Tanzania Journal of Engineering and Technology 2023, **42(2)**: 55-64

Websites: https://ajol.org/tjet; https://tjet.udsm.ac.tz

ISSN 1821-536X (**print**); ISSN 2619-8789 (**electronic**)
https://doi.org/10.52339/tjet.v42i2.913

Regular Research Manuscript

Determination of Cyanide Concentration Levels in Surface Water and Soil from Artisanal Small-Scale Gold Mining Villages at Chunya, Mbeya - Tanzania

Consolatha A. Mbare, Mahir M. Said† and Rwaichi J. A. Minja

Department of Chemical ad Process Engineering, University of Dar es Salaam, Dar es Salaam, Tanzania

†Corresponding author: mahir@udsm.ac.tz, saidmahir@gmail.com

ORCID: https://orcid.org/0000-0002-1343-6255

ABSTRACT

This study aimed to determine levels of cyanide (CN) pollution in the soil and surface water at selected mining sites of Mbeya region. A total of (n = 124) samples were collected and analyzed by spectrophotometry. The cyanide levels of soil-based samples and water-based samples at Mwasenga, and Ifumbo mining sites were above the permissible limits. This was due to poor disposal of tailing from the gold processing plants and mismanagement of wastewater. On the other hand, the Cyanide was within the allowable limit for both soil and water at Godima, Itewe, Ashishira and Nyatula mining sites. This was attributed by proper management of wastewater by using artificial tanks, ponds and trenches. Also, it was observed that there is a mobility of cyanide from the processing mining site, if the tailings and wastewater are not well managed. The concentration of cyanide in the soil and water samples of about 2 mg/L was observed at distance of more than 70 m from the processing plant at Mwasenga, the situation is even worse at Ifumbo, where the cyanide concentration in soil and water were about 25 and 8 mg/L respectively, at a distance of more than 50 m from processing plant

ARTICLE INFO

Submitted: Dec. 30, 2022

Revised: Apr. 20, 2023

Accepted: Apr. 30, 2023

Published: June, 2023

Keywords: *Cyanide; Small-scale Gold Mining; Environmental Pollution*

INTRODUCTION

Mining sector, both small-scale and large-scale, in Tanzania is among the sectors that are playing a major role in the national economic development (Pedersen et al., 2019, World Bank, 2015). This is evidenced by the Bank of Tanzania's (BOT) Quarterly Economic Bulletin of June 2020, which shows that Tanzania's gold production increased by 23.5% in quarter four of the year 2019, from 9,949 kg in September 2019 to 12,289 kg in December 2019 (BOT, 2020). Also, according to the survey done by the Ministry of Mineral and Energy (MEM) in 2012, it is forecasted that, in the year 2025, the mining sector is focused to produce more than 10% of the GDP of the Government of the United Republic of Tanzania (MEM, 2012). By the end the 2022, it had reached 7.3% of Tanzania's GDP (Citizen reporter, October 2022).

Nevertheless, the mining sector being the major contributor to the nation's economy, it is one of the most world's dangerous sectors threatening an ecosystem (Mohsin, 2021). For instance, it was reported that 125 mining-related accidents and 123 deaths were recorded in registered mining sites from 2008 to May 2017 (Mutagwaba et al. 2018). On the other hand, 56 accidents and 140 deaths were recorded from unregistered (illegal) mining sites in Tanzania (Mutagwaba et al., 2018, Nkuli, 2012). According to the Ministry of Energy and Mineral the accidents and deaths are due to lack of resources, safety regulations are not followed, lack of awareness and illiteracy, inadequate equipment used, and remoteness of locations areas (MEM, 2012). Mining-related accidents and deaths are more prevalent in small-scale mining operations than in larger-scale mining (Ajith et al., 2021, ILO, 1999).

