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Oikos

The Zimbabwe Ezekiel Guti University Bulletin of Ecology, Science Technology, Agriculture, Food Systems Review and Advancement

ISSN 2957-8434 (Print)
ISSN 3007-2883 (Online)

Vol. 3 Issues (1&2), 2024

Published by the Zimbabwe Ezekiel Guti University Press
Stand No. 1901 Barrassie Rd,
Off Shamva Road
Box 350, Bindura
Zimbabwe

Typeset by Divine Graphics
Printed by Divine Graphics

SUBSCRIPTION AND RATES
Zimbabwe Ezekiel Guti University Press Office
Stand No. 1901 Barrassie Rd,
Off Shamva Road
Box 350
Bindura, Zimbabwe
Telephone: ++263 8 677 006 136 | +263 779 279 912
E-mail: zegupress@admin.uz.ac.zw
http://www.zegu.ac.zw/press

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The purpose of *the Oikos - The Zimbabwe Ezekiel Guti University Bulletin of Ecology, Science Technology, Agriculture and Food Systems Review and Advancement* is to provide a forum for scientific and technological solutions based on a systems approach and thinking as the bedrock of intervention.

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Natural scientists, engineering experts, technologists, multidisciplinary teams are encouraged.

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ISSN 3007-2883(Online)

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Surface Water Quality Changes Induced by Underground Mining in Gwanda District of Matebeleland South Zimbabwe

RAMECK DEFE[1] AND IRONY MAZURUSE[2]

Abstract

The study, from which this article sprang from, sought to assess the impacts of underground mining activities on surface water quality in Mtshabezi River in Gwanda District of Matebeleland South of Zimbabwe. The research adopts a mixed method approach that utilised both qualitative and quantitative approaches for in depth fact finding. The qualitative approach used depends on open ended questions, structured interviews, direct field observations while quantitative approach utilised depended on closed-ended questions, laboratory testing of water samples and use of statistical tools such as SPSS version 22.0 for data analysis. A survey of 82 respondents and interviews was conducted in the mining communities who depend on water from Mtshabezi River, in Gwanda to identify the main pollutants affecting water quality in Mtshabezi River. Water samples were collected to test for physiochemical parameters (temperature, pH, cyanide and concentration of Zn, Ni, Fe and Cu). Results from the tests conducted show that nitrates ranged from 3.5 and 8.4 that is within the range of WHO guideline of 10mg/l. From the data that was collected only 20% was within the WHO standards, High level of iron in Site 2 and 3 was as a result of direct deposition from the mine. The level of zinc concentration in Mtshabezi River was ranging from 0.4 to 3.8mg/l

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of zinc concentration that is above the limits of WHO guideline. The study recommends regular monitoring of surface water sources undertaken by EMA and sub-catchment councils to ensure the quality of water is not compromised.

Keywords: water quality; underground mining; water pollution; Mtshabezi River; surface water.

INTRODUCTION

Mining has significant negative impacts on the quality of water in water bodies, both surface and underground. (WHO, 2019). Underground mining can result in waste materials being carried into water sources (Dietler *et al*., 2021). Song *et al*. (2020) posit that underground mining includes human excavations beneath the ground's surface through shafts to search for, develop, or produce precious minerals. Hard minerals such as zinc, iron, gold, nickel, lead, and tin can be excavated using the same various mining processes (Akter *et al*., 2016; Roy, 2019). The waste from mining activities contains poisonous substances that are harmful to wildlife and pollute water bodies. Unsustainable mining activities also causes reduction of aquatic life and pollution to surface water sources because of chemical substances drained from the mining pursuits.

In North America, mining has resulted in long-term disturbance of aquatic and terrestrial habitats and water quality systems, with significant "off-site" repercussions, such as stream contamination (Patil *et al*., 2012; Haddaway *et al*. (2019). They extract desired minerals, heap leaching with acids using cyanide that has a significant impact on surface and groundwater. Failure of companies to comply with their mining plans in the United States has resulted in harming of aquatic life through erosion and sedimentation, dewatering wetlands, diverting and channelising streams and contaminating surface water and aquifers with toxic chemical (Zibret *et al.,* 2018; Simonin *et al.*, 2021).

Gold production in Sub-Saharan Africa has increased and it is estimated that, Sub-Saharan Africa is contributing 35% of the region's gold (Chuhan-Pole *et al*., 2017). Fianko (2021) postulates that, regardless of its contribution to gold production, mining has had a negative impact on Ghanaian and other countries' water bodies. Many rivers have been contaminated as a result of mining activities, with adverse consequences for rural communities built along these rivers. River Birim in Ghana is one of the rivers impacted by the mining activities (Fianko, 2021). The River Birim is contaminated by mining activities which has led to the loss of marine life scarcity of drinking water in several villages along the river (Hadzi *et al.,* 2018). The rural communities that rely on rivers as a source of water face serious health risks (Yankson and Gough, 2019).

Mater (2019) contends that mining activities in Rwanda's Burera produce effluent containing a variety of chemical pollutants, that degrade the quality of both surface and groundwater resources. The effect of degraded water quality is felt not only in the mine's immediate vicinity but also downstream of the mine. Waste rock dump effluent caused ARD into stream and river waters (Nahayo and Ntwali, 2017). Hirwa *et al.* (2019) aver that the use of lime materials and caustic soda to neutralize drainage and avoid the release of pollutants into water, that results in the lowering of pH in water.

