

ILLEGAL GOLD MINING AS IT AFFECTS RIVER WATER QUALITY: CASE OF RUNDE RIVER

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE OF BACHELOR OF
SCIENCE HONOURS DEGREE IN NATURAL RESOURCES MANAGEMENT AND
AGRICULTURE

BY

MAKONESE TAFARA R125099A

JUNE 2016

DEPARTMENT OF LAND AND WATER RESOUCES MANAGEMENT

MIDLANDS STATE UNIVERSITY



DECLARATION

I, **TAFARA MAKONESE (R125099A)**, a candidate for the degree of Bachelor of Science (Hons) in Land and Water Resources Management do hereby declare that this thesis has been produced from my original effort and investigations to the best of my knowledge, such work can be submitted to any institution. All additional information has been acknowledged by use of references.

Tafara Makonese

(Student Name)

Signature

Date

Doctor A. Munodawafa

(Supervisor)

Signature

Date

DEDICATION

This is for my mom your love brought me here, my dad thank you for teaching me how to fish and my siblings your presence complete my world I could not be strong without you.

ABSTRACT

Mining waste is the major threat to water quality in Runde river . The main objective of the study is to investigate the effects of illegal gold mining on the water quality of Runde river. Three sampling sites were noted which were at least 500 m apart. They were named 1,2 and 3 with site 1 located before the mining zone and site 2 was adjacent to the mining zone and site 3 after the mining zone. Samples were taken for the dry season (September , October) and the wet season (February). 3 grab samples were taken at each sampling point to make a composite sample , 5 replicates of these composite samples were done across the river at each sample site. Based on the results obtained illegal gold mining along Runde river has led to poor water quality as all the parameters at some point were above the WHO standards especially at site 2 and 3. This raises concern as the river is a major source of water for a number of human activities and hence the need to maintain its quality at desirable level. There is need for responsible authorities to find alternatives sources of water and /or adaopt new technology of water treatment of raw water and also reduce the levels of pollution of the river.

ACKNOWLEDGEMENTS

First and foremost I would like to give praise to the almighty God for guiding me throughout this time I was doing my research. My sincere gratitude goes to my supervisor Doctor A. Munodawafa for working extremely hard with me on this research, I greatly appreciate her effort.

To all my lecturers, I thank you so much for guiding me through-out my academic studies at this institution. Your guidance and knowledge is greatly appreciated.

Finally, I give thanks to my fellow colleagues Innocent and Travolta for the support and encouragement throughout my studies.

LIST OF FIGURES

Fig 1a; Concentration of mercury in the dry season	12
Fig 1b; Concentration of mercury in the wet season	13
Fig 1c; Comparisons between seasons	13
Fig 2a; Concentration of copper in the dry season	15
Fig 2b; Concentration of copper in the wet season	15
Fig 2c; Comparisons between seasons	16
Fig 3a; Concentration of iron in the dry season	17
Fig 3b; Concentration of iron in the wet season	18
Fig 3c; Comparisons between seasons	18
Fig 4a; Concentration of turbidity in the dry season	19
Fig 4b; Concentration of turbidity in the wet season	20
Fig 4c; Comparisons between seasons	20
Fig 5a; Concentration of pH in the dry season	22
Fig 5b; Concentration of pH in the wet season	22
Fig 5c; Comparisons between seasons	23
Fig 6 A summary of results versus WHO standards	
Error! Bookmark not defined.	

LIST OF ACRONYMS

AMD.....	acid mine drainage
Cu.....	copper
Fe	iron
Hg	mercury
NTU.....	nephelometric turbidity units
pH.....	hydrogen potential
WHO.....	World Health Organisation
S1.....	upstream
S2.....	mining area
S3.....	downstream

;

TABLE OF CONTENTS

DECLARATION	i
DEDICATION	ii
ABSTRACT	iii
ACKNOWLEDGEMENTS	iv
LIST OF ACRONYMS	vi
TABLE OF CONTENTS	vii
1.0 INTRODUCTION	1
1.1 JUSTIFICATION	3
1.2 OBJECTIVES AND HYPOTHESIS	4
1.3 HYPOTHESES	4
2.0 LITERATURE REVIEW	5
Table 1. Maximum permissible level of micronutrients in agriculture (WHO)	9
Table 2, Maximum permissible concentration of selected metals in drinking water (WHO)	9
3.0 MATERIALS AND METHODS	10
3.1 Site description	10
3.2 Experimental Design and Sampling	10
4.0 RESULTS AND DISCUSSION	12
5.0 CONCLUSIONS	26
5.1 RECOMMENDATIONS	26
APPENDICES	27
REFERENCES	36

1.0 INTRODUCTION

Mineral resources are valued and used for humans needs evident of many precious mineral resources where their ownership and exploitation can lead to conflicts. A good example of these conflicts were experienced in DRC (Democratic Republic of Congo) where it has fallen victim to the 'resource curse,' a theory which shows that an abundance of natural resources in developing countries generates a higher threat for civil war and little or no development (Anon n.d.). In DRC the International Rescue Committee (IRC) estimated about 5.4 million deaths due to the conflict between 1996-2010. Even worse, 45% of these were children. An additional 45,000 still die each month, even after a peace treaty to end the war(Carpenter & Conrad 2012). The exploitation of minerals is related with the disturbance on the environment.

With this high incidence of conflicts more emphasis is given on the economic viability of the mines forgetting the impacts of these activities on the environment. It is their exploitation of both finite and renewable resources that is threatening the environment that we are living in. The effects of this exploitation are acute and easily identifiable and /or gradual and are long term. The environment includes both land and water resources and it is of necessity to take into consideration the effects of mining on water resources since these are mainly overlooked. It is agreed that water is an economic good, a social good, finite, non-substitutable and vital to all forms of life (ICWE, 1992), it follows that every living thing depend on water for its day to day life and need to be accessed in the best state in terms of quantity and quality thus the need to conserve it. On a national scale (Zimbabwe) there has been a sprouting in the number of illegal gold mines both reef and alluvial mines. Alluvial gold mining has been a major cause of concern as gold can be extracted through panning where water is used to wash the mineral rich soil. Gold panning has been the worst enemy of the environment for a long time in Zimbabwe (Bhebhe 2006). It is easier to perform compared to reef gold mining because the minerals is found deposited almost in their pure form and hence more people opt for it consequently leading to degradation of the aquatic environment because the panning process involves deposition of contaminants directly into e river

Gold mining have undesirable impacts on water quality other than the land resources alone if no proper preventive measures are put in place. This is marked by the substantial change in the

variations in the aquatic ecosystems as some species are wiped out and or migrate as the water carries more salts and also more humans would have occupied the animals' territory in exploration of the mineral(UNDP, 2006). These are usually overlooked as their effects are not easily identifiable and they are long term but they pose a hazard to many water users. These effects are more prominent and of concern if the mining is illegal where there is no regulation and control of the mining operations and mining effluent discharge. It usually associated with river pollution namely acid mine drainage, heavy metal pollution and high turbidity of river water, leading to poor water quality.