The mining industry, and in particular gold mining in Artisanal Small-Scale Mining (ASSM), has been using cyanide in its production processes for many decades due to the low cost and its effectiveness towards gold dissolution (Verbrugge et al., 2021, Ntalikwa, 2015). The recovery of gold has been replaced by cyanide due to the environmental and health effects of mercury (Zolnikov and Ortiz, 2018; Velasquez and Veiga, 2007). Despite cyanide's low cost and effectiveness in gold recovery, its high binding ability with active Iron (Fe) atom in cytochrome oxidase and inactivation of oxidative respiration pose its toxicity (Gomezulu et al., 2018). According to a toxicological study, short term exposure to high concentrations of cyanide causes harm to the nervous, respiratory and cardiovascular systems of living organisms (Zuhra and Szabo, 2021, Gomezulu et al., 2018). In addition, mishandling of cyanide may contaminate water and soil when released to the environment. Poor disposal of tailings is a major environmental problem that has both visual effects on the landscape of tailings disposal and ecological effect through water pollution, air pollution and soil pollution being caused from the discharge of contaminated waste which is released to the environment (Mutagwaba et al., 2018, Dzombak et al., 2006). This study determined the concentration of cyanide in the soil and water around the small- scale mining sites in Chunya district.

METHODOLOGY

The study was conducted in villages at Chunya district in Mbeya Region of Tanzania. The six mining villages selected were: Itewe, Nyatula, Ashishira, Ifumbo, Mwasenga and Godima as shown in Figure 1. Table 1 shows the latitudes and longitudes of the study locations. The sampling sites were selected based on the presence of gold Artisanal Small-Scale Mining (ASSM) process.

Two types of samples were collected, surface water 55 samples and 69 samples of soil making up a total of 124 samples. The six sampling sites were, Mwasenga, Godima, Nyatula, Itewe, Ashishira and Ifumbo. Water samples were collected from either effluent stream originating from the mine site or from ponds and rivers near the mine sites depending on each mining site location. While soil sediments sample were collected from the tailing and around the heap in slope direction. Each material samples were collected in triplicate. A sample from each point was treated by adding 10 mL of NaOH to raise sample pH to 11 (Allen, 1989).

