. Therefore, the simple random method was used to select the members of Kabwe Kamukuba cooperative respectively. The selection of respondents was in such a way that they all had an equal chance of participation.

Then under non-probability sampling, the researcher used purposive sampling. Guarte and Barrios defined purposive sampling as strategy in which particular settings, persons or events are selected deliberately in order to provide important information that cannot be obtained from other choices (Guarte and Barrios, 2006). The researcher targeted people whom he thought had the information especially those in public offices. Thus, in this case, the Kabwe Kamukuba cooperative leaders, agency officials were purposively selected because of its nature of operations which was in-line with the research problem.

Data collection and methods

In this section, research instruments adopted in the study were noise meter kit for noise pollution determination, pH meter, atomic absorption spectrometry metal concentration measurement as well as observations, guided-interviews and structured questionnaires as primary data sources, and documentary review as secondary data source. Hence, both primary and secondary data such experimental and data from articles, respectively, were collected. Furthermore, analysis of the water contaminants, degree of noise pollution as well as air pollution were conducted.

Observation

With observation methods, the information was sought by way of investigating direct observation without asking the respondents (Rolfe, 2001). The researcher used participant observation method by eye witnessing the impact of artisanal mining on the environment particularly water, land, air and forest/vegetation. The method is of importance to the researcher since it eliminates biasness from respondents. The instruments of data capturing such as air, water, and noise were planted to help enhance observations.

Interview guide

A structured interview schedule as one of the types of interviews which provides a guide for questions and topics that must be covered, was used in the study. It was conducted personally by the researcher face to face with the members of the cooperative and the locals. This method was chosen because the researcher wanted to explore deeply into a topic as well as to comprehend the views given by the respondent who is directly involved in the operations.

Structured questionnaire

A questionnaire (see the details in the supplementary section) was used to allow wide coverage of collecting data within a short time and free expression of individuals. The questions in the questionnaire were closed ended. Structured questions helped the respondents to give precise answers and not diverting from the topic of study. Self-administered questionnaires were filled in by respondents from government agencies such as ZEMA, ZMERIP, local authority, due to the fact that they provided them with more time to answer at their own pace and free time. Thus, questionnaires helped the researcher to get enough information quickly and in a short period. Also, participants were expected to have more information on the risks that small scale mining operations pose to the environment. After the questionnaires were filled up, the researcher collected them on a third day.

Quantitative analysis

A number of analysis tests were conducted in order to determine the contaminants present in water and noise as well as the extent of noise pollution.

Analysis of water quality

The analysis of the pH of water quality from January to December 2023 proceeding to Chowa-Mutwe Wansofu area from Kabwe Kamukuba cooperative mining operating site was performed using Extech PH220-S Waterproof Palm pH Meter housed at Sable Zinc Mine. This was conducted by daily sampling of the water from that operating site and checking its pH. Per month, the average reading and the standard deviation in order to ascertain the accuracy of error were calculated. Furthermore, the analysis of the metal ions was conducted using the Atomic absorption spectrometry (AAS) using specific bulbs for each metal ion analysis.

Analysis of noise quality

Noise pollution, the unseen pollutant, on the plant was determined using a noise detector called Sound Level Meter (SLM) model SL-5868P. Any unwanted sound that penetrates the environment is noise pollution (Gonzlaz, 2014; Harnapp and Noble, 1987). In general noise pollution refers to any noise irritating to one's ear which comes from an external source (Gonzlaz, 2014). The noise meter kit was used for the determination of noise pollution. This instrument is usually used in industries to determine the intensity of sound in decibels (dB) in a given environment at a specific moment. Owing to different instruments used on the plant, the dissipated proportion of noise per plant section was measured on a daily basis from January up to December. The noise pollution contributed by the administration offices was also recorded within the stipulated period. The average per month plus the standard deviation was calculated and compared to the reported threshold limit value of 85.0 dB by several workers (Sayapathi et al., 2014a; Sayapathim et al., 2014).

Analysis of air quality

Dust buckets were used to monitor the fall out dust for a period of thirty days in each month from January to December, 2023 at Kabwe Kamukuba cooperative mining operating site. The buckets are placed at 2.2 m above the ground so as to prevent interferences as well as the precipitation phenomenon. Further, in order to prevent loss of the particles collected, the buckets were partially filled milli-Q water to which
a biocide is added to prevent the growth of algae.

Data collection

Data was collected through questionnaires and interviews. The researcher physically visited the Kamukuba cooperative work site to administer the questionnaires (see the supplementary information), and conduct the interviews. Administering the questionnaires in person ensured that assistance was given to respondents who were in need of help in understanding some questions and that all the filled questionnaires were collected for processing.

Data treatment methods and procedures

According to Anderson (Anderson, 1979), data analysis involved a number of closely related operations, which is performed with the purpose of summarizing the collected data and organizing them in such manner that they answered the research questions.

In respect with qualitative data, this study recorded in a notebook during interviews, analyzed using thematic analysis based on the themes derived from research questions. Research question one and two were qualitatively analyzed using thematic analysis. Thematic analysis describes that we label phrases or paragraphs of the data by giving them a code, which is done by using the research question as an interpretive tool. Then we group these coded data into theoretically relevant categories, and we look for over-arching themes to these categories, and in many cases respondents" actual words were reported, qualitative data was used to support quantitative data while thematic analysis examined the intensity with which certain words were used [51]. It systematically describes the form or content of written and or spoken materials.

On the other hand, Kothari [52], quantitative data gathered from miners by using questionnaire were cleaned, edited, coded and entered in computer software using Microsoft excel. This will generate descriptive statistics such as percentages and averages. Also, origin software was used to plot some tables, chart and figures. Since the information was accompanied with different statistical data. The information collected was presented using suitable tools such as bar graph, tables and pie charts since they are suitable methods of presenting data. In the same manner, the data siphoned via analysis in the laboratory was also presented using the same procedure.