The contamination of water owing to unlawful gold mining has been evident in the Zambezi basin. Small scale mining and alluvial gold panning activities have taken over as an outcome of both the economic structural adjustment programs (ESAPs) and persistent famines within the SADC region (Shoko 2002). Most of this mining activity takes place on riverbeds and banks and releasing enormous amounts of silt and heavy metals into river systems, dams and lakes. This has also caught up with the Runde River after discovering of gold deposits along its banks and attracting a huge population both far and near in order to get a living from it. This means that there is increase in:

High concentration of heavy metals from the mineral soils can be a threat to human health and life as they cause a number of water borne diseases as drinking water is an important factor in passing on of diseases. A strong association between polluted drinking water with heavy metals from some Cities in Egypt chronic diseases such as renal failure, liver cirrhosis, hair loss, and chronic anemia were identified in a publication by (Salem *et al.* 2000). This shows that these heavy metal like lead, copper and iron are of great concern as they are not easily noticeable in drinking water hence the need to carry out this study.

Mercury concentration: a heavy metal whose occurrence in river water is a bit different because it is introduced by gold panners during the processing of gold. Mercury is used aimed at extracting gold from ore or soil by forming an amalgam or a blend of almost equal parts mercury and gold. The amalgam is heated, vaporizing the mercury from the mix and gold remaining behind (WHO 2013). The miners uses elemental mercury to precipitate gold and it reacts with other elements to form inorganic mercury compounds like mercurous chloride (Poulin *et al.* 2008). The inorganic form of mercury can get to humans via drinking water causing diseases like

the pink disease in young children(Poulin *et al.* 2008). It can go under biotransformation by aquatic organisms forming organic compounds like methyl mercury which is harmful to humans which can poison the central nervous system(Takizawa 1972a).

Turbidity , this refers to the suspended solids within the water and the mining activities causes high volumes of silt to be deposited into the river this reduces the quality of river water and also reduces carrying capacity of the river due to siltation (Shoko 2002). This shortens the live span of a reservoir as in the case of Runde river which is a sources of water to a lot of communities downstream. Continued deposition of sediment results in loss of storage capability of the river

This research aims at establishing the change in the water quality of Runde river in Zvishavane due to the introduction of alluvial gold mining using iron, copper , mercury ,turbidity and pH because extreme concentrations of these lead to poor water quality and pose a threat to human health.

1.1 JUSTIFICATION

The year 2000 marked an increase in the number of illegal gold mining predominated by alluvial mines in Zimbabwe (Jerrie and Sibanda 2010). This was due to people trying to improve livelihoods through trade in gold. Although people benefited from the gold the integrity of both terrestrial and aquatic ecosystems was compromised. Land use by illegal gold mining increased by 400 percent in between 1999 to 2012 and the rate of environmental degradation tripled in 2008 when the gold prices were higher (National College of Sciences 2011). This becomes an environmental concern as it accelerates erosion and all the sediments will eventually find their way into the river causing high turbidity. Furthermore the process of gold panning involves high water use and this adds more sediments into the river water.

The excavation practice in search of the mineral creates a lot of waste dumps. Mining involves production of large quantities of waste, especially from gold mines, which account for more than 99% of ore extracted as waste (Adler & Rustler, 2007). These dumps are rich in heavy metals which were in the soil under anaerobic conditions in the soil making them insoluble. When these heavy metals react with oxygen and water they become soluble and find their way into the

stream or they directly deposited into the river through the panning of the mineral rich soil. These heavy metals can cause a long list of diseases including Alzheimer's disease, Parkinson's disease, other brain and neurological disorders; it can also have negative effect on agriculture as irrigation with these ions causes salinization. This exposure of the compounds to water and oxygen can lead to formation of acid water termed acid mine drainage. The acidic nature of this water does not support life of many organisms in the water and also of plants under irrigation.

The study is justifiable as it tries to note the possible cause of pollution of water in the Runde river highlighting the possible short comings associated with the pollution. This would likely consientize responsible authorities like councils on economic challenges involved in high levels of pollution and also the general public of the health risk they can encounter in the long run.

1.2 OBJECTIVES AND HYPOTHESIS

General objectives

The main objective of this study is to investigate the effects of illegal gold mining on the water quality of Runde river.

Specific objectives

- To evaluate the changes in the water physical characteristics (turbidity, pH) as affected by mining activities
- To assess the concentration of heavy metal pollutants (mercury, iron, copper) associated with mining activities

1.3 HYPOTHESES

H₀- Gold mining result in increased hydrogen potential (pH) and turbidity

H₁- Gold mining has no significant effect on hydrogen potential and turbidity

H₀- Gold mining activities result in a significant increase of heavy metal concentrations in rivers

H₁- The presence of heavy metals is a result of natural processes

2.0 LITERATURE REVIEW

2.1. Properties and uses of gold

Gold is treasured for its multiple properties for example shine and its luster. It is mainly known for its bright yellow color, which makes it suitable to use in jewelry industry. It is a transition metal with the atomic symbol Au and atomic number 79 (Encarta Encyclopedia - Gold website). It is a malleable and ductile metal making it easy to be shaped into different shapes (Wikipedia- Gold website). Gold can be easily melted and reshaped a number of times without changing in its content making it more durable because it is inert. Gold does not react with air, heat, water, or most other solvents, which explains why “its radiance is forever” (Bernstein, 2000). Its chemistry makes it almost completely resistant to corrosive agents. It is these properties that make it valuable and its monetary value in trading. Gold is durable and very rare; it has a very high monetary value. Many nations have gold stocks as it is used reference metal for most national economies, the total world gold reserves are about 50,000 metric tons (Butterman 2005). This creates the pressure by individual states to stock as much gold as possible thus create a need to produce more of it by countries with it.

2.2. What is water quality?

Water quality refers to a broad range of things which are related to how one identifies water concerns and how different individuals address it (University of Arkansas 2007). Water quality describes the properties of the water which includes chemical, physical, and biological characteristics mainly focusing on its suitability for a precise purpose such as drinking or swimming (National Marine Sanctuaries 1999), hence water used in industry has a lower water quality compared to that used for domestic purposes. Pollution of the water sources has become a major concern due to the exponential growth of human activities and high levels of technology which generate a lot of effluent which will end up in the water sources. Pollution of surface water sources can be nonpoint or point sources where nonpoint sources comes from distant sources from the landscape getting into surface water after an overflow producing precipitation

event, while point sources refers to direct depositing of effluent into rivers from anthropogenic activities for example municipal waste ,manufacturing and mining waste water being drained into water sources. Taking the case of the Runde River, the flourishing of alluvial gold mining has become a cause for concern because it produce a lot of effluent into the river and it causes a lot of alterations to the chemistry of water which are harmful to life on earth and the economic viability of other water dependent sectors.

There is need to monitor water quality so as to prevent mishaps related to poor water quality for example diseases and increase in cost of purifying water by councils. Diseases related to scarce safe water supplies together with poor sanitation and hygiene has death tolls about 3.4 million per year, affecting mainly children (WHO, 2008 and Kengne and Quot, 2011). Generally people are aware of the biological contaminants and pay very little attention to the non-biological contaminants turbidity, iron copper, mercury and pH. The change in one of the parameters to undesired levels can lead to water scarcity as its quality is poor and to purify it its costly.