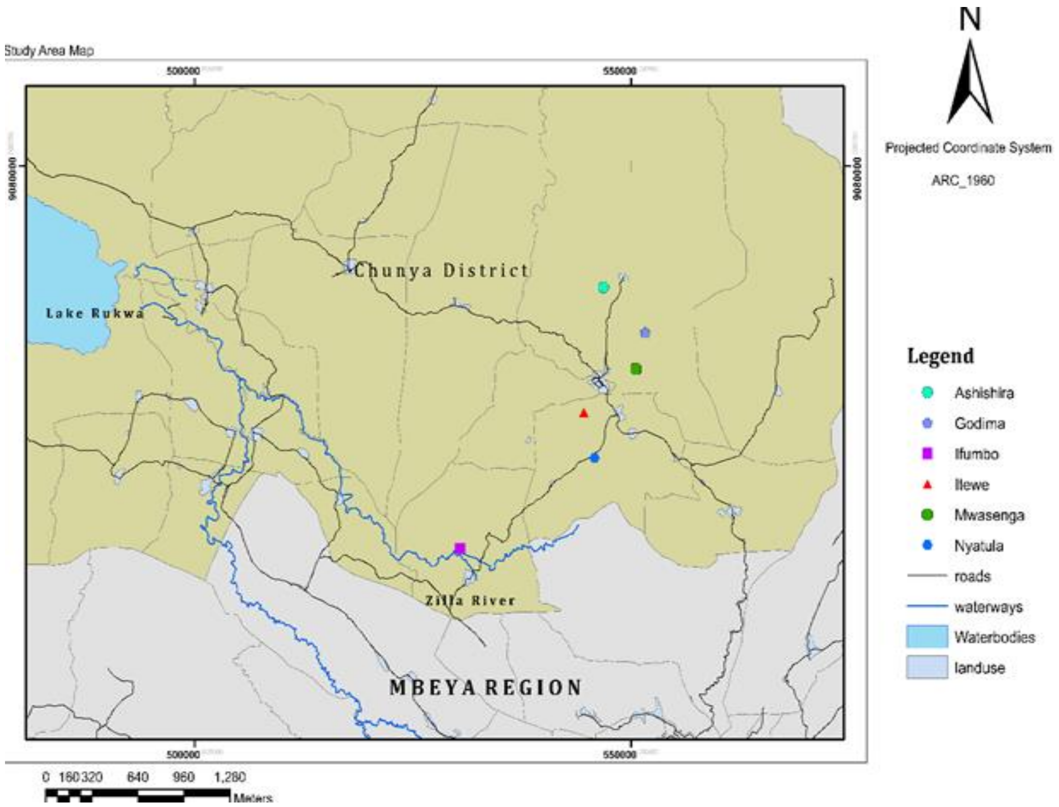

Figure 1: Map showing location of Chunya district and the villages sampling mining sites.

Table 1: Latitudes and Longitudes of the villages sampling mining sites in Chunya District

S/No	Code	Village Name	Latitude	Longitude
1	IF	Ifumbo	8.712472°S	33.282778°E
2	ASY	Ashishira	8.435040°S	33.428870°E
3	NYL	Nyatula	8.712472°S	33.283089^{0}E
4	MSG	Mwasenga	8.513965°S	33.457290°E
5	IT	Itewe	8.553075°S	33.403255°E
6	GDM	Godima	8.479629°S	33.471436°E

According to APHA (1998) when pH decreases, solubility increases, and particles become more mobile. At pH below 8, more cyanide exists as a gaseous, which is extremely toxic thus, it is necessary to keep cyanide under a basic medium (Anning et al., 2021; Bitala et al., 2009). The degree of alkalinity and acidity was measured by pH meter as it is known that pH influences the degradation of cyanide (Bitala et al., 2009).

The preparation of water and soil samples for analysis was done at the Botany Department Laboratory, University of Dar es Salaam. Samples were prepared according to the standard operating procedures for preparing soil and water sample (USEPA, 2016). The soil samples were then ground using mortar and pestle to a fairly uniform size and sieved through 2.00 mm mesh to obtain a representative sample for subsequent metal analysis. The surface water samples were prepared by filtering through a cotton cloth to remove suspended matters. Sample extraction was done according to the method reported by Allen (1989). Extraction of stable CN present in soil was done after pre-treating the soil samples with cuprous chloride in hydrochloric acid. 5 grams of soil sample were added into distillation tubes and 5 mL of 2% cuprous chloride in 5 M HCl (w/v) was added and then diluted to 80 mL with distilled water. The obtained solution was heated and distilled into 5 mL of 1M of Sodium Hydroxide (NaOH). The process continued until 40 mL of distil was collected. The obtained distil (40 mL) was then used to analyse total CN – using Ninhydrin colorimetric assay.

Colorimetric determination of total Cyanide was done according to the method reported by (Drochioiu et al., 2011). 1 mL sample of distilling from soil and each water sample was kept into a cuvette and 0.5 ml of 0.225% Ninhydrin solution in 2% Sodium carbonate was added to the solution. The pH of the solution was adjusted by adding 2 mL of 2.5 M Sodium Hydroxide to a pH of 12.8. This changed the colour of solution to deep blue depending on CN– concentration in the sample and standard solution of KCN. The absorbance of each sample was obtained using UV-visible Spectrophotometer JENWAY 6305 model (PerkinElmer Inc., United States).

The absorbance produced is directly proportional to the concentration of the absorbing atoms at a given wavelength. Therefore, by measuring the amount of light absorbed by known standards, the absorbance and hence the concentrations of the unknown samples can be determined. In this study, the absorbance of CN standards was measured to enable the quantitative determination of the samples' CN. The calibration curves for the cyanide concentration were made by running a chain of standard solutions prepared by serial dilution such as 0, 1, 2, 4, 8 and 10 mg/L. Through the data points the best fit straight line was drawn from linear regression of absorbance versus concentration as shown in Figure 2. The concentration of CN – was determined with the aid of a standard calibration curve. The absorbance of each sample recorded from UV-visible Spectrophotometer was then correlated by linear graph and its unknown concentration was determined as per Lambert-Beer law (Skoog et al., 1992).