The increase of underground mining activities has become one of the most serious problems on surface and underground water in Zimbabwe (Arhonditsis, 2022). Underground mining activities in Gwanda accelerated the rate and degree of changes on the natural environment, through processes of blasting and drilling rocks that is done in the extraction of gold. Pollution of water sources by these mining activities has increased the threats to access clean water for domestic use at the household level. Underground mining in Zimbabwe has, however, proved to be one of the most serious problems affecting the quality of surface water. Hence, it is against this background that this research focuses on the impacts of underground mining on the surface water quality of the Mtshabezi River, Gwanda. The information obtained from assessing surface water quality can be utilised to develop a sustainable water quality management framework that be used to manage water quality.

STUDY AREA

The geographical coordinates of Gwanda District are 20º56´20.0´´S, 29º01´07.0´´E (Latitude: 20.938889; Longitude: 29.018611). Wolfram (2020) argues that the average elevation of Gwanda is 3,300 feet (1,006m) above mean sea-level. The area under study is Gwanda District in Matebeleland South Province, Zimbabwe. Gwanda is located 134Kilometres (83miles), by road, South East of Bulawayo, the second largest city of Zimbabwe (UCZA, 2020). The district is approximately 11 000 km in length and is drained by two major rivers, the Tuli in the west and the Mzingwane in the east. The district is divided into four sub catchments (Shashe, Upper Mzingwane, Mwenezi and Lower Mzingwane) in hydrological zone B, one of Zimbabwe's six hydrological zones. Mtshabezi River is a tributary of the Thuli River in Southern Zimbabwe and it flows through Gwanda (Wardhani *et al*., 2022). Gwanda district is in ecological region 5 that is characterised by prolonged hot summers, and short cool winters. Gwanda receives rainfall that is less than 450mm. Gwanda is rather dry compared to the rest of the nation, making it vulnerable to drought. The map below graphically shows the location of Gwanda.

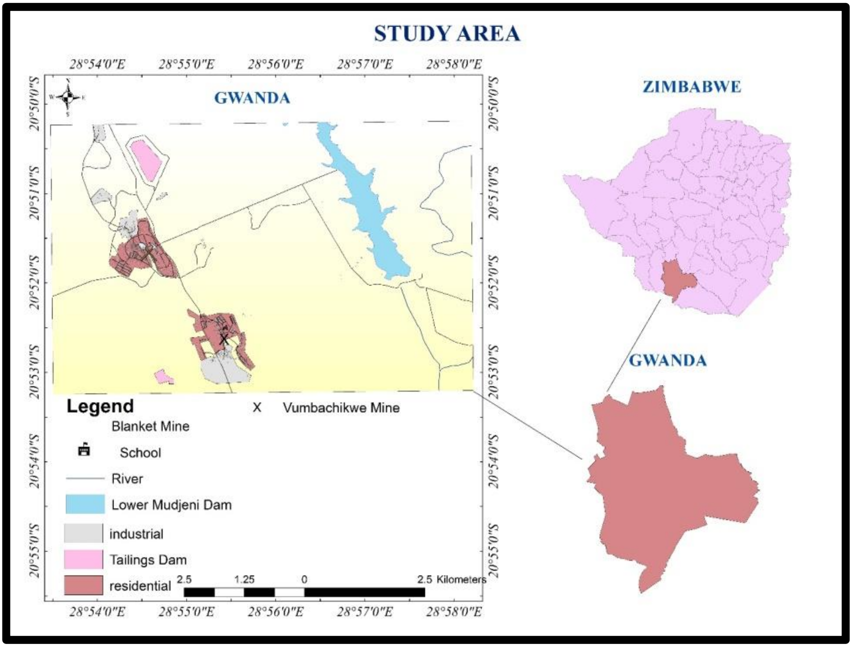

Figure 1: Map of Gwanda District *(Authors, 2022)*

The total population size of Gwanda district comprises 7380 males and 8069 females. Gwanda district has 10 wards under the governance of 10 councillors. It comprises both private and public schools, 5 primary schools, 2 secondary schools and tertiary (UCZA, 2020). Although Shona and Basuto people live in Gwanda, Ndebele is the language that is spoken by the majority of the population. It is mainly based in extensive type of farming and is suitable for extensive cattle ranching. The Municipality of Gwanda town states that Gwanda is well known for its commercial and industrial activities. Its main economic activity is mining of gold at Vubachikwe Mine, Blanket Mine, Jessie Mine and Freda Mine. The mines in Gwanda use water from the Mtshabezi River during their mining activities.

METHODOLOGY

The research adopts a a mixed method research design. The research design enable the researcher to become more knowledgeable about research methods appropriate for the subject (Cresewell and Cresewell, 2017). It aids in integrating the main components of the study in a cohesive and reasonable manner, confirming that the topic was properly addressed. The research design adopted has 2 main approaches namely quantitative and qualitative. The qualitative research allows the researcher to study things in their natural form and to elucidate facts in terms of the target population's interpretations of the effects of underground mining on surface water quality. The qualitative approach depends on interviews, open-ended questions and field observations. Quantitative approach used closed ended questions, water tests and use of statistical tests to analyse data. The research targeted 410 households in in Gwake, Sigodo and Mtshabezi villages of Gwanda District who directly depend on Mtshabezi River water. These were targeted to obtain data on the risk of underground mining.