2.2.1Mercury

Sources of mercury into humans is mainly through their diet especially fish and water. Inorganic forms of mercury is the most common type of mercury that is present in water and is harmful in high concentrations. Organic mercury toxicity can also be noted even at very low concentrations contrary to inorganic mercury (UNEP Chapter3, paragraph53, 54 2010). Mercury is called a neurotoxicant as it affects the nervous system for example the brain development for unborn babies; it also affects child cardiovascular system leading to child mortality since children are born with heart diseases (IARC, 1993). This happened in Minamata, Japan in 1953 where cases of fetal minamata disease was recorded after the mothers were exposed to methl mercury during pregnancy due to eating fish from polluted water sources (Takizawa 1972a).

2.2.2Copper

Copper is a transition element which is stable in its metallic state and forms monovalent and divalent compounds. Dissolved copper can sometimes cause a light blue or blue green color and an unpleasant metallic bitter taste to drinking water. Blue to green staining of porcelain sinks and

plumbing fittings occurs when concentrations of dissolved copper in tap water is high. The natural presence of copper in water is a factor of pH, dissolved oxygen and presence of oxidizing agents (US EPA 1995). Mining will just increase the concentration of the copper and its compounds on which the oxidizing agents will act upon thereby increasing the copper concentration. A high concentration of copper in drinking water can be seen by nausea, vomiting and diarrhea (Chris Dinsen Rogers 1999), thus it is of great need to know the copper levels in water in order to maintain them at desirable levels and maintain the general populace's health.

2.2.3 Iron

Some metals which are found in mining waste forms the basis of the micro nutrients which are very crucial in plant nutrition and for human diet. Iron is very important in human as it helps in building of red blood cells and formation of chloroplasts in plants which is vital for photosynthesis. However iron is required in limited quantities and an excess will lead to toxicity leading to stunted growth of plants (FAO1999)

2.2.4. pH

pH is the measure of the concentration of hydrogen ions in a solution. Values of pH below 7 represent an acidic solution, above 7 represent alkaline and 7 represent neutral pH. Drinking high pH water can result in eye and skin irritation. Acidic water causes leaching of metals from plumbing system which can be toxic to humans thereby the metals find entry into human bodies through drinking water

Agriculture can be greatly affected by pH, irrigation with water outside pH range will result in nutritional imbalances in a sense that some nutrients will become unavailable in pH extremes or may contain a toxic ion which may affect the growth of plants.

2.3. The panning process

There are mainly two ways to separate gold from the soil which are the use of the sluice box or use of the wooden separating bowl. The sluice box (see annexure1) method is where by the panners constructs a platform using mud and stones from river such that the platform has flat top where a sieve plate (see annexure 2) is placed to remove stones from soil by washing it with water and a gently sloping single channel towards the main river channel (Hill 1999).The

suspected gold rich soil is trapped by pieces of rough cloth are lined along the channel going to the river. Using the wooden bowl the panner swells the bowl since the relative density of gold is high it settles at the bottom of the bowl. The sediments from the panning are let to flow into the water their content in water.

Turbidity

Turbidity is the clarity of water which is determined by the presence of suspended insoluble solids (Diamant *et al.*, 2013). Turbidity is measure of optical properties that causes light to be scattered and absorbed rather than being transmitted without alteration in the flux level through the trial (Allen and Brocher, 2008). Turbidity has to be considered because during the process of separating the gold from the soil there is disturbance of the river bed and also introduction of new particles of different weight and sizes which might scatter incoming light leading to water being hazy. High turbidity can considerably decrease the visual quality of lakes and streams (MPCA2008) having harmful effects on aquatic life by reducing food supplies, degrading spawning beds and affecting gill function.

The european Inland Fisheries Advisory Commission lists four ways through which fine particles can be harmful on fish by:

- Directly killing or reducing rate of growth and resistance to diseases
- Causing poor fish eggs' development
- Changing natural movements and migrations of fish species
- Reducing food availability and quantity

High turbidity result in increase of water treatment for drinking and food processing cost. Water with high sediment load will also fill the conveyance system with mud and silt, and can block valves and taps (Sheet n.d.). This leads to increase in maintenance cost of the water facilities. High turbidity can also cause reduced effectiveness of chlorination hence it leads to unsafe water being supplied to the general populace. As in the case of Runde river where it supplies water for communities downstream namely Mabasa growth point, Mabasa primary and high school,

Chemhini primary school, just to mention a few an increase in turbidity increase the possibility of the populace drinking unsafe water. This is also supported by literature ,where chlorination of water is done quite low turbidity prevent chlorine from killing the bacteria in the water efficiently (Sheet n.d.).

Table1.Maximum permissible level of micronutrients in water used for agriculture (WHO)

MICRO NUTRIENT	CONCENTRATION [mg/l]
Copper (Cu)	0.20
Iron (Fe)	5.0

Table 2, Maximum permissible concentration of selected metals in drinking water (WHO)

ELEMENT	CONCENTRATION mg/l
Mercury [Hg]	0.006
Copper [Cu]	0.2
Iron [Fe]	0.3
pH	6.5-8.5
Turbidity	5NTU

3.0 MATERIALS AND METHODS

3.1 Site description

The site is located along the Runde River in Madamwa village located 5km downstream of Korogwe gorge coordinates at $20^{\circ}06'23.54''S$ to $30^{\circ}03'17.59''E$ (see annexure4). At this point the river is flanked by two hills, on the north side there is the Zhara mine where reef gold mining is being done. At the banks of the river in line with the Zhara mine, illegal alluvial gold miners are thriving, extracting alluvial gold and processing it in the river using traditional primitive (use of sluice box and separating bowl) methods leading to pollution of the river water.

The study site falls in the Runde catchment area and lies in agro ecological region IV thus agriculture production is low due to low annual rainfalls and overdependence on rain fed agriculture. The area has loam and red clay soils which are rich in iron and copper compounds which gives the reddish color of the soil.

The mining area is located in line with the Zhara mine gently sloping towards the river.

3.2 Experimental Design

The river was divided into 3 sections which are at least 500 m apart where grab samples for the composite samples were taken. The sample sites were numbered 1, 2 and 3 (see annexure 4) where:

SAMPLE SITE 1

The site is located above the mining area in the upper course of the river. This site shows the river water quality before the water passes through the mining area and is the basis for comparisons of the other sites

SAMPLE SITE 2

It is the point in line with and/or the zone where the mining and mining processes are carried out. At this point samples are taken in order to note and assess the effects of the mining activity on water quality.

SAMPLE SITE 3

Site 3 is located downstream after the mining and processing zone. Its purpose is to assess the river water quality downstream of the mining site and comparing with the other sites.

Sampling

Samples were taken for dry and wet seasons in order to assess the effectiveness of the dilution effect of water. Water samples were taken across the river and on each of the samples site and five composite samples were taken using 1000 ml water bottles and packed in cooler boxes in order to maintain the river water conditions.

The lag time between samples was one month with first three samples being taken in September with one sample taken and the following months one samples each. During the wet season the lag time reduced to 2 weeks because of the short duration of the wet season. One sample was taken at the end of December and two weeks after the last sample was taken. The lag time between samples during the wet season reduced because of the erratic rainfall patterns experienced nationwide.

A total of five samples were taken and the treatments were the difference in the differences in the seasons in which the samples were taken.

In the laboratory all samples were tested for all parameters namely mercury, copper, iron, turbidity and pH.