Conclusively, the data that was collected had been analysed within the participants' point of view. Accounts of analysis were put into writing. Qualitative methods as well as quantitative methods were used to analyse the data. The data collected was compiled and presented through simple tables and Microsoft excel. It was later discussed using the thematic approach.

Ethical considerations.

The researcher recognised all those who were in charge of the site of investigation by getting permission from them before proceeding with his research. During the administration of questionnaires and interviews, the researcher assured respondents of confidentiality, privacy and anonymity by not letting the respondents to identify their names on questionnaires, and that the information was only for academic purposes.

FINDINGS

Presentation of data

Response rate

Figure 2 indicates the results of the targeted sample size, response rate and respond as a function of varying groups viz., co-operative (CP), local residents (LR), Environmental Health Technicians (EHT) and local authorities (LA) plus the total for all groups combined taking into consideration the questionnaire used. A higher number of those involved in the operations of the CP of 75 was targeted, whereas that of the LR, EHT and LA were 70, 02 and 03, respectively. It can clearly be noted that response rate in all the groups is 100 %. Furthermore, the total targeted sample size and response were all 150m indicating that a 100 % response rate was attained.

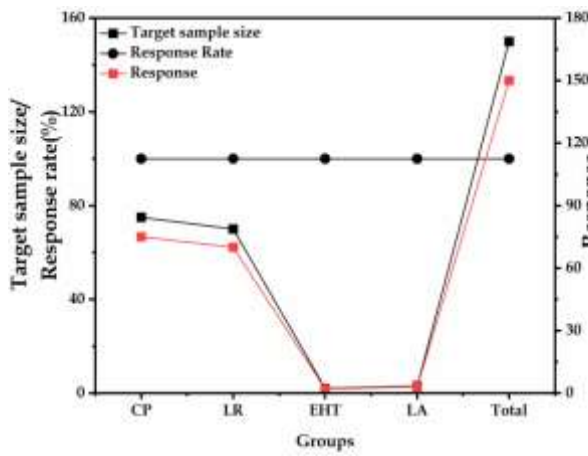

Figure 2: Targeted sample size, response rate, response as a function of the groups (respondents viz., co-operative (CP), local residents (LR), Environmental Health Technicians (EHT) and local authorities (LA) plus the total for all groups combined)

Distribution of respondents in terms of age

The age of respondents was also studied in order to comprehend which certainty of the results as shown in **Figure 3**. As can be observed 26.67% of respondents were within the age ranges of 15-25 years old, 22.00% within 26-35 years old, 22.67% within 36-45 years old, 13.33% within 46-55 years old, 8.67% within the age range of 56-65 years, and 6.67% were 66 years old and above.

Therefore, it can be observed that both the percentage and frequency decreased with increase in the age of respondents. The current youth population aged between 15-35 years accounts for 48.7 % of the total sample population (UNFPA, 2024).

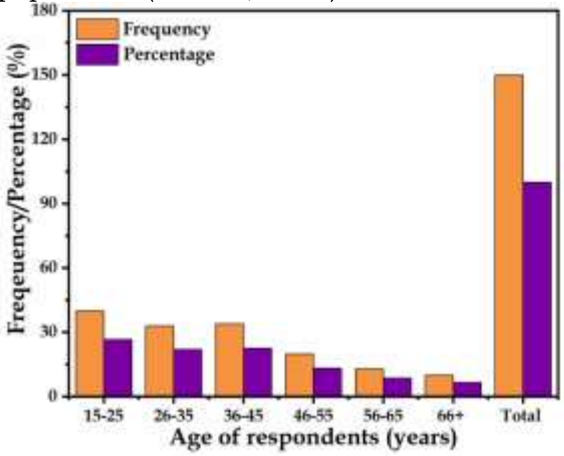

Figure 3: Frequency and percentage of responses as a function of age of respondents

Marital status of respondents

The marital status of the respondents was also analysed shown in **Figure 4**. 73 % of the respondents are married, 17 % are single and 10 % are divorced. This indicates that the majority are the heads of the house and therefore have a duty to provide for their families. Further, data also provided confidence in the results to be tackled on the environmental and social risks of the ASM since close to 75 % of the respondents were mature people and hence expected to have a slightly better understanding of the topic under investigation.

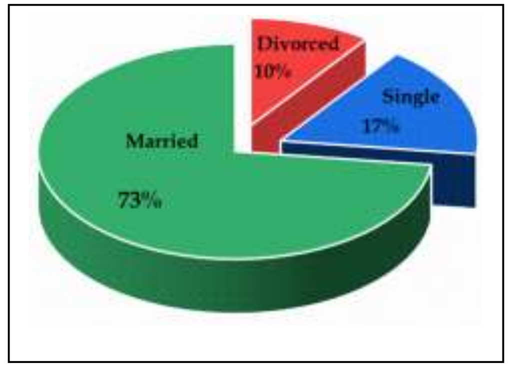

Figure 4: Marital status of the respondents

Academic Level of respondents

The academic level of respondents was also studied. 50 % of the respondents only attained primary level, 33% reached secondary level, where 10% had attended tertiary education and 7% have been trained in various fields. Note that, 90% represents the small-scale miners under the cooperative and few locals, were 10% represents the relevant authority personnel.

Environmental impact of mining activities

Prior to analyzing the impact of the ASM operations in the area, the availability of such mining activities in the environment were first noted via the respondents and hence the importance of the next section.

Awareness of mining activities in the area

The Figure (**Figure 5**) below illustrates the awareness of the residents on the current existence of mining activities by the artisanal small scale miners (cooperative) in the area. From the data collected and responses given, 80.00% of the respondents were fully aware of any sort of mining activities taking place within the area, while 20.00% did not have knowledge on any existing mining activity. From this fraction, it is evident that mining activities are taking place in the area.