The results were compared with various established standards such as Tanzania Bureau of Standards (TBS), World Health Organization (WHO) and Environmental Protection Agency (EPA). The permissible levels of the concentration of cyanide set for surface water and soil were 0.2 mg/L and 0.4 mg/L respectively.

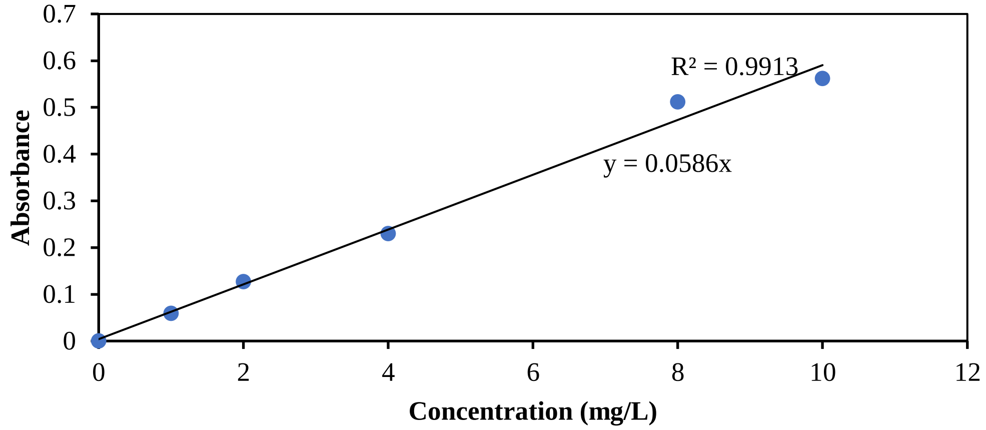

Figure 2: Standard Calibration Curve for Cn Determination.

RESULTS AND DISCUSSION

Analysis of cyanide concentration in soil samples around the tailing dumping site

Among all the six sampling sites, cyanide content in soil was detected at Mwasenga and Ifumbo. The mean concentration of cyanide detected at Mwasenga soil samples was 2.658 ± 0.787 mg/L, while at Ifumbo soil samples was 26.139 ± 0.601 mg/L. Comparing to national and international recommended range of cyanide in soil-based samples, the mean concentrations of cyanide at Mwasenga and Ifumbo mining site were higher than the TBS permissible concentrations limit of 0.4 mg/l for soil samples. In the case of Godima, Nyatula, Ashishira and Itewe mining sites, the mean concentrations of cyanide were below the instrumental detection limit (BDL) of < 0.001 mg/L).

These results reveal that the soils at Mwasenga and Ifumbo mining sites are contaminated with cyanide. This is because of improper disposal of tailing and wastewater as shown in Figure 4, which is contrary to the environmental requirements (EPA, 2021; Botz, 2001). Furthermore, it was observed that the dumped tailings in these mining sites were not properly managed as they are dumped without treatment procedure. As a result, when it rains, the cyanide leached to the ponds, rivers and soil.

In case of Godima, Nyatula, Itewe and Ashishira mining sites, the non-detection of cyanide is attributed by management of contaminated wastewater through construction of artificial tanks, ponds and trenches for recycling of collected runoff wastewaters from tailings as observed in Figure 5.

