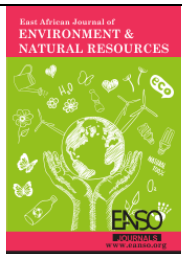

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Original Article

Review of the Environmental Impacts Mitigation Measures on Water Resource Management of Mining Projects in Tanzania, the Case of Buzwagi Gold Mine

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ABSTRACT

The study aimed to review the implementation of mitigation measures recommended during the Environmental Impact Assessment (EIA) of Buzwagi Gold Mine (BGM) to protect water quality and availability in the surrounding villages. This was done by evaluating the predicted impacts on water resource management and assessing the proposed mitigation measures outlined in the EIA. The effectiveness of mitigation measures for groundwater quantity was assessed by measuring water levels in 11 wells, which are in the village close to the mining area during both dry and rainy seasons. Additionally, the mitigation measure aimed at preventing groundwater contamination was evaluated by analysing the quality of water and sediments from the wells. A total of 28 water samples and 28 sediment samples were collected and tested for total cyanide and heavy metals. The results indicated that wells located near the mining area were contaminated with cyanide, whereas those farther away were not. Furthermore, sediment samples from the wells closer to the Tailings Storage Facility (TSF) exhibited higher concentrations of heavy metals compared to those situated farther from the TSF. The depth of water levels in the wells was lower during the rainy season than in the dry season. The study concluded that not all mitigation measures proposed in Environmental Impact Statements (EIS) are fully implemented in Tanzania's mining areas, and among those that are implemented, not all are effective.

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INTRODUCTION

The Environmental Impact Assessment (EIA) plays a crucial role in environmental protection. Despite its importance, studies indicate that in some cases, project proponents completely disregard the mitigation measures recommended during the EIA process (Fatehali, 1990; Arts et al., 2000; Wood, 2003). Certain projects, such as mining, have significant adverse environmental impacts, and ignoring the predicted consequences of these projects can put nearby communities at serious risk. (Hodgson, 2010) describes the toxicity of mercury, especially when it is converted to readily absorbed methyl mercury by bacteria in the aquatic sediments. When in methyl mercury form, it is extremely dangerous. By 1970 in Japan, mercury caused at least 107 deaths and more than 800 cases of mercury poisoning were reported (Hodgson, 2010).

Arsenic, some chromium compounds, as well as Nickel, are also well-known human carcinogens (Hodgson, 2010), they are therefore very dangerous. In addition, acute chromium exposure is known to its kidney damage (Gilbert, 2004). Despite the importance of follow-up in proposed mitigation measures suggested during EIA of developmental projects, especially mining, studies show that in a few cases where follow-up is done, it is not done well (Morrison-Saunders & Bailey, 1999).

Mining has been identified as one of the sectors where conducting an EIA is mandatory in Tanzania (URT, 2004). Cyanide, an extremely toxic compound (Basile, 2008), requires costly transportation, storage, and cleanup procedures. It is also recognised as a hazardous pollutant frequently released into the environment (Osabamiro, 2020; Gomezulu et al., 2018). In addition to cyanide, heavy metals are commonly found in gold mining areas. Some heavy metals, such as mercury, cadmium, and arsenic, are highly toxic. EIAs for mining projects require the protection of both surface and groundwater from contamination by cyanide and heavy metals.

Communities surrounding Buzwagi Gold Mine rely entirely on groundwater as their primary water source. Their close proximity to the mine makes them highly vulnerable to pollution from cyanide used in gold extraction, as well as heavy metals and other hazardous substances. Additionally, groundwater resources are at risk of depletion due to pumping activities associated with open-pit mining. This study aims to quantify the levels of cyanide and heavy metals in water and sediments while also assessing water availability for mining communities. This assessment serves as a means of evaluating the extent to which water-related mitigation measures recommended in the EIA have been implemented.

METHODOLOGY

Buzwagi Gold Mine is located in northern Tanzania, within the Shinyanga region. This region is part of the Lake Victoria zone (Figure. 1). The mine is surrounded by three villages: Mwime, Mwendakulima, and Chapulya (Figure. 1). Additionally, Nyihogo village, situated more than 8 km from the project site, was included in the study