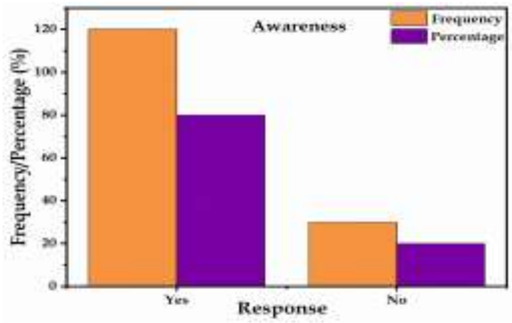

Figure 5: Awareness of the existence of mining activities

Response on negative effects of extraction methods

Figure 6 describes the responses from the respondents on the whether the mining method used has an effect on the environment or not. 89% of the respondents consented that the extraction method used has a negative effect on the environment, while 11% disagreed that the method do not have any effect

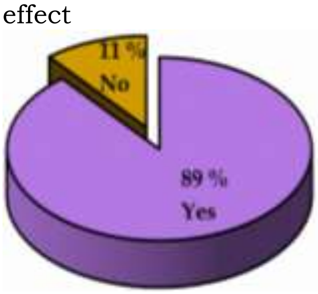

Figure 6: Response on the negative effects of the used methods of mining

Response on negative effects of extraction methods

Figure 7 describes the effects of mining on the physical environment, were 28% of the results represented land degradation (LD), 27% represents the amount of air pollution (AP) in the area, 10 % of water pollution (WP), 20% noise pollution (NP) and 15% represents soil contamination (SC) resulting from mining activities. This clearly proves that mining of any sort poses a risk on the physical environment.

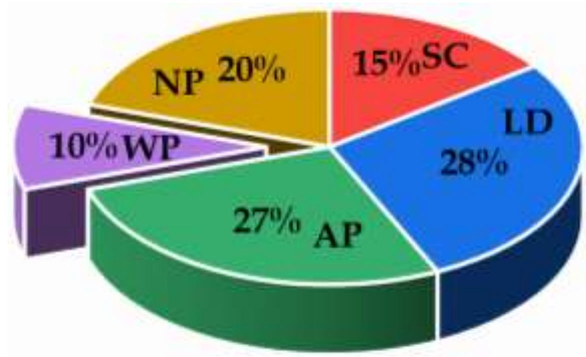

Figure 7: Effects of mining activities (where NP, SC, LD, AP, WP indicate noise pollution, soil contamination, land degradation, air pollution and water pollution, respectively)

Quantitative analysis

Analysis of ground-water quality

Groundwater monitoring was carried out from seven (07) monitoring wells dotted around Sable Zinc Kabwe–Enviro Processing Limited sites and description of the Monitoring Borehole Locations are shown in **Figure 8**. Further, Sable Zinc Kabwe Limited deep groundwater monitoring wells were drilled in 2022. Each borehole is covered and locked to prevent contamination of the ground water samples. The boreholes monitor the near-surface groundwater quality in the plant area and around the mine dumps areas, and the following parameter were monitored.

Figure 8: Description of the Monitoring Borehole Locations indicated in yellow as ground-water (GW)

pH of ground-water quality

The pH of various sections including outside the plant, along Lusaka Road, was conducted as a function of the months from January to December, 2023 as shown in **Figure 9**. The

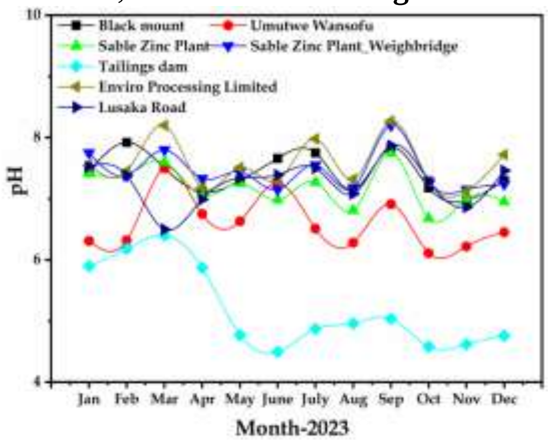

Figure 9: The average pH of the ground water per month for specific ground water site for each in the year 2023

standard limit for the pH of the environment is 7-7.5 (Crommentuijn et al., 2000). The pH of water is an important measurement of the water quality. The water quality in various areas analyzed indicated that the pH for all the sections was between 4 to 8.3, with the tailing dams having the lowest pH between the values of 4 to 6.3. It is also important to note that more points had pH values of more than 7.

Metal ion concentration in ground-water quality

The concentration of the common metal ions in ground water was reported in this section as shown in **Figures 10** and **11**, respectively.

Zinc (Zn) concentration in ground-water quality

Figure 10 shows the analyzed concentration of Zn in various locations in and outside the plant in 2023 from January to December. As can be noted, the concentration of Zn was below 500 mg/L. However, close interrogation of the results indicated that the proportion Zn in ground-water situated at Sable Zinc plant, Black Mountain, Sable Zinc plant weighbridge, near Lusaka Road and Enviro Processing Limited was well below 30 ppm and mostly of nil concentration, except for Sable Zinc Plant and Enviro Processing Limited which possessed a concentration of approximately 50 ppm in the month of December. However, it was also observed that the concentration of Zn in ground-water

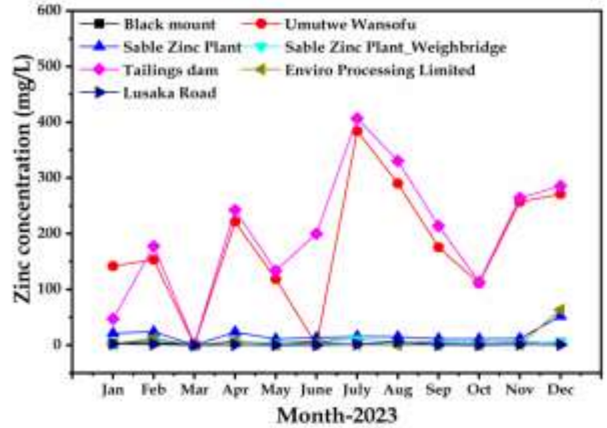

Figure 10: Concentration of zinc (Zn) ions in ground water as a function of months throughout the period of 2023

was in general higher compared to other sections in Umutwe Wansofu and Tailings Dam areas. The set limit by ZEMA is 1 mg/L [55]. Therefore, Tailings dam and Umutwe Wansofu in several months contained more concentration of Zn than the set limit.