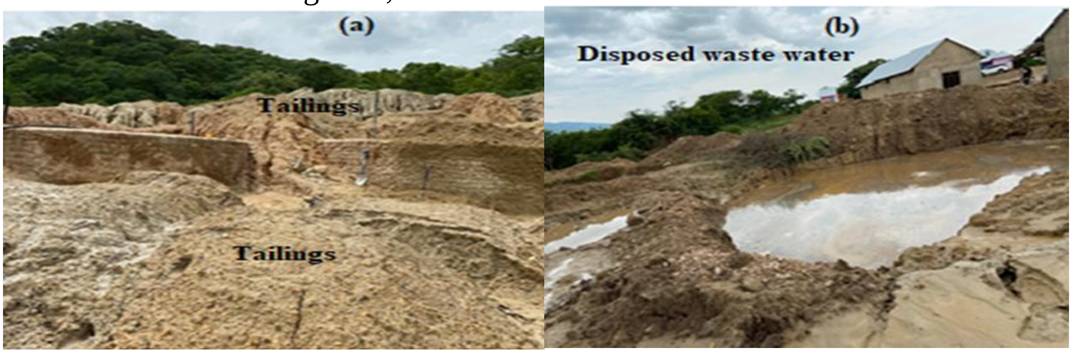

Figure 3: Effect of Gold mining extraction (a) Tailings and (b) Disposed wastewater at Ifumbo mining sites.

Figure 4: Artificial tank for storing wastewater at Godima

Analysis of cyanide concentration in water- based samples around wastewater ponds

The mean concentrations of cyanide in water-based samples of the six sampling sites are as shown in Table 2. These findings concur with the finding reported by Bitala et al. (2009) on the levels of cyanide in soil, sediments and water from the vicinity of North Mara gold mines in Tarime District, Tanzania.

It was also noted that Ifumbo and Mwasenga mining sites had higher average concentrations of cyanide among the six mining sites. This could be due to leakage of contaminated wastewaters from poorly constructed ponds as it was observed. In addition, this may be due to wastewater runoff from the poorly disposed of tailings as a result of the absence of trenches which are used for collection of wastewaters as was observed in the areas. Nsimba (2009) and Wills and Munn (2006) also discussed the leaching of cyanide from poor constrcted ponds. The average concentrations of cyanide in wastewater at Mwasenga and Ifumbo mining sites were observed to be higher than the TBS permissible limit. On the other hand, the cyanide detected for the water samples from Godima, Nyatula, Ashishira and Itewe mining sites were within the limit set by TBS.

Table 2: Cyanide concentration in water for the six mining sites

Site	Mwasenga	Ifumbo	Godima	Nyatula	Ashishira	Itewe
Cyanide concentration (mg/L)	2.013 ± 0.040	9.469 ± 0.956	0.032 ± 0.009	0.026 ± 0.009	0.031 ± 0.013	0.021 ± 0.005

Cyanide spreads around Mwasenga and Ifumbo mining sites

The distribution/spread of cyanide at Mwasenga and Ifumbo to the surrounding has been anticipated, because of the observed high concentration of cyanide around the processing plant and barren tank. The analysis of cyanide around the two processing plants using distance from the processing plant and altitude as main parameters lead to the results as shown in Figure 6. It was assumed that the mobility of cyanide will flow from high altitude to low altitude.