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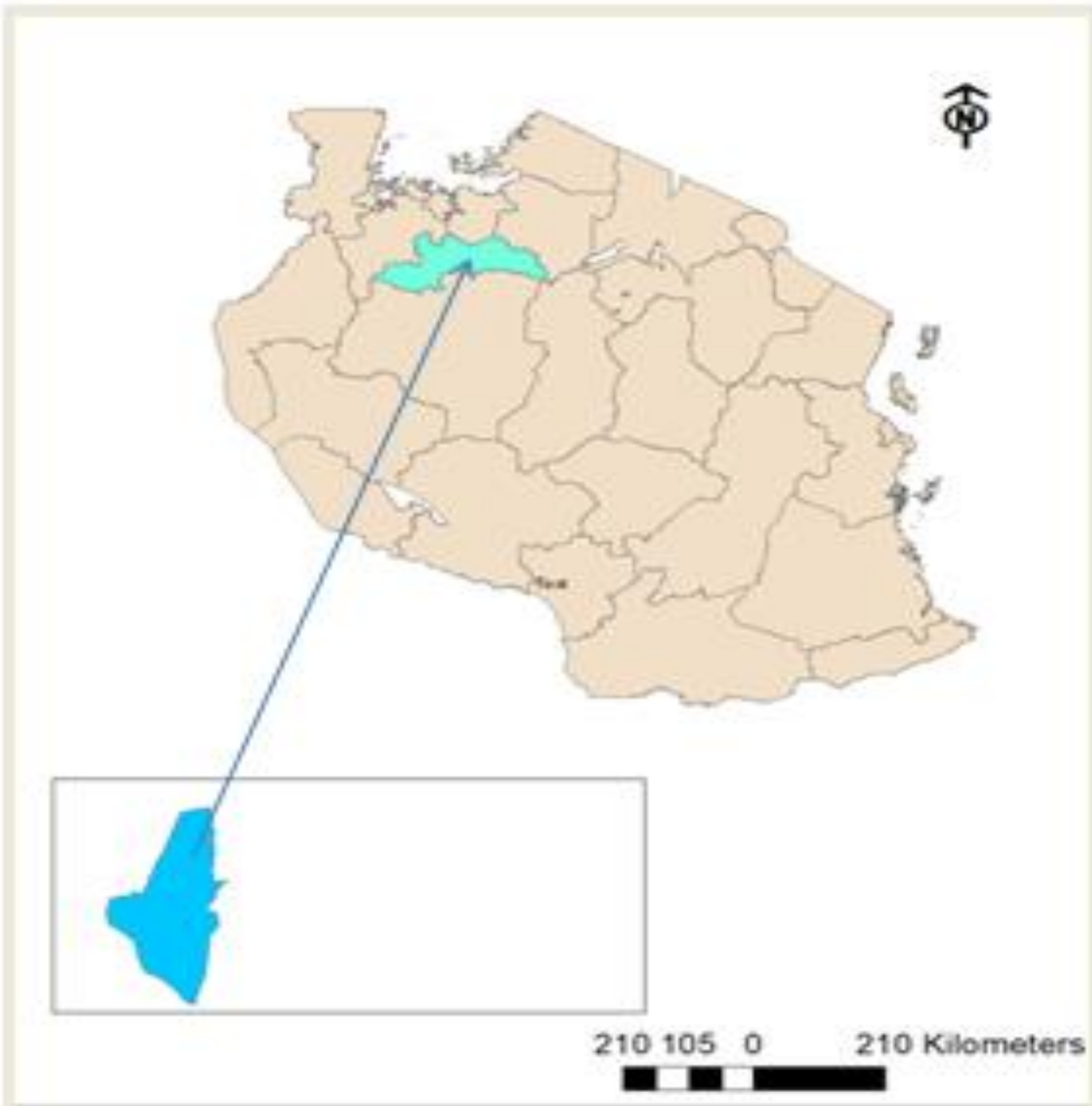
as a control area. This village was selected based on the fact that it is far from the mining area and it has therefore not been affected by the mining operations, and therefore the wells in the village have also not been affected by mining activities. Results from Nyihogo were compared with those from the villages closer to the mine to assess the potential environmental impact. The mine is situated approximately 6 km west of Kahama town.

According to the Tanzania census of 2012, the population of Kahama Town Council was recorded at 242,208, with 13,711 residents in Mwendakulima Ward (URT, 2012). By 2022, the population of Kahama had increased to 453,654, with 25,418 people residing in Mwendakulima Ward (URT, 2022). Mwendakulima Ward, being the closest to Buzwagi Gold Mine, is particularly relevant to this study.

Figure 1: The Map of the Study Area



Sample Collection

Various types of samples were collected as described below:

Water and Sediment Samples

Water and sediment samples were collected from wells used by communities surrounding the mining

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area. The purpose was to investigate the potential leakage of hazardous chemicals from the mine into community wells through seepage. A total of 28 water samples and 28 sediment samples were collected, 14 from each season (rainy and dry). Of these, 11 samples per season were taken from wells located near the mine, while the remaining 3 were collected from wells situated farther away in the village, serving as control samples.