Lead (Pb) concentration in ground-water quality

Figure 11 illustrates the concentration of lead in ground-water in Black mountain, Umutwe Wansofu, Sable Zinc Plant and weighbridge, Tailings dam, Enviro Processing Limited and Lusaka road areas. As can be observed, the concentration of Pb in all the stated sections was below 4 mg/L, with that in the tailings dam higher, whereas in other sections close to less than 1 mg/L. The set limit by ZEMA is 0.5 mg/L [55]. Therefore, the tailings dams contained more Pb than allowed.

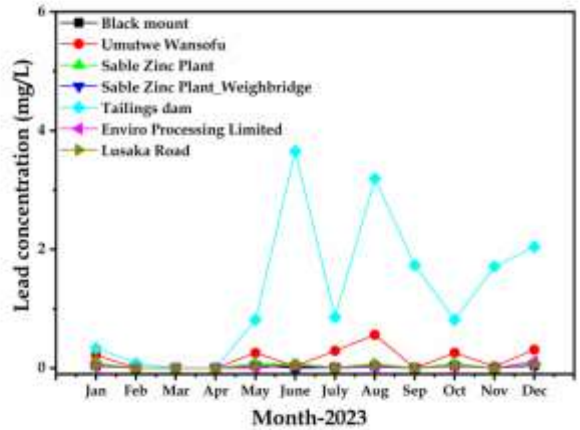

Figure 11: Concentration of lead (Pb) ions in ground water as a function of months throughout the period of 2023

Analysis of noise quality

The proportion of noise generated per section of the plant was determined on a daily basis and the average per month recorded in the year 2023 starting from January to December as shown in **Figure 12**. The threshold limit set by ZEMA is 85 dB. It can be noted (see **Figure 12**), that the amount of noise generated in all sections was below the set, implying that all the plant sections are generating noise within the acceptable limits that may not harm the operators and community's hearing ability. It can be also be noted that more noise of value 75.94 dB was generated at the leach plant section, whereas the lowest proportion of noise was dissipated at the Metallurgical (MET) plant and was of value 54.55 Db. It is also interesting to note that more noise was generated from the administrative offices, a place where there are no running equipments compared to the metallurgical pilot plant.

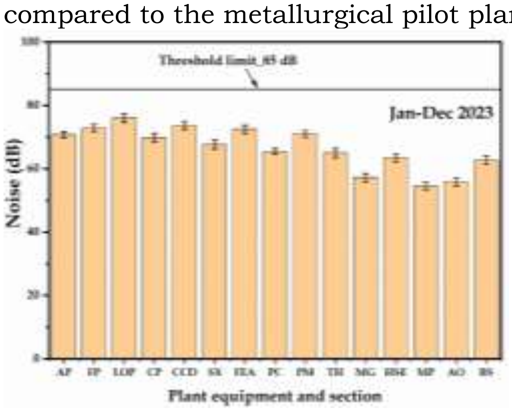

Figure 12: The amount of noise dissipated from the Acid plant (AP), Flotation plant (FP), Leach and Oxygen plant (LOP), Cobalt plant (CP), Counter current decantation (CCD) area, Solvent extraction plant (SX), Front end area (FEA), Primary jaw crusher (PC), Primary ball mill (PM), Tank house (TH), Mine garage workshop (MG), Health and Safety (HSE) induction area, Metallurgical pilot plant (MP), Administration offices (AO) and Boiler shop (BS) for the period of January to December, 2023

Analysis of air quality

Fall out dust using installed dust buckets was monitored for a period of thirty days in each month throughout 2023 and the results are as shown in **Figure 13**. In general it can

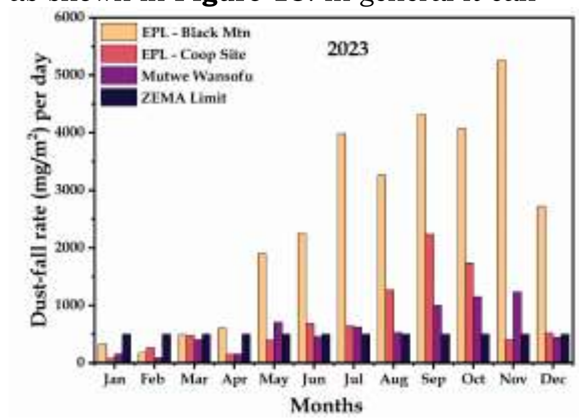

Figure 13: Air quality results after mining and transportation of Zinc–Lead tailings from EPL dams

It can be noticed that from April till December, the dust-fall rate in Enviro Processing Limited and Black Mountain was higher compared to other areas with the highest being in November and a decrease in December. Further, it was also observed that in nearly all sections, there was an increase in the dust fall rate from January till November and a decrease in December.

Land degradation

During field work it was noticed that the area where the co-operative was operating from, had changed were as the little natural vegetation that had grown in site was completely ripped off as can be seen in **Figure 14(a)** and **14(b)**. Thus, the bareness of land could have greatly contributed to air pollution. Furthermore, it was also noticed that the pits formed during such mining activities was filled up by the rains thereby leading to the facilitation of breeding areas for mosquitoes (see **Figure 14(c)**). The environmental impact of small-scale mining activities due to poor mining practices is severe and wide spread. In most cases, large areas of land have been abandoned with pits and quarries without post reclamation hence rendering it unsuitable for farming or any other activity as seen in **Figure 14**

Figure 14: Land degradation during Zinc material reclamation by Cooperatives

Social risks associated with mining activities

Figure 15 illustrates that social problems are prominent during mining activities, with 37.33% land disputes, 24.00% engagement in drug abuse, 22.67% standing for school drop outs with an intention of making money, 10.00% prostitution activities and 6.00% transmittable diseases such as, syphilis, gonorrhea, HIV etc.