Analysis of variance was performed using GenStart 14th edition through a completely randomized design at 5% significance

4.0 RESULTS AND DISCUSSION

MERCURY

Fig 1a shows that the concentration of mercury during the dry season was lower at upstream with mean of 0.002mg/l than the mining area with a mean of 0.0098 mg/l. Further downstream mercury concentration in the river water however reduced to 0.0069mg/l but it was lower than site 2 values. Mercury concentration for the wet season showed a similar trends with the river water concentration being 0.0008 mg/l at the upstream,0.0063 at the mining zone and downstream had 0.0052 which were lower than the dry season values

The mercury concentrations in both seasons and for the study sites were significantly different with P value at 0.001

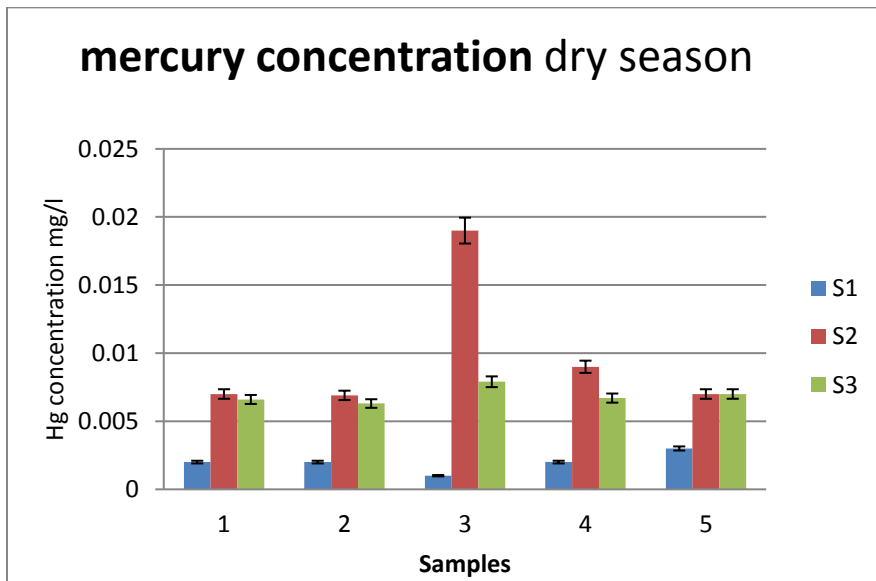


Fig 1a. A comparison of mercury concentrations amongst sampling sites in the dry season

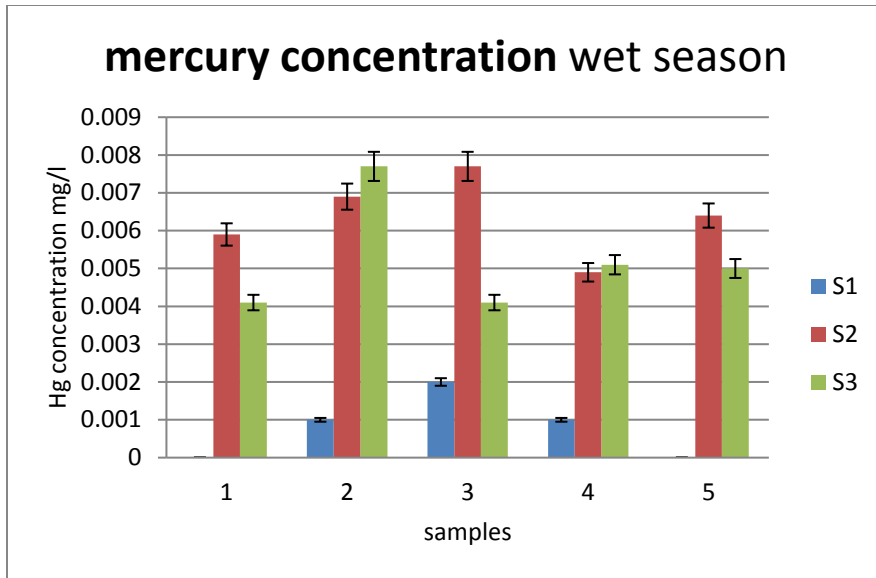


Fig 1b. A comparison of mercury concentrations amongst sampling sites in the wet season

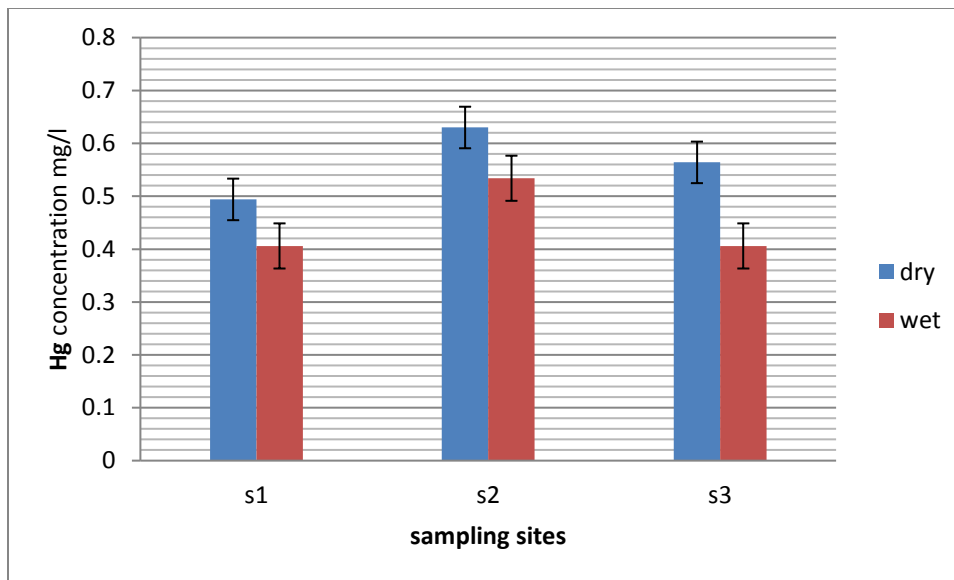


Fig 1c. A general comparison of the seasons using sampling site means

The increase in mercury concentration may be attributed to humans introducing it into the river during the gold panning process. The use of mercury in gold panning is because of its capability to make simpler the process of gold separation, low costs and its ability to be

reused(Mudyazhezha & Kanhukamwe 2014). Gold has a high density and it easily settles at the base of separating bowls during extraction. The gold is usually found in small pieces scattered in the gold rich soils and mercury is used to precipitate these pieces making easier extraction. This means that there is direct contact with mercury by the miners and mostly they do not have protective clothing. High exposure to mercury is fatal as in the case of roman slaves who often died due to this exposure (encyclopedia.com2006). The drop in the mercury concentration downstream and during the wet season is linked to the dilution effect of water. This corresponds with what Nkuli (2008) found where there was drop in mercury levels at sampling point during the wet season where natural purification of the river was high (Nkuli 2008). Mercury can get into human system through food, irrigation with water containing mercury or fish inhabiting in mercury contaminated rivers, this forms organic mercury compounds which are hazardous to human health for example methyl and ethyl mercury (Takizawa 1972b). This becomes an issue of concern as there a number of nutritional garden downstream and the river has been a fish source to communities around it. These pollution can be fatal in the long run as people die due too mercury poisoning as in the case of minamata japan where 100 cases were reported and 50 of these people died(In n.d.1994).