Measurement of Water Table Depth

The depth of the water table was measured during both the dry and rainy seasons. This was done to assess the availability of water for nearby communities throughout the year and to evaluate whether the mitigation measures intended to ensure water availability were effectively implemented.

Interview Data

Interviews were conducted with 100 residents living in villages surrounding the mine. The purpose of these interviews was to gather community perspectives on the availability of water for their daily needs.

Documentary Review

Relevant documents were also reviewed, including the Environmental Impact Statement (EIS) and auditing reports from BGM. The EIS was analysed to identify water-related impacts and the proposed mitigation measures. Auditing reports were examined to evaluate the implementation and effectiveness of these measures.

Ethical Consideration

In this research, care was taken to follow ethical guidelines. When possible, local leaders were involved in the research to make the process more open and to make sure it reflected the community's needs and concerns. To protect the people who took part, their names and personal details were not included in any notes or reports. Only the research team could see the original data. This helped people feel safe to speak honestly without worrying about being identified or facing any negative consequences.

Preparation and Analysis of Water and Sediment Samples

Cyanide Analysis

To determine cyanide concentrations, a standard method as in (APHA, 1999) was used; cuprous chloride was first added to the samples. The samples were then digested by dilution and heated, during which hydrogen cyanide (HCN) gas was released. The evolved HCN was distilled into 5 ml of sodium hydroxide (NaOH) solution. To develop colour for measurement, chloramine was added, followed by the addition of the pyridine-pyrazolone reagent. The absorbance was then measured at 620 nm, and the cyanide concentration was determined based on this reading.

Heavy Metal Analysis

Prior to analysis, water samples intended for heavy metal testing were digested by heating after the addition of nitric acid. Sediment samples, on the other hand, were digested using aqua regia, a mixture of hydrochloric acid and nitric acid in a 3:1 ratio and then heated. The concentrations of heavy metals were determined using Inductively Coupled Plasma (ICP). The metals analysed included nickel, lead, manganese, and iron.

RESULTS AND DISCUSSION

Review of Impacts and Mitigation Measures

The identified impacts related to Water Resources Management (WRM) were primarily aimed at preventing:

- Groundwater contamination,
- Runoff from the mine is reaching nearby settlements, and
- Over-abstraction of groundwater, which could limit water availability for local communities.

Since there are no nearby rivers, surface water was not considered in the assessment. Therefore, the

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suggested mitigation measures focused on maintaining downstream water quality and controlling seepage from the Storm Water Storage Pond (SWSP) and the Tailings Storage Facility (TSF).

Impacts on Groundwater Quantity

Two main impacts on groundwater quantity were predicted, each with corresponding mitigation measures. These are summarised in Table 1.

Table 1: Predicted Impacts on Groundwater Quantity and Corresponding Mitigation Measures

Predicted Impacts	Suggested Mitigation Measures
(a) Lowering of the water table due to water abstraction and dewatering of the open pit during the operation phase.	(i) Proactive mitigation through the implementation of a Community Well Program (CWP) and improvement of existing wells (e.g., deepening or reconstruction).
	(ii) Regular monitoring of groundwater abstraction to ensure compliance with permitted withdrawal rates.
	(iii) Replacement of liners and evaporation covers of the Water Storage Pond (WSP) and SWSP when degraded.
(b) Reduction in available water for local users at closure.	(Same as above measures apply)

Source: Environmental Impact Statement (EIS) of BGM

Assessment of Water Availability for Local Users

The availability of water for local users was assessed through a combination of resident interviews and measurement of water table depth in community wells. Additionally, a review of Environmental Auditing Reports was conducted to evaluate the implementation of Mitigation Measure (ii) from Table 1, which addresses the monitoring of groundwater abstraction.

The objective of the Community Well Program (CWP) under Mitigation Measure (i) was to enhance community water access by deepening or reconstructing existing wells. Of the 100 residents interviewed in the communities surrounding the mine, 62% reported that they had locally constructed wells. However, only 11 residents (18% of those with wells) stated that their wells had ever been visited as part of the mitigation efforts. Despite these visits, none of the wells had been deepened or reconstructed, which is contrary to the proposed mitigation strategy.

Further assessment of water availability was carried out by surveying the same 100 residents. Respondents were asked to express their level of agreement with the statement: “Water is available throughout the year without any shortage.”
Responses were recorded using a five-point Likert scale: Strongly Agree, Agree, Uncertain, Disagree, and Strongly Disagree.