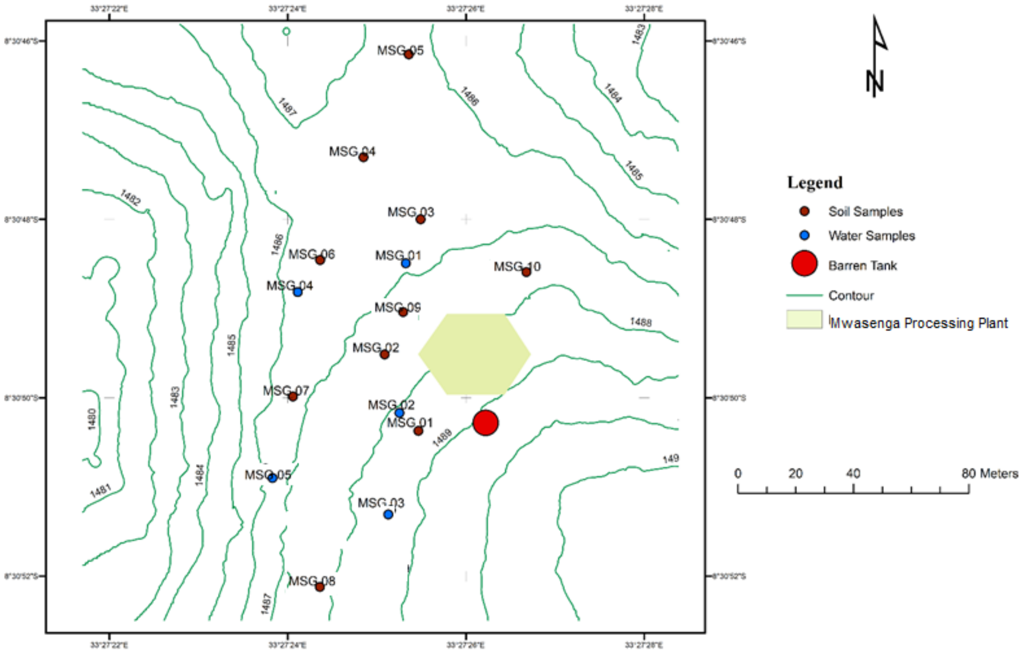

Figure 5: Cyanide concentration map at Mwasenga mining site.

Figure 6 represents cyanide concentrations at Mwasenga mining site. It was observed that the area that is near the processing plant and barren tank have higher concentration of cyanide above 3 mg/L, the concentration decreases as distance increases from the processing plant as shown in Table 2. Moreover, the concentration of cyanide varied slightly with altitudes from highland to lowland. The highlands were observed to have higher concentrations of cyanide than the lowlands. This is because most of processing mining sites are located in the highlands. The concentration in surface water is 2 mg/l for all sources that are nearby the mining sites as shown in Table 3. A similar finding has been reported by Allen (1989). Higher concentration of cyanide was observed in the area closer to the barren tanks as a result of continuous disposal of tailings, Figure 7.

Figure 6: Disposed tailings at Mwasenga Mining site.

Table 2: The Average Concentrations of Cyanide in Soil Sample with respect to Distance (m) and Altitude (m) at Mwasenga mining site from Processing Plant

Code	Distance (m)	Altitude (m)	Concentration
MSG 01	23	1488.250	3.867 ± 0.813
MSG 02	42	1487.500	3.789 ± 0.703
MSG 03	48	1487.750	2.718 ± 0.600
MSG 04	74	1486.750	1.567 ± 0.156
MSG 05	63	1486.250	1.296 ± 0.125
MSG 06	66	1486.250	2.426 ± 0.213
MSG 07	76	1486.500	2.829 ± 0.245
MSG 08	79	1487.500	2.427 ± 0.330
MSG 09	47	1487.250	2.606 ± 0.265
MSG 10	64	1487.500	2.848 ± 0.415

Table 3: The Average Concentrations of Cyanide in Surface Water Sample with respect to Distance (m) and Altitude (m) at Mwasenga mining site from Processing Plant

Code	Distance (m)	Altitude (m)	Concentration
MSG 01	62	1486.750	2.041 ± 0.040
MSG 02	41	1488.000	1.903 ± 0.013
MSG 03	30	1488.250	2.039 ± 0.045
MSG 04	78	1486.250	2.017 ± 0.031
MSG 05	67	1487.000	2.023 ± 0.036

Figure 7 shows the sampling location in Ifumbo mining site. The site consists of three mining processing plants and one barrel tank (pond). Nearby, there is a river Zilla. The pond that collects wastewater is not properly constructed as shown in Figure 4b. As a result, when it rains the cyanide spreads to the whole area. The cyanide concentration at Ifumbo is about 26 mg/L and 10 mg/L in soil and surface water respectively. The results are shown in Table 4 and 5.

With regard to the level of cyanide contamination, it is evident that the soil and surface water samples at Ifumbo mining site have a very high risk of causing detrimental effect to living organisms. The soil and surface water samples' cyanide levels extremely exceed the limits specified by TBS.