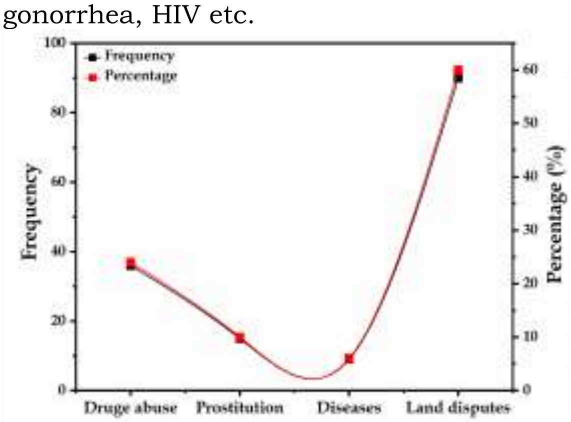

Figure 15: Social risks associated with mining activities

Sustainable measures to mitigate the impact of mining on the environment

Figure 16 highlights the possible solutions to environmental degradation caused by mining activities, 26% represents issuance of mining permits, 21% calls for sensitization on the evils of mining on the environment, 17% calls for the implementation of policies to govern mining activities, were as 19% represents community development in form of infrastructure, e.g. health centers and other 17% calls for financial support to the cooperative so as to engage in sustainable activities other than mining.

Figure 16: Sustainable measures on mining

DISCUSSION

The results obtained after analysis of the raw data as shown in the previous section is further discussed. In this section apart from discussing the obtained results, counter-measure to aid in achieving the ZEMA set limits are also proposed.

Quantitative analysis

pH of ground-water quality

As shown in **Figure 9**, the pH levels was observed to be lower in the tailings dam compared to other sections within and outside the plant. This implies that the differences between the pH levels in the tailings dam to the set limit of value 7 by ZEMA is higher relative to that from other sections. Therefore, this discussion will be centered on the possible causes of low pH levels in the tailing dams and the possible ways to combat this challenge. Firstly, the lower level of pH in the tailings dams could have been due to the fact that after leaching of the copper ores as well as cobalt ores using high concentration of sulphuric acid, the solids after further concentration of leached solids in the counter current decantation section, the solids are pumped to the tailings. Of course,a known concentration of quicklime is added to further increase the pH value to 7. This then implies that the lower pH values in the tailings could be due to the addition of lower dosages of quicklime. The usage of quicklime to improve the pH value to neutral pH in hydrometallurgical plants is well known (Ding and Zhang, 2020; Vandyck et al., 2023; Wei et al., 2022). Apart from the supposed lower dosage of quicklime added to the highly acidic solids discharged into the tailings, another source of lower pH value in the dams could be the presence of sulphur (S) minerals such as pyrite and chalcopyrite. It is well noted that the S minerals present in the ores fed into the leaching circuit either partially do not get leached using concentrated sulphuric acid at room temperature and atmospheric temperature. Other than the S minerals being a source of S in the tailings dam, the other potential source of S to the solid material possibly in huge dosages are the sulphate ions from the concentrated sulphuric acid used as a leaching media. Several workers have reported on the ability of acidophilic microorganisms to feed on the sulphur present thereby reproducing different types of acids including sulphuric, acid, salicylhydroxamic, humic acids to name a few, in the environment or tailings dams [59-62]. The dangers of such environments is that this acidic water moves down and mixes with the ground water as evidenced in Figure 8 leading to lower acid levels and end up in the community thereby posing untold damage to human life. Acidic water apart from being a danger to other aquatic lives promotes erosion of the enamel thereby increasing tooth decay and cavities (Jameel et al., 2024), irritates the esophagus and stomach linings hence leading to heartburns, ulcers and acid reflexes (Velasquez-Manoff, 2023), reduction of calcium in the body owing to the reaction of the calcium with the acid (Shaker and Deftos, 2023), facilitates corrosion of pipes thereby leading to damage (Hussein Farh et al., 2023), promotes existence of metal ions such as arsenic, lead, manganese, copper, zinc and many other in high concentrations (Singh et al., 2023) to mention only a few. With the aforementioned negative effects of acidic pH, it is therefore important for the ASMs to find long lasting solutions to these worrisome challenges. One of these solutions could be the addition of the correct concentration of the quicklime without reservations to the high acidic solids as they get discharged to the dams in order to attain the pH value of 7-7.5. Secondly, in order to prevent the production of acids from S discharged into the tailings dam, Sable Zinc mine Limited has introduced the removal of the S minerals via flotation prior to feeding the ores containing S minerals. In this, the amount of S discharged to the dams would be less. Thirdly, the plants should also consider utilizing other acids such as the green organic acids (Mohanty et al., 2023) that are eco-friendly especially that there is a promotion of the reduction of the carbon footprints globally. The employment of green organic weak acids instead of concentrated sulphuric acids would also aid in preventing the discharge of the sulphate ions present in the solids to the dams.

Metal ion concentration in ground-water

The concentration of the common metal ions viz., Zn and Pb in ground-water reported in **Figures 10** and **11**, respectively, is discussed in detail.