COPPER

Figure 2a shows that there is an increase in the concentration of copper in the dry season from the upstream with a value of 0.382 mg/l, mining area with a value of 0.71mg/l and downstream value 0.422mg/l. During the wet season figure 2b shows that copper concentration was significantly higher at P value 0.001 with means 0.546mg/l, 0.876mg/l and 0.604mg/l for upstream , mining area and downstream respectively

The differences in the concentrations for all the study sites were significantly different at P value at 0.001.

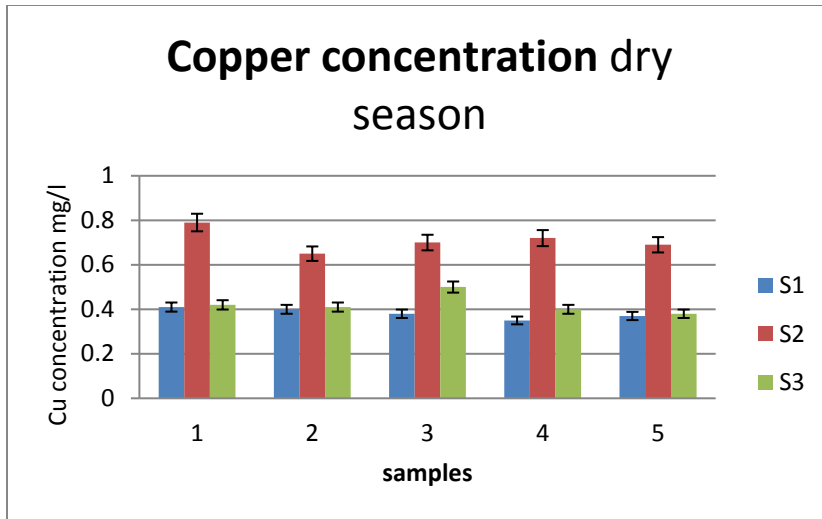


Fig 2a. A comparison of copper concentrations amongst sampling sites in the dry season

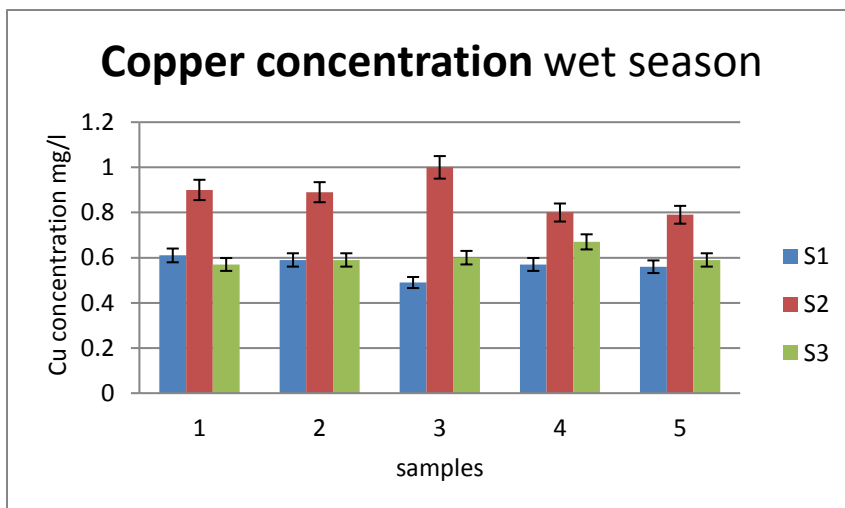


Figure 2b. A comparison of copper concentrations amongst sampling sites in the wet season

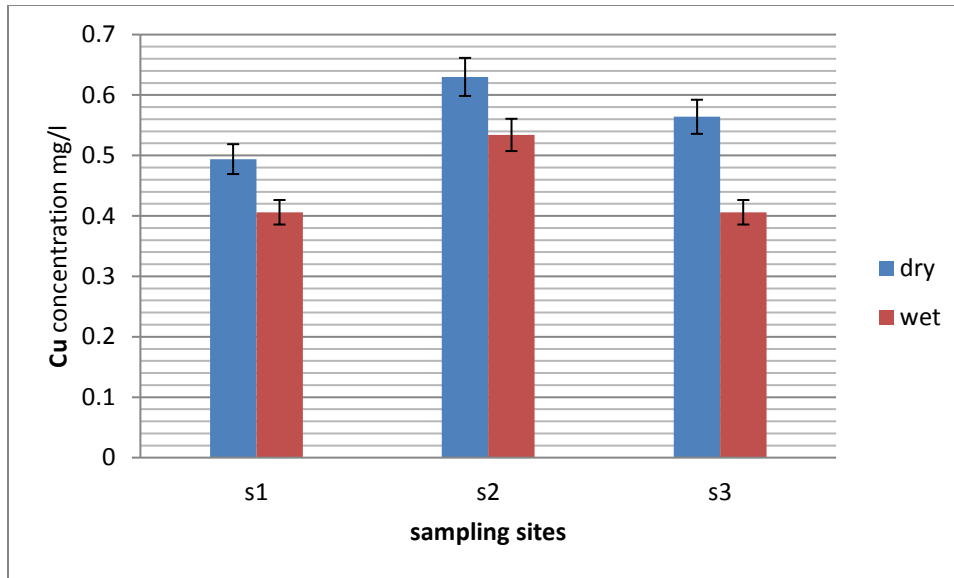


Fig 2c. A general comparison of the seasons using sampling site means

The presence of copper in the water can be attributed to its natural presence in water this occurs when flowing water comes in contact with rock or soil containing copper (Salem *et al.* 2000). High copper levels at site 2 were due to direct deposition of copper bearing soils by gold panners into the river. Most of the copper found in soil can be found in form of silicates which gives the reddish color of soil and these are hydrolyzed to release copper ions into water (Schulte 2004). An even higher concentration of copper was observed during the wet season and can be a result of natural processes like high rates of water erosion which lead to more silt from the red clay soils rich in copper ions being deposited into the river. Copper is essential in the body at limited levels but in its high concentration can have serious health effects like immune system breakdown leading low resistance to any opportunistic diseases (Salem *et al.* 2000). This pose a threat to the health of the residents around madamwa village as they do not have a reliable source of water. They only have one borehole which does not supply water during the dry season and they have to resort to the river water. Copper has negative effects on agriculture where in its undesirable amounts it kills plant roots and when taken up by plants it is hardly translocated by plants thereby interfering with the osmosis of the plant. If sheep graze on area contaminated with

copper it leads to copper poisoning and ultimately death as it accumulates in their liver (In n.d.1994)

IRON

An increase in the iron concentration for the dry season was observed from the upstream to the mining area with values 0.494mg/l and 0.63mg/l respectively, followed by a decrease downstream with a value of 0.564mg/l. In the wet season the values showed the same trend but slightly reduced compared to the dry season's values which were 0.406mg/l, 0.534mg/l and 0.416mg/l for upstream , mining area and downstream. The iron concentration in the river water was significantly different between the seasons at P value 0.019.