The results showed that more than 40% of respondents were uncertain about the year-round availability of water. Meanwhile, 37% either disagreed or strongly disagreed with the statement, indicating they experienced water shortages. In contrast, only 21% agreed or strongly agreed that water was available throughout the year without shortage (see Figure 2).

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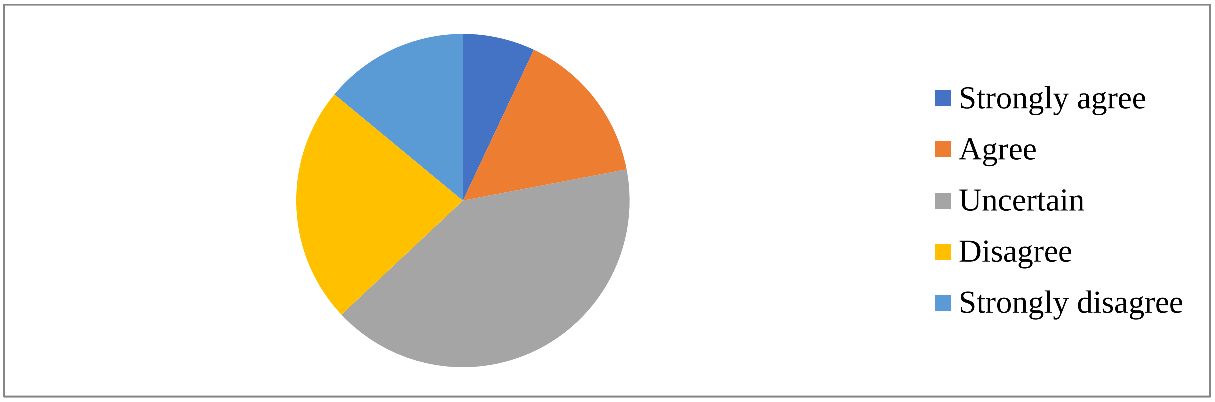
Figure 2: Community's Views (in %) on the Availability of Water for Local Users

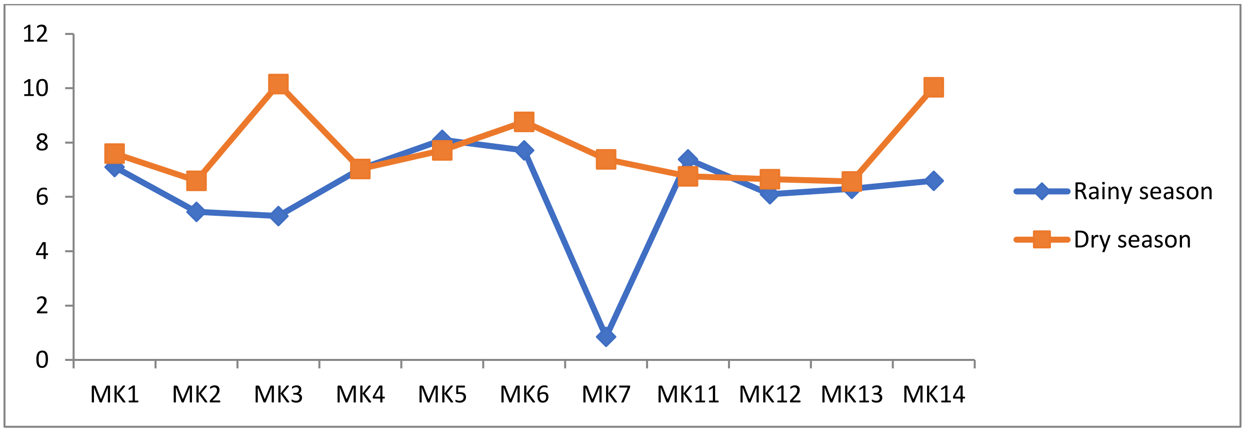


Seasonal Variation in Water Availability

Field observations by the researcher indicated that water availability in community wells varied significantly between seasons. During the rainy season, wells generally had an abundant supply of water. However, in the dry season, a noticeable shortage was observed, residents often had to wake up very early in the morning to search for water due to the limited supply.

Measurements of depth to water levels taken during both the rainy and dry seasons confirmed this observation. In 10 out of the 11 wells monitored, water levels were higher during the rainy season as compared to the dry season (see Figure 3). Statistical analysis using Graphpad Instat with a paired t-test revealed a significant difference between the two seasons. The mean depth to water in the dry season was significantly greater than that in the wet season, indicating lower water availability during dry periods (P = 0.0032, $P < 0.05$) at a 95% confidence level.