Zinc (Zn) concentration in ground-water quality

Figure 10 indicated the concentration of Zn in ground water. As already highlighted, in most months in different areas indicated in **Figure 10**, the concentration of Zn was beyond the set limit by ZEMA. Further and as expected, owing to the measured acidic pH values in tailings dam section, the concentration of Zn reported was quite high. Surprisingly, in Umutwe Wansofu area, a higher concentration of Zn similar to that in dams was also reported. As already elaborated in the previous section (**5.1.1. pH of ground-water quality**), the precipitation of Zn increases with increase in pH, implying that the lower pH values especially in acidic regions is high. The average calculated pH values for the 2023 in various reported section viz., Black Mountain, Umutwe Wasofu, Sable Zinc Plant, Sable Zinc Plant Weigh-bridge, Tailings dam, Enviro Processing Plant Shaft and Lusaka Road were 7.4, 6.6, 7.2, 7.4, 5.2, 7.6 and 7.3, respectively. Interestingly, it can be noted that the average concentrations of Zn in the aforementioned areas were 4.53 mg/L, 176.9 mg/L, 17.4 mg/L, 4.60 mg/L, 201.3 mg/L, 7.63 mg/L and 1.12 mg/L, respectively. Hence as already indicated, the higher concentration of Zn in the dams amounting to 201.3 mg/L was higher than the rest owing to the lower pH value of 5.2 compared to other sections. This was followed by the Zn concentration in Umutwe Wanofu area amounting to 176.9 mg/L at average pH value of 6.6. Therefore, the lower concentration of Zn in other sections could have been due to higher pH values analyzed. Further, it is also important to note that though the ZEMA set limit for Zn was 1 mg/L, almost all the sections even those with pH value of 7-7.5 contains Zn beyond the above stated limit. This implies that the pH though reduces the proportion of Zn, does not ultimately reduce the metal concentration to below 1 mg/L. This was also confirmed by other earlier workers as shown in **Figure 16** (Heakal et al., 2018). In **Figure 16**, it can be seen that below pH 6, the case of the dams, Zn exists in Zn^{2+}, whereas at pH 6.6, the case of Umutwe Wansofu area, 90 % and 10 % of Zn exists in the form of Zn^{2+} and $Zn(OH)^{+}$. Since it is required that Zn concentration be reduced to maximum of 1 mg/L, the usage of pH control cannot aid in totally combating this challenge. Therefore, other strategies need to be proposed that would aid in reducing the concentration below those limits whiles maintaining the pH. Since globally there is a focus on the utilization of eco-friendly reagents to mitigate any effect such as this one, the utilization of polysaccharides to combat this concern is suggested.

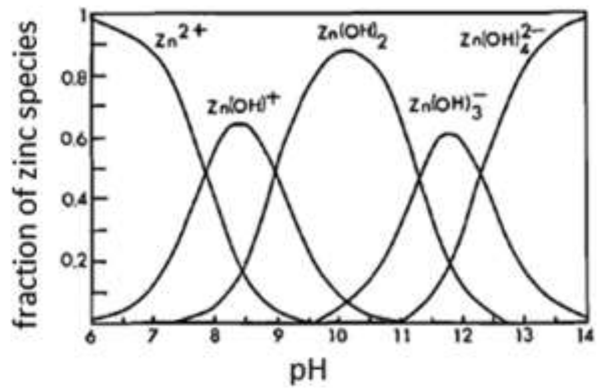

Figure 17: Distribution diagram for zinc species as a function of the solution pH at 25 °C (Cano et al., 2010; Heakal et al., 2018)

Firstly, there is need of increasing the pH to a minimum value of 7. Since both metal ions present at that pH are cationic, the subjection of this ground water to anionic polysaccharides would easily aid in further reducing the concentration of Zn. For example, a number of workers have indicated xanthan gum, an anionic polysaccharide with various carboxylate groups providing anionic behavior to the polysaccharide as shown in **Figure 18**. While it is well known that polysaccharide possess a variable viscosity due to changes in pH and presence of metal ions, other workers have reported that the viscosity of xanthan gum rarely changed with changes in the aforementioned parameters (Mweene, 2020). Several other workers have reported on the application of xanthan gum

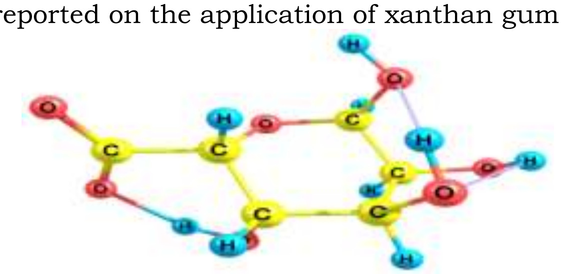

Figure 18: Xanthan gum monomer

as depressant due to its ability to interact with metal ions on the surface of minerals (Ming et al., 2020; Mweene et al., 2021; Zhao et al., 2019). Furthermore, another common polysaccharide that could be used in reducing the proportion of Zn in the water is citric acid as in **Figure 19**. The advantage with citric acid is that this polymer consist of three carboxylate functional groups as opposed to on contained in xanthan gum monomer. However, unlike xanthan gum monomer, citric acid possess a compromised viscosity, a proper needed to depress and easily complex with the metal ions in solution. Therefore, though citric acid could be used, it will have to be replaced time and again leading to high dosages used and thereby increasing the cost required for treatment. Therefore, in the long run, xanthan gum will be better and economical. It is important to mention that citric acid is a common acid that is present in lemons. Therefore, lemons could be used for this strategy.