Key stakeholders namely the Ministry of mines and mining development of Matebeleland South, Gwanda Municipality, Zimbabwe National Water Authority (ZINWA), The Sigodo, Mtshabezi and Gwake village leaders, were also targeted to give detailed data concerning the impacts of mining of water in Mtshabezi River. A 20% sample frame was calculated from the target population (Depoy and Gitlin, 2005). Using a 10% sampling frame, 82 households were selected for the study. Systematic random sampling was adopted to distribute questionnaires in the three villages selected. With systematic random sampling, every 10^{th} household was selected for the study.

Selection of key informants for the interviews was conducted using the purposive sampling. The purposive sampling technique was used to select the Municipality of Gwanda personnel, Mzingwane catchment council manager, Ministry of mines and mining development personnel, Blanket mine safety officer, and village leaders' and ZINWA Officer.

WATER QUALITY SAMPLING

Water sampling is critical for accurate water analysis results (Katsanou and Karapanagioti, 2016). The researcher selected four sampling points along the Mtshabezi River to collect the water samples. Samples were collected in May (2022) and June (2022) from a total of 4 sites that were randomly selected along Mtshabezi River, however the sampling sites were close to the mine to note the susceptibility to pollutants through leachates and seepage. From the sampling points that were selected by the researcher, there was a control point (S1) for comparison with the other three samples that were affected by the mining activities. The second site was taken up-stream (S2), the sample Whites Farm (S3) was also taken since there have been cases of livestock death due to the contaminated water and the last site was taken downstream (S4) as shown in Figure 3.1. The control point was selected by the researcher for comparison with the other three to help in identifying the underground mining physiochemical parameters that are affecting the Mtshabezi water source. Sampling locations were selected by the researcher based on the characteristics of the water condition, that is, its colour.

Table 3.2: Sample sites and coordinates

Sample site	**Latitude**	**Longitude**
Control point	20º49´51.41" S	28º56´4.68" E
Second site	20º50´40.43" S	28º56´38.43" E
Third site (whites farm)	20º51´13.13" S	28º56´58.23" E
Fourth site	20º51´50.01" S	28º57´15.78" E

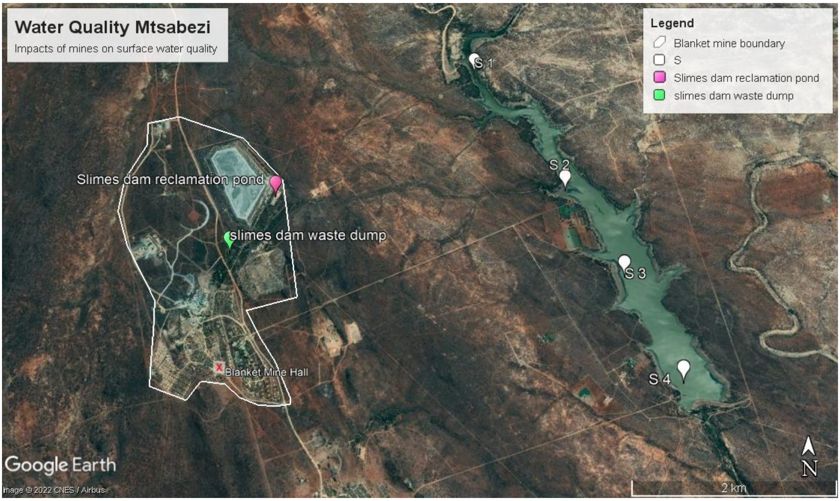

Figure 2: Sampling site locations in Mtshabezi River and Blanket Mine.

The researcher used questionnaires comprising both closed-ended and open-ended questions. The questionnaires were distributed to the targeted villagers in Gwanda District that included Mtshabezi village, Sigodo village, Gwakwe. The questionnaire was alienated into three sections: A, B, and C. Section A of the questionnaire contained personal information such as their gender, occupation, age and education level. Section B contained questions related to objective number one, that is to identify main pollutants Mtshabezi River and Section C contained questions related to objective number three, that is to assess the effectiveness of the existing policies, their implementation and performance over the past 10 years. A total of 82 questionnaires were self-administered to the selected households in Gwanda district that use the Mtshabezi River.

The researcher conducted interviews on a face-to-face basis with key informants who were selected using purposive sampling namely: Municipality of Gwanda Officer, ZINWA (Mzingwane catchment council), Ministry of Mines and Mining Development, Blanket Mine leaders, and village leaders near the river. An interview guide was used to guide the discussion and the guide was designed as argued by specific objectives of the study.

FINDINGS

Data analysis is the process of gathering, modelling and analysing data to obtain insights that aid decision-making (Calzon, 2022). Qualitative data were subjected to content analysis.

Presentation and analysis of data are very essential in research because raw data is difficult to understand, hence data collected by the researcher was summarized, processed and analysed for better understanding. The data presentation requires skills and knowledge of the data. To reach a more meaningful and robust conclusion this research employed descriptive analysis to analyse the field obtained data. Data from the respondents of the questionnaires was analysed using descriptive analysis, thus all the quantitative data that was obtained was analysed using the technique as it was ideal for expressing a measure of central tendency. The analysed data were then presented on bar graphs, pie charts and tables using Microsoft Excel to draw robust conclusions. Data analysis enabled the researcher to draw conclusions concerning the impacts of underground mining on surface water quality in Mtshabezi River. Narrative analysis was used by the researcher to analyse the responses from the interviewees. The analysed qualitative data were then presented on tables and graphs using Microsoft excel.