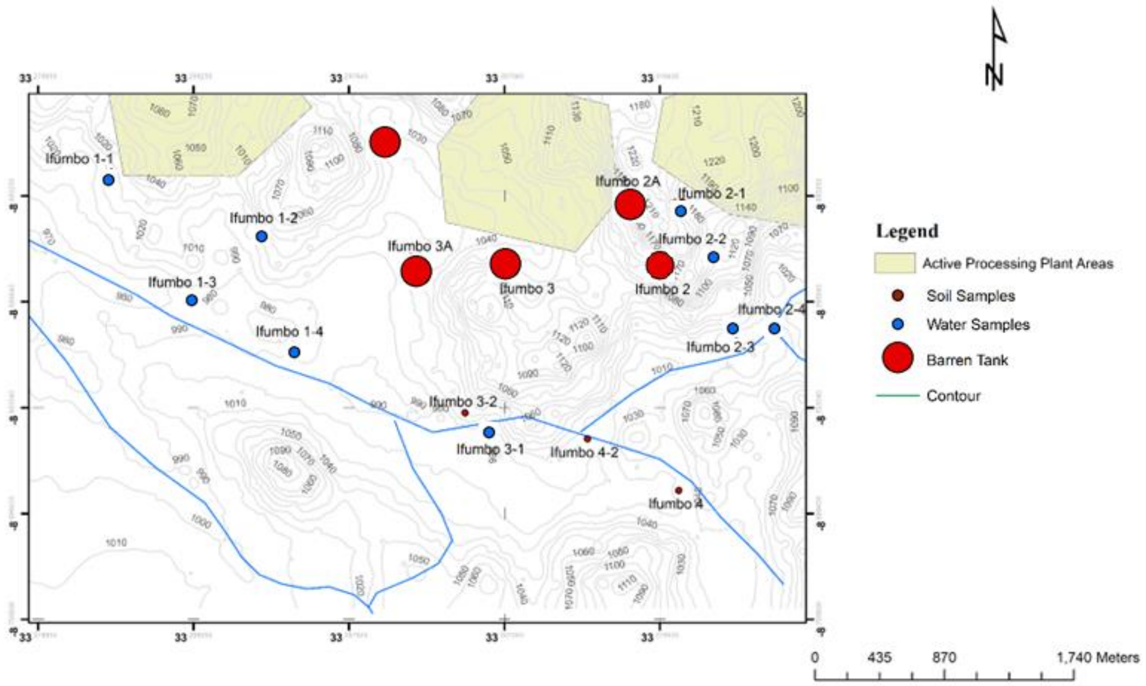

Figure 7: Cyanide concentration at Ifumbo mining site.

Table 2: The Average Concentrations of Cyanide in Soil Sample with respect to Distance (m) and Altitude (m) at Ifumbo mining site from Processing Plant

Code	Distance (m)	Altitude (m)	Concentration
IFM 01	24	1025.000	26.180 ± 0.600
IFM 02	33	1005.000	26.790 ± 0.615
IFM 03	20	1140.000	26.537 ± 0.714
IFM 04	45	995.000	26.293 ± 0.610
IFM 05	26	1010.000	26.553 ± 0.643
IFM 06	32	1016.000	25.991 ± 0.601
IFM 07	25	1110.000	26.463 ± 0.605
IFM 08	27	1135.000	26.424 ± 0.642
IFM 09	31	1145.000	25.131 ± 0.614
IFM 10	55	1165.000	25.024 ± 0.700

Table 3: The Average Concentrations of Cyanide in Surface Water Sample with respect to Distance (m) and Altitude (m) at Ifumbo Mining site from Processing Plant

Code	Distance (m)	Altitude (m)	Concentration
IFM 01	23	1010.000	10.590 ± 0.955
IFM 02	15	1030.000	10.284 ± 0.924
IFM 03	27	980.000	9.381 ± 0.945
IFM 04	46	985.000	8.652 ± 0.705
IFM 05	51	985.000	8.440 ± 0.702