Figure 3: Seasonal Comparison of Depth to Water Levels in Community Wells



The Environmental Auditing Report of 2014, conducted by NEMC, revealed that the mining company was unable to measure the volume of water abstracted, as no water flow meter had been installed. This indicates that Mitigation Measure (ii) from Table 1, monitoring of groundwater abstraction to ensure that permitted rates are not exceeded, was not implemented as planned.

Impacts on Downstream Water Quality

Three potential impacts on downstream water quality were identified during the operation phase of the mine. For each predicted impact, a specific mitigation measure was proposed. These are summarised in Table 2.

Table 2: Predicted Impacts on Downstream Water Quality and Corresponding Mitigation Measures

Predicted Impacts	Mitigation Measures Suggested
(a) Deterioration of downstream water quality during the operation phase due to surface water releases from the open pit.	(i) Operational spill control measures are expected to limit explosive spillage to no more than 3%.
(b) Contamination from leaks or spills in the plant area during operation.	(ii) Implementation of spill prevention and containment systems, including emergency response, clean-up, and rehabilitation. The plant area was designed as a closed system.
(c) Increased suspended solids in downstream water due to surface runoff from collection channels.	(iii) Installation of siltation control structures, such as silt fences or silt curtains, was proposed as a mitigation measure.

Source: Environmental Impact Statement (EIS) of BGM

The implementation of these mitigation measures was assessed through field observation. The author observed that silt fences and silt curtains, as proposed in the EIS, had been installed on-site (see Plate 1). This indicates that the spill prevention and siltation control measures were indeed implemented, thereby supporting the conclusion that mitigation strategies to protect downstream water quality were effectively put in place.

Plate 1: The Silt Fence and Silt Curtains Surrounding Buzwagi Mine

Source*: (By the author in January 2018)*

Impacts on Groundwater Quality

In relation to groundwater quality, one key impact was predicted, along with a corresponding mitigation measure, as presented in Table 3.

Table 3: Predicted Impact on Groundwater Quality and Associated Mitigation Measures

Predicted Impact	Mitigation Measure Suggested
Contamination of groundwater due to seepage from the Plant Site Water Pond (PSWP), Storm Water Storage Pond (SWSP), and Tailings Storage Facility (TSF).	Zero discharge from PSWP and TSF will be ensured.

Source**:** Environmental Impact Statement (EIS) of BGM

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To evaluate the effectiveness of the proposed seepage control mitigation measures, both water and sediment samples were collected from wells surrounding the BGM mining area. These samples were analysed for total cyanide and selected heavy metals during both the rainy and dry seasons, in order to detect any signs of contamination.

In addition to sample analysis, Environmental Auditing (EA) reports were reviewed to assess the implementation of the zero discharge policy and other mitigation strategies aimed at preventing groundwater pollution.

Assessment of Water Quality

The analysis of cyanide levels in water revealed generally low concentrations, with detectable amounts found only in wells located near the mining area, specifically wells labelled MKW-1 to MKW-6 and MMW-1 to MMW-5 (see Table 4). In contrast, cyanide was not detected in wells located farther from the mine, identified as NY-1 to NY-3. All cyanide concentrations detected were within the World Health Organisation (WHO) recommended limit for drinking water, which is 0.07 mg/L. These findings suggest that mining activities are a likely source of localised cyanide contamination in the groundwater.

In terms of heavy metals, the results showed a more variable pattern. Notably, in some instances, wells located farther from the mine exhibited higher concentrations of certain heavy metals, such as lead, compared to those nearer the mining site (refer to Table 4). Lead was detected only during the dry season, and all observed levels exceeded the WHO permissible limit of 0.01 mg/L for drinking water.

Iron concentrations in water were also significantly high. In 9 out of the 14 wells (64%), the levels of iron were higher during the dry season than in the rainy season. This seasonal variation is attributed to dilution effects: during the rainy season, increased water volume results in lower concentrations of contaminants, whereas in the dry season, reduced water availability leads to higher concentrations.