LABORATORY WATER QUALITY ANALYSIS

The researcher employed the Standard Operation Procedures (SOP) for Chemistry Methods (CM) and Biological Methods (BM) used at Environmental Management Agency Laboratory (EMAL) for laboratory analysis. The results were authorized to the Zimbabwe's Standards SAZS 560:1977. The methods and water quality parameters used in solving the problem are presented in Table 3.4. When heavy metals were being tested in water, samples were digested with a 5ml di-acid solution (HNO_3: $HCIO_4$: 9:4 ratio) on a hot plate. After that, 0.45 m filter sheets were used to filter the acidified water samples into 50 ml volumetric flasks. The concentrations of Zinc, Nitrates, Iron and

Copper were examined using an inductively couple's plasma spectrometer. pH was determined using a pH meter. The tube was rinsed with the water sample after each test's procedure. To prevent skin, contact with the water, gloves were put on. To mix the samples, they were covered and inverted multiple times. The test tube was placed inside the Wide Range pH Comparator, that was then exposed to light. The sample colour was compared to a standard colour, and the pH value was determined. Turbidity was determined using the turbid meter.

A control sample was prepared using recorded formalin and distilled water. Distilled water was used to dilute the waste water samples. The turbid meter was then used to measure and record the samples. Utilising UV-Vis Spectrophotometric SOP/CM23, nitrate levels were calculated. A conical flask with a ground glass stopper was filled with a sample of water. After bringing the pH down to 9.0 with 2.0 ml of the buffer solution and vigorously mixing the mixture for five minutes, 5.0 mL of a 20 percent naphthalene solution in acetone was added. Filtration on a glass filter was used to separate the generated solid mass that was made up of naphthalene and the metal complex. Water was used to clean the residue, that was then dried in the fold of the filter glass. The solid mass was dissolved in DMF (Dimethylformamide) and brought to volume in a 5.0 mL volumetric flask using the same solvent. The complex's absorbance was expressed in mg/L. Aliquots were tested daily over the duration of the test's seven working days, and the mean value was calculated.

Table 1: Parameters measured in the study area for the sampling period 02 May and 27 June 2022

Parameters	**Methods used**	**Units**
Ph, Temperature	Automatic pH- Meter and HACH with a temp and pH probes	pH units and °C
Metals: Zn, Fe, Hg	Inductively coupled plasma spectrometer	Mg/l
Cyanide	HACH DR 4000V spectrometer	Mg/l
Nitrates	UV-Vis spectrometer	Mg/l

FINDINGS

The research identified the main pollutants in Mtshabezi River caused by the mining practices being done. From the data that was collected, it was found that the main pollutants in Mtshabezi River were caused by mining processes at Blanket Mine. The data that was collected indicated that 26% of the respondents postulated that the main river contaminants were effluent deposited during and after gold processing is done through oxidation. Key informants that gave this detailed information were the workers that work at blanket mine that are familiarised with different activities. The laboratory analysts postulated that the processes involve biological oxidation where the sulphates that be coating the gold be removed through the use of different chemicals including mercury, sulphate and cyanide.

After the process of removing ore the slurry is pumped into tailing dams, the effluent is seeped down contaminating groundwater that is the major source of surface water. 8% of the respondents confirmed that tailing dams are also a source of contaminating surface water. The reason could be due to the fact that they contain effluents with un-extracted cyanide, mercury, sulphide, copper and iron among other chemicals that are used during blasting, gold extraction and processing. All this is deposited into the Mtshabezi River affecting the aquatic life that people from Gwake, Sigodo and Mtshabezi village depend on for enhancing their diet. This finding is in line with Makoni (2015) who also found out that, a major source of water pollution from mining activities is the tailing dams that pollute the environment through overflowing and evaporation causing acid rain which cycles back to the environment.11% of data collected from the field showed that, there are effluent control ponds at Blanket mine that have an impact on the river and the community at large. Through seepage, leaching and overflow during the rainy season it is discovered that the ponds are contributing efficiently to pollution in the community and the river. This was also postulated by ZINWA personnel during an interview who confirmed that the soil from the surroundings was contaminated as argued by the test they conduct yearly and this was attributed to runoff that occurs during ponds and slurry dam overflow.

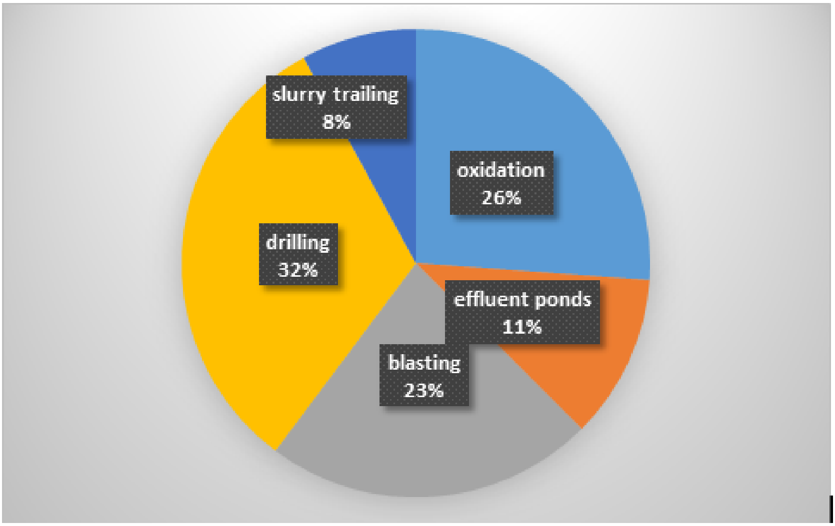

Figure 3: Sources of pollutants that affect Mtshabezi River.