CONCLUSIONS AND RECOMMENDATIONS

The total cyanide levels found in the soil and surface water samples were below the set limit (0.2 mg/L for water and 0.4 mg/L for soil) except for the two mining sites at Mwasenga and Ifumbo. This was due to the poor construction of the artificial ponds which are used to store wastewater and poor disposal of tailings for the two mining sites.
It is recommended for the government to enforce the laws and regulations as per National Environmental Management Council requirements to ensure that Artisanal Small Scale Miners design and construct proper mining site infrastructures which are well managed in compliance to environmental requirements so as to prevent cyanide pollution to the environment.
The ASSM should ensure proper barricade of their mining sites so as to avoid other people and animals to access the mining areas which are highly contaminated.

REFERENCES

Ajith M.M., Ghosh A.K. and Jansz J. (2021). A mixed-method investigations of work, government and social factors associated with severe injuries in artisanal and small-scale mining (ASM) operations. Safety Science. Jun 1;138: 105244.

Allen S.E., (1989). Chemical Analysis of Ecological Materials (Second ed.). Oxford London: Blackwell Scientific Publications.

American Public Health Association (APHA). (1998). American Water Works Association and Water pollution control Federation, Standard Methods for the Examination and Waste Water. 20th Edition, page 60-430.

Anning C., Wang J., Chen P., Batmunkh I. and Lyu X. (2019). Determination and detoxification of cyanide in gold mine tailings: a review. Waste Management & Research. **37**(11):1117-26.

Bank of Tanzania's (BOT) (2020). Quarterly Economic Bulletin of June 2020. VOL. LII NO.2

Bitala M., Kweyunga C. and Manoko M. (2009). Level of Heavy metals in Soil, sediment and Water from the Vicinity of North Mara Gold Mine in Tarime District, Tanzania

Botz M. (2001). Overview of Cyanide Treatment Methods. Mining Environmental Management, Mining Journal Ltd, Page. 28-30.

Citizen reporter, (2022). Mining Sector Hits 7.3% of Tanzania's GDP, https://www.thecitizen.co.tz/tanzania/news/business/mining-sector-hits-7-3-percent-of-tanzania-s-gdp-3977880.

Drochioiu G., Sandu I., Gradinaru R., Zbancioc G. and Mangalagiu I. (2011). Ninhydrin-Based Forensic Investigations: Ii. Cyanide Analytical Toxicology. *International Journal of Criminal Investigation*, **1**(4): 213–226.

Dzombak D.A., Ghosh R.S., and Wong-Chong G.M. (2006). Cyanide in Water and Soil Chemistry, Risk and Management.

EPA (2021) *Cyanide Water Pollution*. Retrieved from Search Water Filters: https://www.searchwaterfilters.com/waterpollution/Cyanide/#:~:text=Benefits%20of%20Water%20filtration%20and%20protection%20from%20Cyanide,occur%20in%20drinking%20water%20 without%20causing%20bodily%20damage.

Gomezulu E.S., Mwakaje A. and Katima H.Y. (2018) Heavy metals and Cyanide distribution in the villages surrounding Buzwagi gold mine in Tanzania. *Tanzania Journal of Science*, **44**(1): 107–122.

International Labour Organization (ILO) (1999) Social and Labour Issues in Small-scale Mines. Report for discussion at the Tripartite Meeting on Social and Labour Issues in Small-scale Mines. ILO. Geneva

Ministry of Energy and Minerals (MEM) (2012) Artisanal and small-scale mining in Tanzania. Dar-Es-Salaam.

Mohsin M., Zhu Q., Naseem S. Sarfraz M. Ivascu L. (2021). Mining industry impact on environmental sustainability, economic growth, social interaction, and public health: an application of semi-quantitative mathematical approach. Processes, **9**(6):972.

Mutagwaba W Tindyebwa JB Makanta V Kaballega D and Maeda G 2018 Artisanal and small-scale mining in Tanzania–Evidence to inform an 'action dialogue'. London: IIED.