Table 4: The Levels of Cyanide and Heavy Metals in Water During the Dry and Rainy Seasons

	Dry season					**Rainy season**				
Well name	CN	Pb	Fe	Mn	Ni	CN	Pb	Fe	Mn	Ni
NYW-1	BL	0.36	0.19	BL	BL	BL	BL	0.05	BL	BL
NYW-2	BL	0.04	0.05	BL	0.02	BL	BL	0.18	BL	BL
NYW-3	BL	0.02	0.05	BL	0.05	BL	BL	BL	BL	BL
MKW-1	0.63	BL	0.16	BL	BL	0.27	BL	0.02	BL	BL
MKW-2	0.6	0.02	BL	BL	BL	1.07	BL	0.03	BL	BL
MKW-3	BL	BL	0.25	BL	BL	BL	BL	0.11	BL	BL
MKW-4	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL
MKW-5	0.33	BL	0.21	BL	BL	0.23	BL	0.1	BL	BL
MKW-6	BL	BL	0.19	BL	BL	BL	BL	0.05	BL	BL
MMW-1	0.4	BL	6.92	BL	BL	BL	BL	3.38	BL	BL
MMW-2	0.77	BL	2.1	BL	BL	BL	BL	0.82	BL	BL
MMW-3	BL	BL	BL	BL	BL	1.1	BL	1.93	BL	BL
MMW-4	BL	BL	1.79	BL	BL	BL	BL	1.27	BL	BL
MMW-5	0.6	BL	BL	BL	BL	BL	BL	0.78	BL	BL

Note**:** BL means Below Detection Limit

Assessment of Sediment Quality

The analysis of sediment samples revealed a pattern similar to that observed in water samples. Cyanide contamination in sediments was detected only in wells located near the mining site. In contrast, no cyanide was detected in sediment samples collected from wells far from the mine during both the rainy and dry seasons (see Figures 4 and 5). These findings further support the conclusion that cyanide

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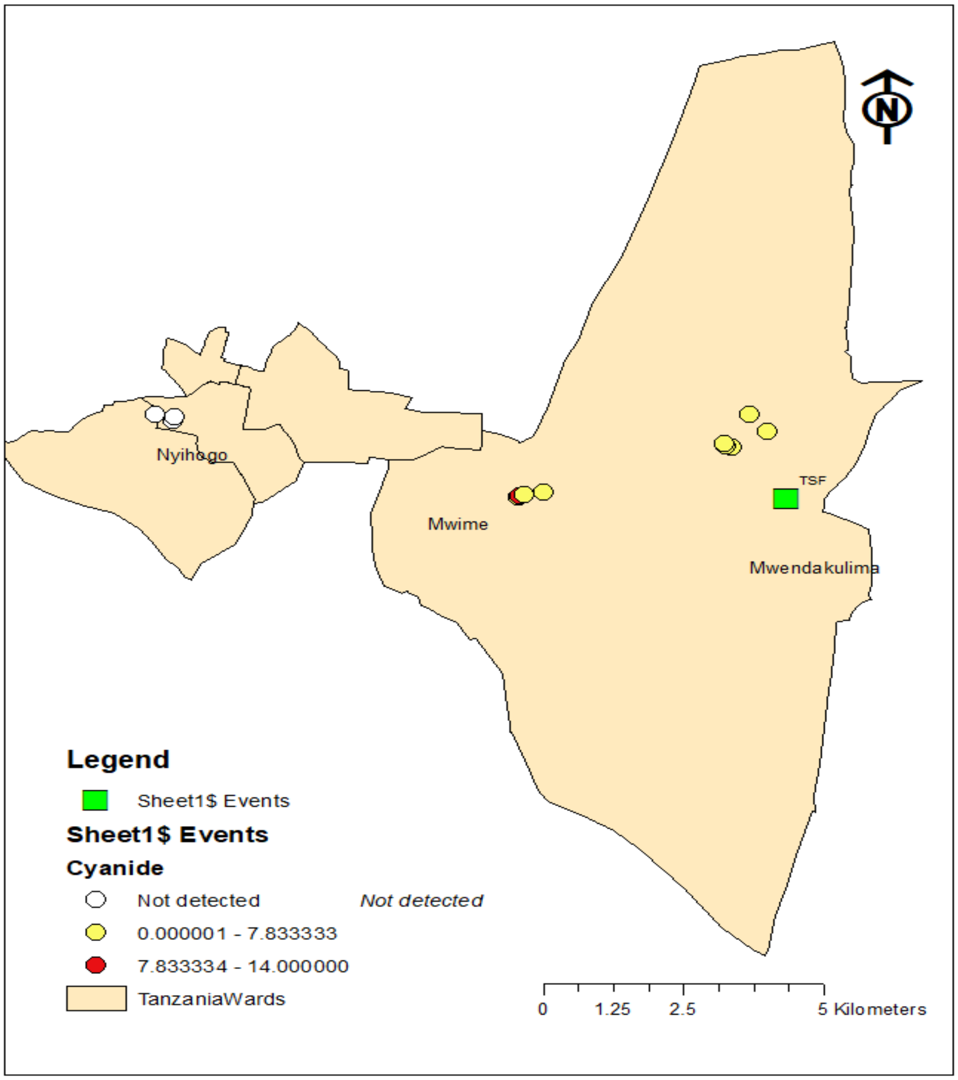
contamination is localised and likely attributable to mining activities. The absence of cyanide in distant wells indicates that the impact does not extend far beyond the immediate vicinity of the mine.