Moreover, from the questionnaires that were collected it was discovered that 32% indicated that drilling was affecting water quality and 23% indicated that blasting also contributed to water pollution. There is contamination of water caused by the release or spillage of the blasting chemicals during the processes of drilling and blasting. Sulphides in the rock form sulphuric acid when they are excavated and exposed to water and air during mining. This acidic water then dissolves other hazardous metals in the surrounding rock. Runoff into river then occurs as the acid mine drainage is not controlled. This is in agreement with Bhebhe (2015) who argue that the process of rock blasting and rock drilling that is done in the extraction of gold alters the natural parameters in both the water and the soil such as pH levels, iron level and copper levels as a result of chemicals and explosives used during the process. Therefore, this supports the view that was generalised by the locals among the three villages about the two processes that resulted in the contamination of Mtshabezi River at large. The physiochemical parameters of water quality in Mtshabezi River, Gwanda district.

Table 2: Physiochemical parameters of water quality in Mtshabezi River, Gwanda district

Parameter	Sample Site 1	Sample Site 2	Sample Site 3	Sample site 4	WHO recommendations
Mercury Hg	<0.006	<0.006	<0.0069	<0.006	0.006
Iron Fe	0.2-1.3 (0.8 ±0.4)	2.2-4.7 (3.4±0.6)	2.5-3.9 (3.2±0.5)	1.6-7.3 (4.8 ±1.5)	0.3
Cyanide CN	<0.006	<0.006	<0.006	<0.006	0.006
Ph	7.2-7.4 (7.3±0.1)	6.6-7.2 (6.8±0.3)	7-7.4 (7.3± 0.1)	7-7.3 (7.2± 0.1)	6.5-8.5
Temperature	15.6°C	16.1°C	16.1°C	15.7°C	
Nitrates	0.8-9 (4.5 ±2.3)	3-8.7 (5.3 ±2.2)	2-3.9 (2.9 ±0.8)	1.8-8 (4.9 ±2.2)	0.01-2
Zinc	0.4-1.7 (1.6±1.0)	1.3-3.8 (2.0± 0.6)	1.8-3.7 (2.9±0.4)	0.8-3.8 (1.4± 0.3)	3-5

The range, average and standard deviation is based on 4 values for 4 sampling points

Nitrates concentration ranged from 3.5 and 8.4 and these were below the WHO guideline of 10mg/l. Therefore, their impact on the environment was not adequately felt as evidenced by the data collected from the questionnaire who never complained about stunt infant growth. From the data that was collected although the nitrates were within the recommended range it was noted that the concentration deviated from the control point. There was high concentration in Site 2 and 3 and this indicates areas of direct deposit of contaminants and there was decrease in site 4 this might be due to water dilution from different tributaries. The effects of nitrates were not highlighted by respondents from the three villages that include slow infants' growth that is indicated by Moyo (2016) who postulated that high nitrates in a specific environment may affect the growth of infants.

Potential Hydrogen (pH) values from all selected points in the Mtshabezi River were ranging between 6.6 to 7.4 throughout the sampling period. This is presented on table 4.2 and Figure 1. All the results that were obtained are within the recommended drinking water standards by WHO. Thus, the pH values for all sites are generally neutral showing that level of alkalinity and acidic contents were neutral. Water with high acidic levels be <4.0. From the results that were obtained from the samples, there is indication that the aquatic life was living in a highly recommended environment. However, from the response of the residents, it is noted that there was a great change and possibly of self-purification of the water in the river as they had postulated that there was a massive death of aquatic life in the month of January and February 2022 and from the data that was provided by the laboratory analyst from blanket mine it showed that the water was highly acidic. This is further postulated, by Shoko (2002), who denoted that alteration in acidic contents in the river can result in a massive death because aquatic lives took time to evolve and adapt to the alteration hence massive death can be encountered in the early period. Therefore, as a result of the high death rate of the aquatic life, the mine was suspended from using the river source of water neither depositing its effluent in it. Therefore, when samples were collected during data collection indicated that there was low pH showing that the mine was complying with the recommendation that was set against it.

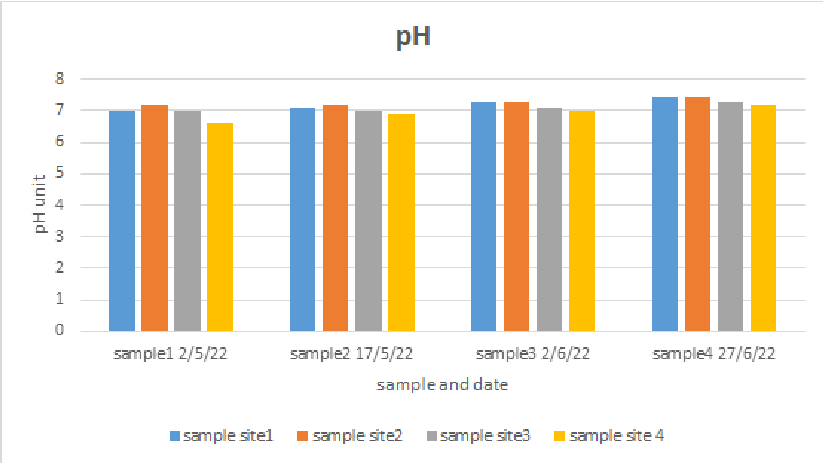

Figure 4: pH level deviation across 4 sites in Mtshabezi River from 02 May to 27 June 2022

Iron concentration ranged from 0.2 to 7.3mg/l in all selected sites as presented on table 4.2 and fig 4.2. From the data that was collected only 20% is within the range and limits that was recommended by WHO that is 0.3mg/l and this was found in sample site 4 that were located downstream of Mtshabezi River. Low levels of iron were scientifically proven to be a result of natural river self-purification and dilution since it was on the downstream and most tributaries be joined there. This is further supported by Nkuli (2008), who notes that at the downstream of a river there are a high number of tributaries that make the waters less polluted as they are frequently diluted. High level of iron in Site 2 and 3 was maybe as a result of direct deposition from the mine and also as a result of its near proximity to the mine. Iron in Site 1 that is the control point was slightly lower than that in Site 2 and 3 this is because there is limited mine effluent deposition into the environment.