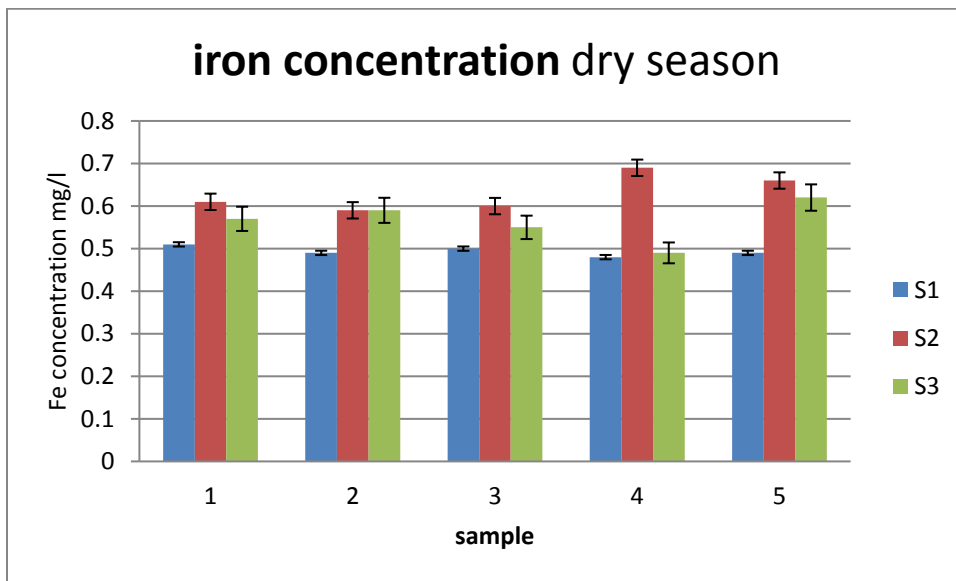


Fig 3a. A comparison of iron concentrations amongst sampling sites in the dry season

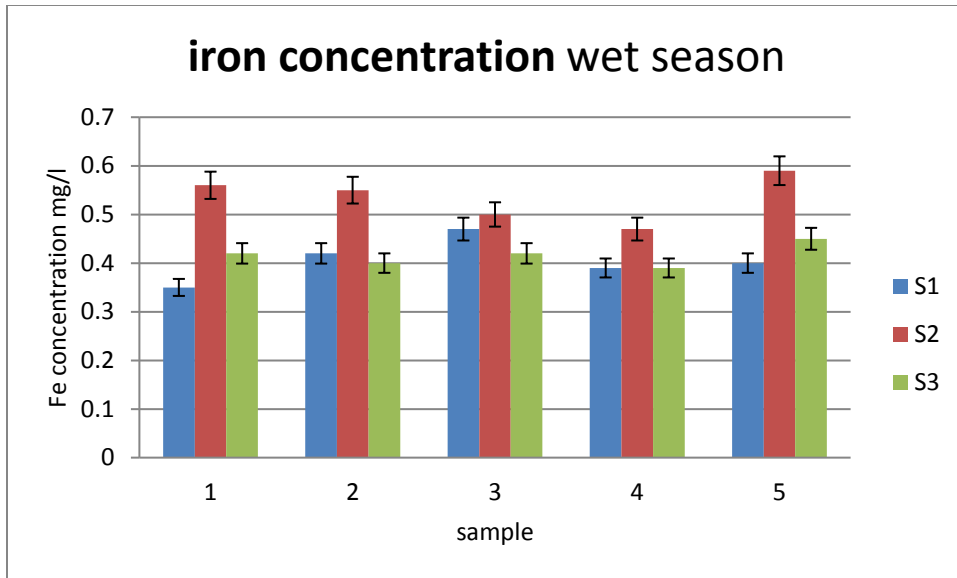


Fig 3b A comparison of iron concentrations amongst sampling sites in the wet season

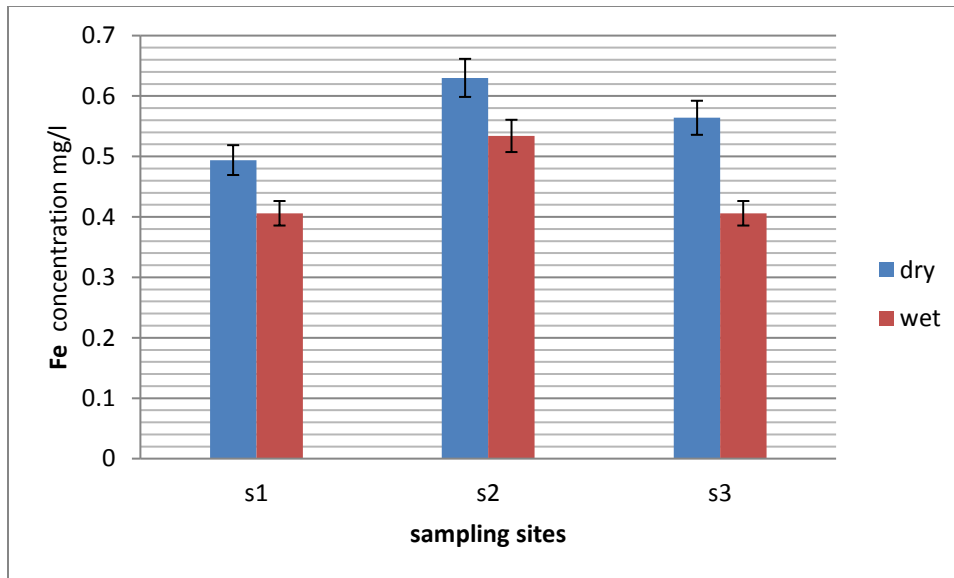


Fig 3c . A general comparison of the seasons using sampling site means

The high concentration of Iron can be attributed to the mining waste finding its way into the river either by drainage water being pumped out of mining shafts, runoff water after or direct deposition of iron pyrites into the river. Iron concentration increase occurs when sulphide

compounds called pyrite are exposed to air and water causing oxidation forming sulphuric acid and releasing iron ions into the water(Nkuli 2008) e as shown by the chemical equation.

$$\text{FeS}_2 + 3,5\text{O}_2 + \text{H}_2\text{O} = \text{Fe}^{2+} + 2\text{SO}_4^{2-} + 2\text{H}$$

This acidity will further react with more iron containing compounds to release more iron into the water. In as much as iron is important for both animals and plants for the manufacture of haemoglobin and chloroplasts respectively it can be toxic in its high quantities. High content of iron can lead to stunted growth of plants as it suppresses the uptake of other nutrients (FAO2005)

TURBIDITY

Turbidity at the upstream of the river had a mean value of 4.88NTU , mining area value of 9.9 NTU and downstream with 6.26NTU during the dry season. In the wet season turbidity was highest with mean values 13.82NTU, 25.66NTU and 15.38NTU for the upstream ,mining area and downstream respectively. P values for comparisons amongst the three site in both season was significantly different at 0.001