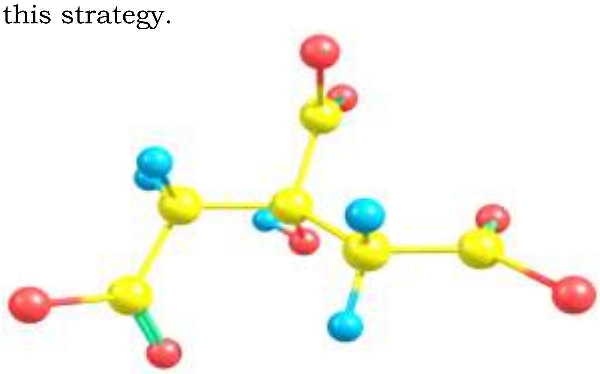

Figure 19: Citric monomer

Lead (Pb) concentration in ground-water

The pH values and Pb concentrations in **Figure 11** for the year 2023 in Black mountain, Umutwe Wasofu, Sable Zinc Plant, Sable Zinc Plant Weigh-bridge, Tailings dam, Enviro Processing Plant Shaft and Lusaka road. As already reported, the pH values were 7.4, 6.6, 7.2, 7.4, 5.2, 7.6 and 7.3 with corresponding concentrations of Pb of value 0.02 mg/L, 0.16 mg/L, 0.04 mg/L, 0.02 mg/L, 1.27 mg/L, 0.02 mg/L and 0.03 mg/L, respectively. Though lower dosages of Pb in all areas were below the 0.5 mg/L set limit by ZEMA, the concentration in the dams was 1.27 mg/L. As already alluded to, this higher concentration in the dams is expected due to lower pH of 5.2. Giraldo and co-workers conducted an extensive investigation in order to understand the precipitation species for Pb at various pH values as shown in **Figure 20** (Moreno-Castilla, 2004). Contrary to what was observed in the case of Zn, the precipitation for Pb begins at pH 4.2 and increases with increase in pH. However, the concentration of $Pb(OH)^{+}$ from 3.8 to 7 increased from pH 3.8 attaining a maximum at pH 6.5 of 10 % and slopes down to an aught concentration at pH 7. Further, at pH 7-7.5, the concentration $Pb(OH)_2$ is close 100 %. Therefore, owing to the presence of the neutral species, the utilization of either xanthan gum or citric acid would only be partially effective.

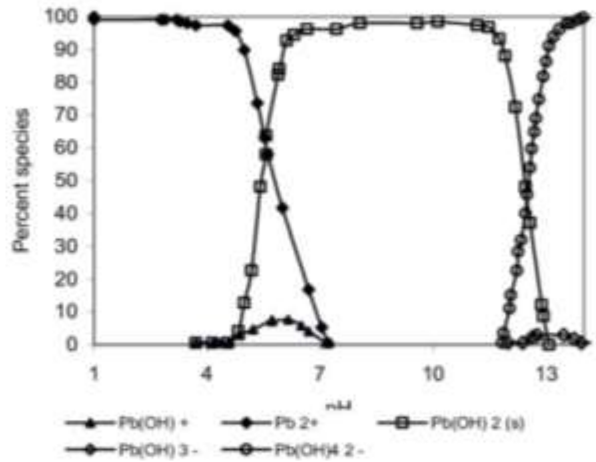

Figure 20: Distribution diagram for lead species as a function of the solution pH at 25 °C (Moreno-Castilla, 2004)

In order to further decrease the concentration of Pb in the dams, it is important as already suggested to increase the pH to 7-7.5. This would lead to the precipitation of Pb forming $Pb(OH)_2$. $Pb(OH)_2$ species are known to be insoluble in water and this explains why the concentration of Pb in ground water is much lower than that of Zn. To further reduce the concentration of $Pb(OH)_2$ in the dams, the ground water could be allowed to pass through guar gum solution (refer to **Figure 21**), slightly negative polysaccharide owing to the presence of hydroxyl functional groups. In this way the $Pb(OH)_2$ is expected to interact with the polysaccharide thereby reducing its passage to the dams. This simply means that the ground water from the dams should be passed through xanthan gum to decrease the concentration of Zn and the filtrate further passed through guar gum to further reduce the concentration of Pb at pH 7-7.5.

Figure 21: Guar gum monomer

Analysis of noise quality

As can be noticed in **Figure 12**, NP throughout the plant was below the threshold limit of 85 dB. It is still important to notice that noise pollution greatly affects the mines and the surrounding communities owing to moving machinery, automobiles and heavy moving equipment during the operations. This usually causes discomfort to nearby people, by disrupting attention and causing hearing problems on a long run. However, as already indicated, mines cannot progress without moving noisy moving equipment. One of the ways of intensifying mitigation measures could be through the utilization of the ear plugs in areas possessing equipment generating noise (Sayapathi et al., 2014b). Further, the mine supervisors could also devise a way were operators in noise areas are rotated to other areas so that they do not spend all the time in noise environments like the crushing and milling sections. Further, concerns on reducing noise should be taken into account even before purchasing the equipment for use. Furthermore, mines could either consider purchasing equipment with inbuilt silencers or properly mounting the equipment in order to reduce on the shock waves and use sound insulated enclosures (Singh, 2017).

Analysis of air quality

It was concluded from the study that air quality was undermined by the mining activities, the ferrying of material to Chengde processing plant, Super Deal and Dongton Mining, as main buyers of zinc material from the cooperative, induced traffic which caused an increase in dust and exhaust gases in the air at and around the project site. As can be observed from **Figure 12**, the dust-fall per day for EPL Black mount increase from January to December compared to the ZEMA set limit of 500 dust-fall per day, where at other studied sites, an increase was observed from January to November and decreased in December. The decrease in both cases could have been due to the rain seasons in those months. It has been observed that many ASM halt operations in the rain season due to lack of shelter and unplanned mining operations. Further being a Zn and Pb plant, the concentration of these elements and others in the dust though not determined could be high. Moreover, large amount of Zn in the dust could result into a condition called metal fume fever. However, this condition is reversible provided the exposure or concentration to the Zinc is minimized or reduced (ASTSDR, 2024). Moreover, in the case of Pb, long term inhalation of dust containing Pb can lead to coma, seizures, corrode the kidneys and stagnation in the development of the nervous system in children, kidney (Gundacker et al., 2021). Apart from these elements, a lot more elements and particularly the dust particle could impact the well being of the miners and the surrounding communities. Therefore, monitoring of the air quality needs to be implemented in the mines which wouldn't only promote health of the miners but also the health of the nearby communities as well as protect the environment. In order to mitigate such challenges, there is need of promoting wearing of masks by all the miners in high dust areas. Further, there is also need of having safety managers that strictly monitor the concentration of dust on the plant and notifying not only the workforce but also the nearby communities if dust levels exceed the set limit. Moreover, especially in third world countries like Zambia and Kabwe in particular, residential areas are build close to the mines and the impact of this challenge is quiet high. This could be mitigated by setting the residential areas very far away from the mines. The dust suppression systems (Huang et al., 2021; Xie et al., 2007; Zhao et al., 2021) could be another strategy that could be used to monitor and improve the air quality including mobile water sprinklers and mist sprayers which could be installed at the loading, transfer and offloading bays. Since the dust also results from the speeding vehicles on the plant. To avoid an increase in dust concentration, a speed limit for the vehicles on the mines should be set and various signposts placed at various locations on the plant.