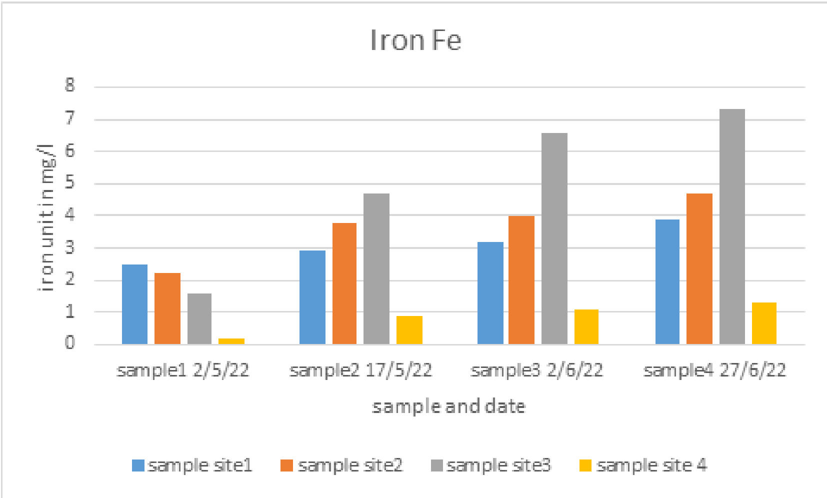

Figure 5: Iron, Fe level deviation across 4 sites in Mtshabezi River from 02 May to 27 June 2022

The level of zinc concentration in Mtshabezi River ranged from 0.4 to 3.8mg/l as shown in Figure 3 and table 4.2. The ranges of zinc concentration are below the limits of WHO guideline of 1-5mg/l. The control point (sample Site 1) that was located in the upper stream measures low volumes of zinc compared to other sites. This indicates that Blanket Mine activities seriously influenced and impacted Mtshabezi River water chemistry that later impacted the locals and the surrounding environment. This is further supported by Nkuli (2008) who postulates that mining activities that involve galvanising releases high levels of zinc that poses dangerous threats to the environment and this was the case with Gwanda District. The researcher found high volumes of zinc in Site 2 and 3 and there was a decrease in site 4, the control point that was Site 1 had the lowest of them all showing that there was no contamination and any deposit that results in zinc accumulation. High concentration of zinc posed a serious threat for the survival of different species that depend on a certain environment.

This was in agreement with Murwira *et al*. (2014) who argue that high concentration of zinc poses serious threat to the survival of aquatic life. This was further evidenced by the information that was obtained from the questionnaire that were distributed and interviews conducted that highlighted that in January 2022 and February 2022 a total of 103 cattle died and massive aquatic lives and gastric, nausea and headaches that were complained by the locals in Gwake, Sigodo and Mtshabezi villages.

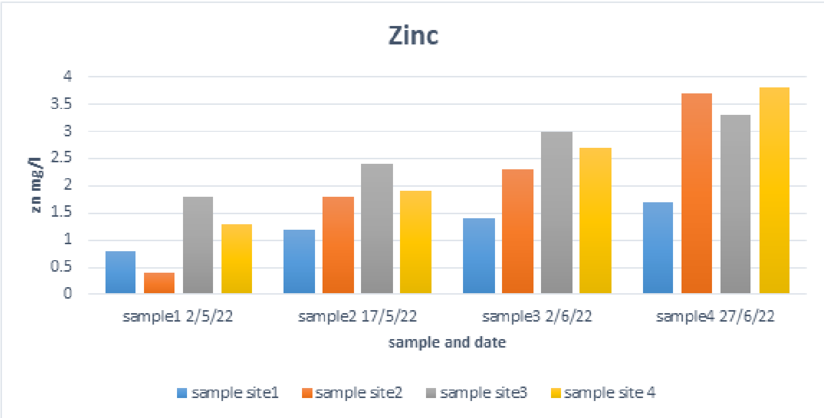

Figure 6: Zinc level deviation across 4 sites in Mtshabezi River from 02 may to 27 June 2022

The concentration values of mercury and cyanide elements were generally low in water. The levels of potential heavy metals mercury and cyanide were below the method detection limits of <0.006mg/l by using Inductively Coupled Plasma Optical Emission Spectrometer (ICP), the reason for these elements being low could be because the mine was not frequently using these elements more frequently as compared to the others. However, in Site 3 there was an increase in mercury level this was because of gold panners that were found in the area along the river. The use of mercury in gold panning is because of its ability to make the process of gold separation since gold has high density.

Effluent Control Ponds analysis results of heavy metals and non – metallic constituents four sampling campaigns from Blanket mine.