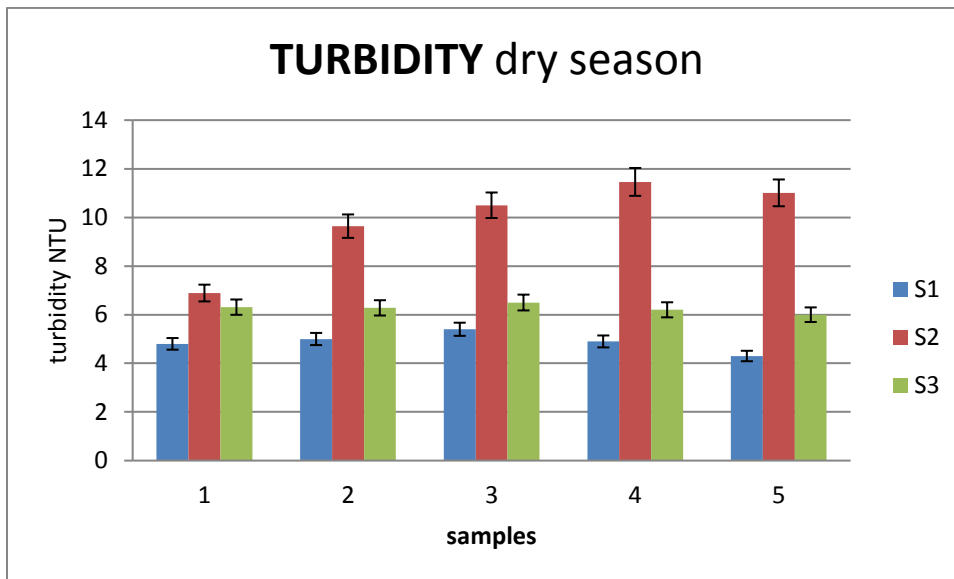


Fig 4a A comparison of turbidity amongst sampling sites in the dry season

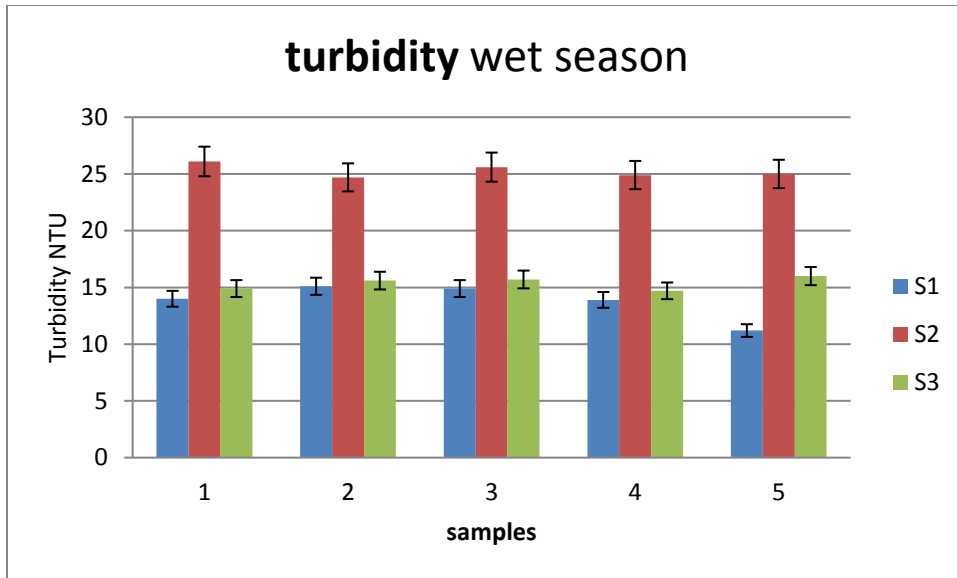


Fig 4b. A comparison of turbidity amongst sampling sites in the dry season.

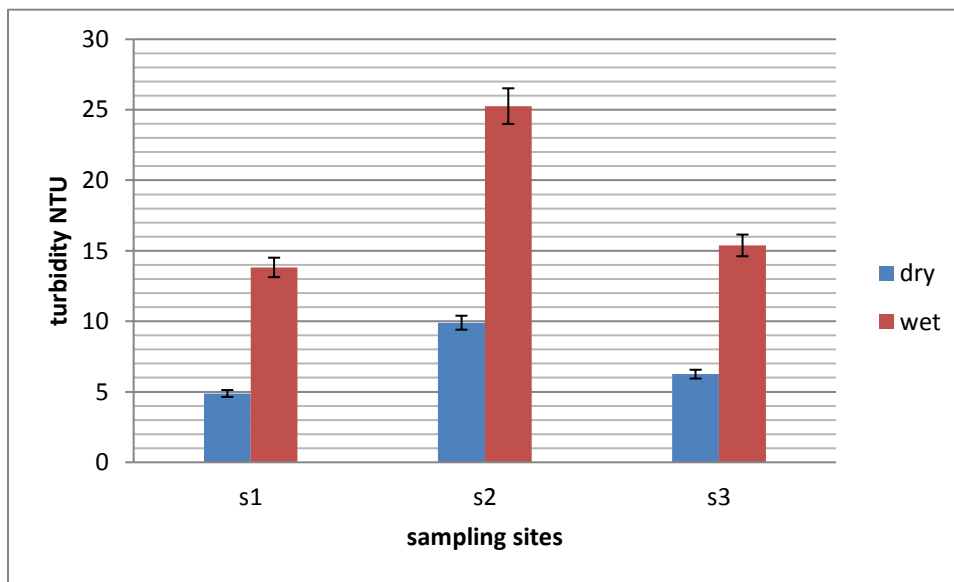


Fig 4c. A general comparison of the seasons' turbidity using sampling site means

The low turbidity at site 1 during the dry season maybe because of low river energy hence the limited sediments it has easily settles giving clear water. This is a result of hardly little

precipitation from the catchment to cause meaningful runoff to promote water erosion. This follows that there is no extra sediment added into the river from itself or from the catchment

The generally high turbidity during the wet season can be linked to high rainfall leading to increased runoff and consequently water erosion in the river and also within the catchment thereby increasing sediment load as shown by the reddish color of river water after rainfall events (Diamant *et al.*, 2013. This tally with what (Sheet n.d.2012) found out, that supplies often undergo water treatment can be affected by turbidity. For example, during the rainy season when mud and silt are washed into rivers and streams. High turbidity on site 2 can be linked to high sediment load being carried into the river in form of gold rich soil by the gold panners as they separate the mineral from the soil(Anon n.d.2010). Turbidity can be of concern as it causes siltation of water sources leading to low storage capacity of rivers and high incidence of floods (Mudyazhezha & Kanhukamwe 2014). High sediment water can cause health threats to many water users mainly depending on chlorination to disinfect water, turbidity reduces the effectiveness of chlorination(Sheet n.d.2012). It can lead to high maintenance costs as settling of sediment can clog or block the conveyance and storage systems.

pH

Fig5a shows a reduction in the pH to acidic from the upstream to the mining area having mean values of 7.54 and 6.12. Further downstream had a higher pH mean of 6.38 with significance at P value 0.001. The wet season showed a high pH with the mining area having the lowest mean of 7.38. The rest of the sites in the wet season was alkaline with a significant difference of P value at 0.001. comparison between the two seasons was significant at Pvalue 0.007.