Land degradation

It was observed that the scenery beauty of the surrounding was in a deteriorated state (for details see **Figure 14**). A large area within the operation site is left abandoned as soon as the material is depleted as required per grade. Pits are left unburied thus paving water to contaminated water, thus creating a conducive ground for mosquito breeding. The environment is destroyed completely such that the soils cannot promote plant growth, these findings are supported by Orozco-Aceves et al., (Orozco-Aceves et al., 2017) who argued that, the extraction of minerals has been considered as a major cause of extensive land degradation, loss of vegetation, and significant deforestation. These changes have been documented over the course of 30 years, in some parts of Cameroon. The environmental impact of small-scale mining activities due to poor mining practices is severe and wide spread. In most cases, large areas of land have been abandoned with pits and quarries without post reclamation hence rendering it unsuitable for farming or any other activity. In cases where mining has been carried out on hilly areas and slopes, severe erosion has taken place and this has resulted in siltation of streams and other water bodies. The effects of abandoned pits and quarries in towns have resulted in water collecting and stagnating in these areas there by contributing to health hazards and potentially increasing the incidence of malaria and other water borne diseases [83].

Social risks associated with mining activities

The study (see **Figure 14**) made it clear that mining activities led to societal issues. One example of this was the high number of teenage school drop-outs, who were completely involved in the activity in an effort to make ends meet. Hison (Hilson, 2012) also reported on this tendency in Ghana. Additionally, because the operation required a large radius for the extraction of zinc ore, land disputes were more prevalent. Furthermore, a lot of young people were abusing drugs because they believed it would improve their capacity to work. The material dealers' interactions with other suppliers and sole proprietors produced a favorable atmosphere for networking in a variety of ways, just as the operation generated cash flow for prostitution.

Sustainable measures to mitigate the impact of mining on the environment

From the findings, it was advised that the relevant authorities should sensitize and educate the people engaged in mining operations on how to safe guard the environment by employing sustainable methods of extractions, following policies and regulations on the environment, that have been put in place by ZEMA, practicing re-afforestation and sealing off the areas were material is been extracted so as to leave surrounding stable and undisturbed. All the mining operations by the small-scale holder should be legalized by obtaining a mining permit.

In addition, artisanal small-scale miners should be engaged in developmental agendas so as to give them an opportunity to voice out their concerns, challenges and opportunities. This is also in line with the study by Agboola and co-workers (Agboola et al., 2020). It was reported that the integration of the artisanal small-scale industry into the development agenda would result in environmental, social, and economic sustainability. According to some studies carried out in Zimbabwe and

Tanzania, 95.5% of miners are working illegally without mining permits, and 94.3% of them do not conduct environmental impact assessments and audits as required by legislation. This will make environmental sustainability more challenging because the lack of environmental impact assessment studies will limit other components such as environmental monitoring and spatial planning for specified artisanal small scale mining areas.

The mitigation of measure to be undertaken in order to reduce both environmental and social risks are highlighted in this section and are as follows:

(a) Training and capacity building; Co-operative members must be trained in sustainable mining practices and how to handle the environment.

(b) Planning for post-mining land use; Encourage and support cooperative members to plan and implement alternative land uses after mining such as agriculture.

(c) Formulate regulations specifically for cooperatives; Cooperatives must have their own guiding principles and be treated and judged according to their capacities. Current law is inadequate on mine closure rehabilitation for cooperatives as they always ride on big mining houses.

(d) Reclamation plan; Develop these plans to restore mined lands to their original state during and after mining operations. This should be enforced and all cooperatives to be depoliticized and made to follow these rules.

CONCLUSION

It can be concluded from the findings that artisanal small-scale mining poses a great threat on the environment, such as land degradation, where the natural state of the physical environment is disturbed living permanent changes. These changes to land topography are usually visible for all to see. For this study, air quality was at the lowest during these mining activities undertaken by the cooperatives. Underground water quality was somewhat the same during the mining activity periods, but this is not to say that the activities had minor impact on groundwater quality but rather, it shows that there is a lag in the groundwater movement. This water contamination will certainly spike in the nearest future; on the other hand, this can be contained by the usage of eco-friendly polysaccharides such as citric acid, xanthan gum and guar gum to complex with the water thereby reducing the concentration of the metal ions such as Zn and Pb. It is also advisable that plants should learn to always add enough quicklime to the highly acidic waste before discharging it into the dams. Noise pollution, though the dissipated amount was within below 85 dB, there is need of promoting usage of ear plugs especially in noise sections like comminution sections.

Social risks are invoked whenever environmental risks such as land degradation kick in. Firstly, it has increased the number of schools drop outs, as youngsters prefer to indulge in these mining activities than attend school. Communicable diseases are so prevalent, as prostitution cases increase due to booming economic activities in the area, this also has posed a greatest risk to the people directly engaged in the activities, thus compromising their life-span. Furthermore, it was observed that disputes over land were common, as the desire to own a bigger portion of land means more material to extract. Also, a majority of youths within the site were more engaged into drug abuse.

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