Slimes dam reclamation pond and slimes dam waste dump are Blanket Mine effluent control ponds that are standing water bodies. The chemical concentration in these ponds exceeds WHO recommended limits for effluent discharge. These ponds were considered as heavy rains might influence the discharge into Mtshabezi River. However, the results that were obtained after the experiments show that they did not serve their purpose of reducing the level of direct effluent discharge into the environment.

Table 3: Effluent Control Ponds analysis results of heavy metals and non-metallic constituents for ten sampling campaigns.

Parameter	**Slimes dam reclamation pond**	**Slimes dam waste dump pond**
Ph	7.1-7.8 (7.4 ±0.2)	3.8-6.9 (5.1±1.1)
Temperature	22.5-26(26 ±1.2)	23.6-28 (26 ±1.2)
Nitrates	4.9-8.4(6.3 ±1)	3.5-7(4.7 ±1.2)
Cyanide	<0.006	<0.006
Iron	5.4-6.7(6 ±0.5)	2-12.5(8.5 ±36)
Mercury	<0.006	<0.006
Zinc	4-12.6(8.2 ±4)	9.3-28(18 ±6)

pH concentration range 3.8 to 7.8, this is a significantly below 6.5 to 8.5. This was also influenced by runoff effluent that include frothier, potassium amyl xanthate all this are used in the recovery of gold from the sulphide. Iron concentration ranges from 2.0 to 12.5 mg/l in all effluent ponds' points. The results obtained were over the expected WHO limits of 3mg/l. The major reason being the ponds are in contact with trailing storage facility in the mine that constitute heavy metals.

This affected greatly the aquatic behaviour when directly discharged. Iron existence is influenced by pH and oxidation reduction. Moreover, zinc concentration range between 4.0 to 28mg/l in all ponds and all the values of zinc concentration are above limit recommended by WHO guideline. From the information that was obtained from data collection it was noted that zinc was from decaying carbon zinc discarded batteries. This is further further by Lennech (2004) who contends that discarded batteries affect the environment through pollution of the soil and water by increasing the already existing heavy metals that later affect survival of different species. It was seen that all effluent ponds had exceptionally high concentrations of all elements investigated with exception to mercury, cyanide and nitrates that were found to be below the method detection limit of <0.005 mg/l. High concentrations of these parameters could have an impact on surface and groundwater system if management strategies are not established. Nitrates concentration ranged from 3.5 and 8.4 were within range of WHO guideline of 10mg/l therefore their impact to the environment were not vigorously felt.

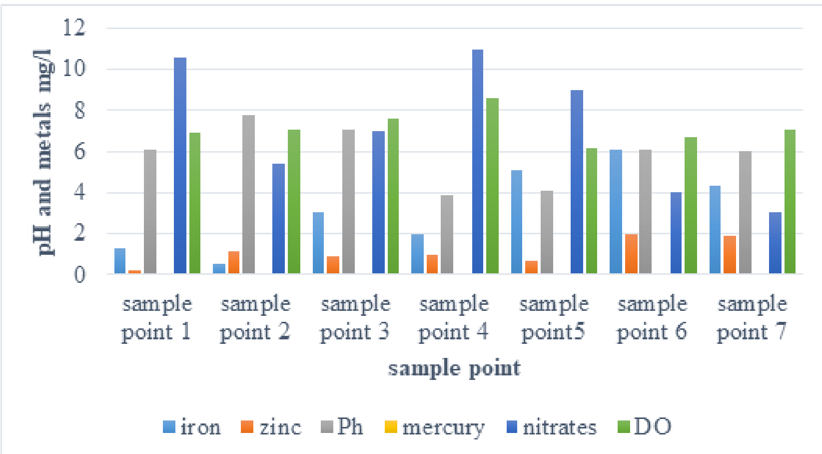

Figure 7: Concentration of different metals and pH on surface water in 2021

A framework of water quality management that can be employed to reduce the impacts of underground mining on surface water quality of Mtshabezi River

To achieve a zero-harm environment, environmental management is a crucial component that should be taken into account and improved. The inclusion of local stakeholders is one of the most effective and crucial actions to be adopted in terms of environmental management (Gerasidi *et al.*, 2009). Stakeholder involvement is acknowledged as a key component in the successful execution of water management strategies, particularly when attempts are made to address competing and conflicting needs in regions susceptible to water scarcity. A deeper knowledge of the various parties with an interest in water management is made possible by including stakeholders. Feresu (2010) is of the view that those who purposefully or unintentionally pollute the environment should face consequences. The polluter pays principle can help to improve this. The Water Act of 1998 and Environmental Management Act of 2002 requirements, that noted the application of the polluter pays principle can manage the discharge licenses and the environmental charges based on the volumes and quality of the effluent released to the environment by a specific individual, further support this. The fact that failure to comply with the rules result in harsh penalties and fines reduces the pollutants emitted into the environment. Additionally, improving the currently in place environmental management tools that regulate water might help prevent the discharge of chemicals into the environment that might contaminate it.

It is advised that metals be precipitated out of the effluent of the control ponds to lessen their mobility through seepage. In order for the effluent from the ponds to leave with low concentrations of metal solids, it was also advised to build additional ponds with adequate retention durations that can boost the removal and retention of metals. Nkuli (2008) claims that acid mine drainage and low pH in Effluent Control Ponds are caused by the weathering of sulphides. Liming techniques and caustic soda can be used to neutralize the drainage and prevent the discharge of pollutants from the sulphides.