Figure 4: Spatial Distribution of Cyanide in Sediments During the Rainy Season



The concentration of cyanide in sediment samples ranged from 2 to 26 µg/g during the dry season and from 0.1 to 10 µg/g during the rainy season (see Figure 4). These results show that cyanide levels in sediments were significantly higher during the dry season, which is consistent with reduced dilution effects in the absence of rainwater. This seasonal variation further highlights the importance of monitoring cyanide accumulation, especially during dry periods when contaminant concentrations tend to peak.

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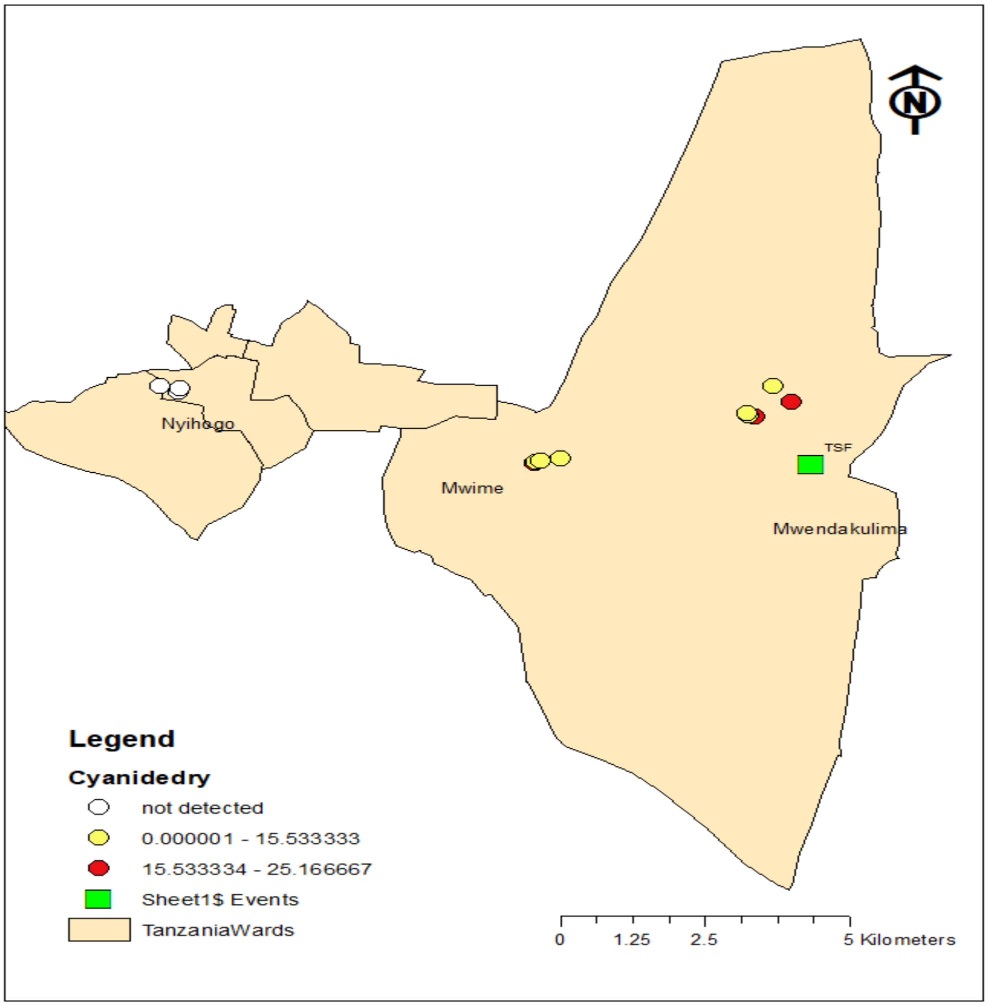
Figure 5: Spatial Distribution of Cyanide in Sediments During the Dry Season



In addition, the auditing report by the Tanzania National Environment Management Council (NEMC) revealed elevated levels of Weak Acid Dissociable (WAD) cyanide in the Tailings Storage Facility (TSF). This form of cyanide poses a significant environmental risk, as it can dissociate even at low pH levels, releasing toxic free cyanide along with a metal cation (ICMI, 2011; APHA, 1998). The concentration recorded exceeded 50 ppm, which is the maximum allowable limit for cyanide in TSFs. Alarmingly, fatalities among birds at the TSF were also documented during the audit, further confirming that the cyanide levels had surpassed the recommended safety threshold.

Regarding heavy metals in sediment samples, the concentrations of most metals, except for nickel, were higher during the dry season as compared to the rainy season (Figure 5). This variation is likely due to dilution effects during the rainy season; as rainwater increases, it dilutes the concentration of metals in sediments. Specifically:

- Lead levels in 6 out of 11 wells (55%) were higher in the dry season than in the rainy season.

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- Iron concentrations were higher during the dry season than during the rainy season in all wells.
- Manganese levels in 9 out of 11 wells (82%) were higher during the dry season than during the rainy season.

Table 5: The Levels of Heavy Metals in Sediments During the Dry and Rainy Seasons

	Dry season				Rainy season			
Well	Pb	Fe	Mn	Ni	Pb	Fe	Mn	Ni
MKW-1	0.80	386.10	5.41	0.41	0.49	98.39	1.21	1.17
MKW-2	1.10	397.30	10.52	0.30	0.81	147.00	2.84	0.51
MKW-3	0.06	226.10	1.55	0.17	0.57	131.00	1.00	6.50
MKW-4	0.12	218.40	5.49	0.21	0.50	131.00	1.57	0.32
MKW-5	0.07	253.00	6.85	0.26	0.47	102.00	2.19	0.36
MKW-6	0.03	244.00	4.19	0.35	0.17	35.00	2.91	1.45
MMW-1	0.15	54.40	0.45	BL	0.11	26.56	0.04	BL
MMW-2	0.19	57.40	1.19	BL	0.32	36.52	0.72	1.65
MMW-3	0.09	213.70	3.08	BL	0.23	81.73	2.06	0.07
MMW-4	0.04	17.87	0.07	BL	0.03	3.92	0.14	BL
MMW-5	0.05	11.32	BL	BL	BL	4.59	0.09	BL

BL means below detection limit.

Furthermore, the concentrations of heavy metals were found to be higher in wells located closest to the TSF, represented in the table by MKWs, compared to wells situated farther from the TSF, labelled as MMWs. This spatial trend suggests that the elevated metal levels in nearby wells may be the result of leakage from the Tailings Storage Facility (TSF).

The presence of cyanide in wells near the TSF, combined with the consistently higher concentrations of heavy metals in these same wells relative to more distant ones, provides strong evidence that the "zero discharge" mitigation strategy was not effectively implemented. This indicates that either:

- The mitigation measures designed to prevent seepage and ensure zero discharge from the TSF were not implemented, or
- They were implemented but proved ineffective in preventing contamination of surrounding groundwater sources.

These findings underscore the need for improved monitoring and maintenance of containment structures at the TSF to protect groundwater quality and public health in nearby communities.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The analysis of water and sediment samples revealed that cyanide levels in all wells located far from the mining area were below the detection limit, while cyanide was detected in wells situated near the mine. Although the cyanide concentrations in these nearby wells remained within the World Health Organization (WHO) permissible limits, their presence indicates seepage from the Tailings Storage Facility (TSF).

Additionally, the concentrations of most heavy metals were higher during the dry season compared to the rainy season, likely due to lower dilution during dry periods. Wells located closest to the TSF showed higher concentrations of heavy metals than those farther away, suggesting that the contamination originated from the mine. This evidence indicates that zero discharge from the TSF, as proposed in the Environmental Impact Statement (EIS), was not achieved, either due to a failure in

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implementing the mitigation measures or due to their ineffectiveness.

Furthermore, the community experienced water shortage during the dry season, and the absence of a water flow meter to monitor pumping rates implies that permitted abstraction limits may have been exceeded.

It can therefore be concluded that:

- Not all mitigation measures proposed during the Environmental Impact Assessment (EIA) process are implemented, and
- Not all implemented mitigation measures are effective in preventing environmental degradation in mining areas.

Recommendations

- To address water shortages during the dry season, mining operations should reduce groundwater pumping rates to ensure sufficient water availability for local communities. In addition, groundwater should not be the sole water source for communities near mining areas. Governments should explore alternative sources, such as inter-basin water transfers, for example, utilising Lake Victoria in Tanzania as a supplemental water source where feasible.
- To prevent contamination of groundwater by hazardous substances, it is recommended that TSF liners be regularly inspected and maintained to ensure the integrity of the containment system and to guarantee zero discharge, as outlined in the EIS.

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