In accordance to the objectives of the national poverty relief strategy, miners should get education on the effects of heavy metal pollution. This supports both the National Strategy for Growth and Poverty Reduction and the MDGs for environmental sustainability. The mine should make sure that there is absolutely no contamination of surface water that comes from the mining site. To determine the various tolerance levels of aquatic species found in the river, a study on species diversity is advised in the study region. The majority of the contaminants analysed had high concentrations in the river, that could be hazardous to aquatic life.

Moreover, there should be specific statutory instruments that monitors use of highly toxic metal by farmers and toxic substance released by miners. Feresu (2010) further argues that this further support requirements of EMA (Chapter 20:27) in section 140, which provides for the management of hazardous waste that affect the environment. It is pursuant to these regulations that no person generate, store, sell, use, discharge hazardous waste to the environment except under licence. Therefore, this enhances environmental protection.

There should be enhancement of the Environment Impact Assessment for every project that is further supported by Bond (2010) who posited that, enhancing environmental impact assessment of every project undertaken in a specified area is an essential tool that help manage the environment as far as the release of contaminants into the environment is concerned. This makes it easier to pinpoint environmental problems and suggest alternatives for a current project. In addition, environmental legislation should be properly implemented and followed up on to promote effective environmental conservation. The Environmental Management Act (Chapter 20:27), Section 140, and the Statutory Instrument 7 of 2007 support each other in regulating waste. Therefore, fines should be implemented as necessary to prevent endangering the environment.

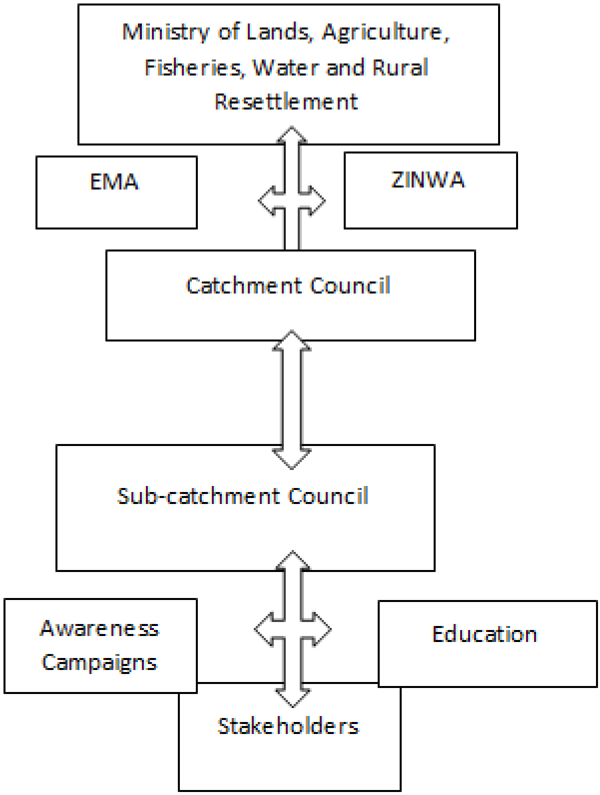

Figure 8: Framework on Water Quality Management

CONCLUSION AND RECOMMENDATIONS

The main pollutants in Mtshabezi River emmanate from the effluent deposition during and after gold processing is done, the process of blasting and drilling rock done in the extraction of gold that alters the natural parameters (pH, iron level and copper levels) in both the water and soil and through the processes of seepage, leaching and overflow pollution occurs in the community and the river. The researcher assessed the physiochemical parameters of water quality in Mtshabezi River. Results show that the physiochemical parameters that had a negative impact on water included iron that ranged from 0.2 to 7.3mg/l in all selected sites, from the data that was collected only 20% was within the range and limits that was recommended by WHO that is 0.3mg/l, high level of iron in Site 2 and 3 was as a result of direct deposition from the mine also as a result of it near proximity to the mine. The level of zinc concentration also had a negative impact on the Mtshabezi River. Zinc was ranging from 0.4 to 3.8mg/l of zinc concentration that is above the limits of WHO guideline.

The effectiveness of the existing policies, their implementation and performance over the past 10 years was also assessed in this research. Results from the data collected show that Blanket Mine is no-longer following some of the policies put across by EMA, this is evidenced by the presence of huge mountains of mine tailing that contain toxic contents affecting water quality, lack of analysis to enhance improvement on the level of contamination done by mine effluents that are discharged into the environment and lack of enforcement and enhancement to reach the required WHO guidelines for drinking water. 22% of the respondents also noted that EMA lacks consistency on enforcing laws that protects the environment that has resulted in the continual of pollution levels in Mtshabezi River.

A framework of water quality management that can be employed to reduce the impacts of underground mining on surface water quality of Mtshabezi River was also developed. Stakeholder participation must be embraced to improve environmental management, stiff penalties and fines for those that intentionally and non-intentionally pollute the environment must be put in place and enhancement of the already existing environmental management instruments that govern water. Education of miners on the effects of heavy metal pollution, there should be specific statutory instruments that monitor the use of highly toxic metal by farmers and toxic substances released by miners and there should be proper implementation and follow up of environmental legislation to enhance proper environmental conservation.

Blanket Mine is recommended to build more ponds with sufficient retention durations to improve metal removal and retention so that the effluent from the ponds can have low amounts of metal solids. Education of miners on the effects of heavy metal pollution in relation to the national poverty relief strategy goals must be done by EMA, ZINWA and Catchment councils to reduce heavy metal pollution on surface water. Specific statutory instruments that monitor use of highly toxic metal by farmers and toxic substance released by miners must be put in place by EMA to help in reducing the rate of surface water pollution.

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