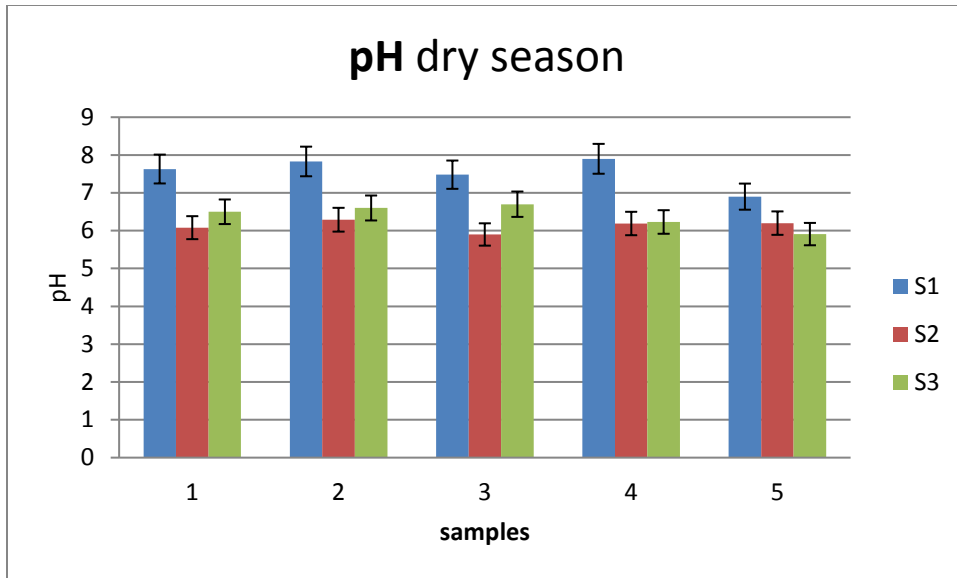


Fig 5a. A comparison of pH values amongst sampling sites in the dry season.

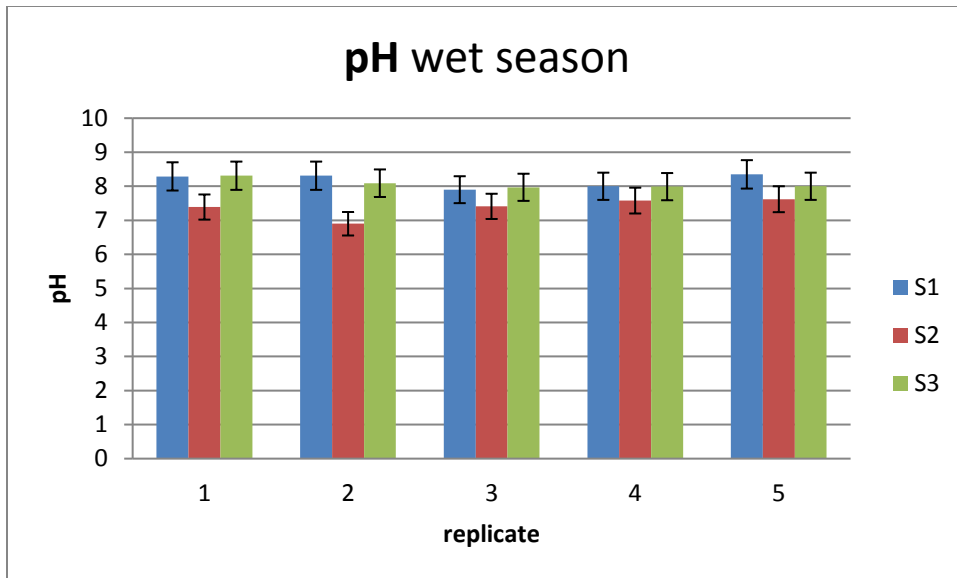


Fig 5b. A comparison of pH values amongst sampling sites in the dry season.

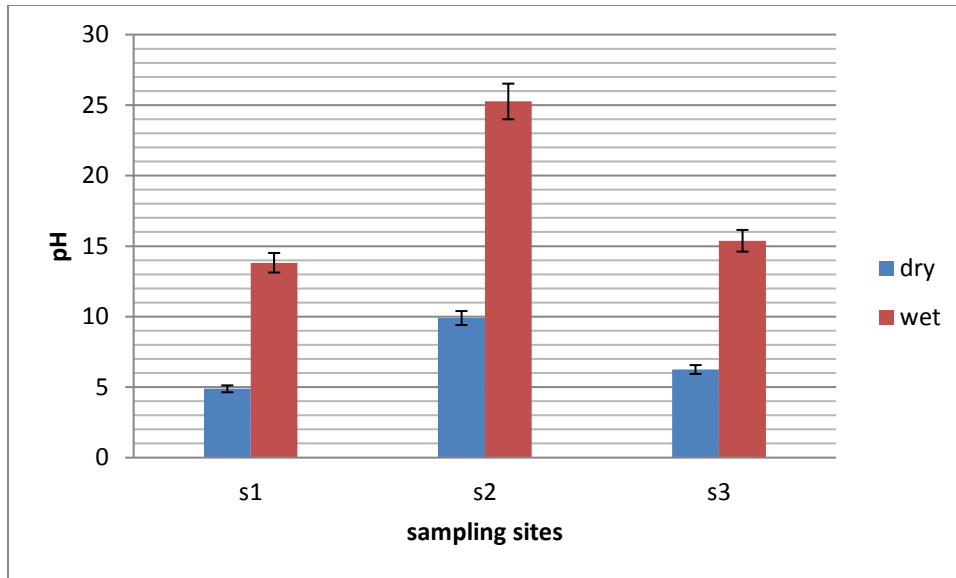


Fig 5c. A general comparison of the seasons' pH using sampling site means

The acidity at the upstream and mining area can be attributed to disposal of acidifying materials mainly sulphides being oxidized in the presence of water to form an acid these will be leached by rain towards the river(Kuyucak 2002). These acid wastes can come in form of acid mine drainage as the illegal miners frequently pump water from the shafts directing it to the river in order to access the mineral seam.



High pH during the wet season can be attributed to high erosion levels of the red clay soils which contain basic compounds like iron oxide, iron hydroxide and copper oxide which causes alkalinity(Environmental Impacts 2002). The pH reduced at site 2 because of the acid mine drainage and quickly rose at site 3. This is because of the natural purification of water which take up more atmospheric oxygen leading to it furnishing hydrogen ions thus neutralizing the acidity.

These changes in pH can have adverse effect on a number of sectors. It can reduce aquatic biodiversity as these organisms took a lot of time to evolve and adapt to the normal conditions and a sudden change of these conditions results death of certain species or migration(Shoko 2002). Extremes in pH can cause nutrient deficiencies and toxicities in agriculture as it causes

nutrient imbalances. Acidic water can cause heavy metal poisoning as it corrodes the conveyance system and find its way into human bodies(Nyakungu & Mbera 2013).

5.0 CONCLUSIONS

From the results shown mercury concentration significantly increased at the mining area and downstream, thus this is attributed to direct deposition of the heavy metal into the river by miners during its use in separating gold from the soil these levels were higher than the permissible WHO standards. Concentration of iron and copper increased having means between 0.71mg/l to 0.42mg/l in the dry season and 0.876mg/l to 0.604mg/l in the wet season. This is a major cause for concern as institutions and areas depending on Runde river as a source of water for use are prone to diseases caused by high concentration of these ions getting into the body. The pH levels at the mining area were the lowest at all sampling points due to the reasons discussed above and the location of the mining site makes it easier for non-point sources of acidity to find their way into the river after the oxidation of the mining dumps and draining of acid water from the mining area. The short distance from the mining zone makes the effluent to easily drain into the river. Turbidity was highest during the wet season and this means that effectiveness of the simple chlorination process of water at Mabasa growth point will be undermined and the population depending on it for water may use poor quality water. In conclusion the results show that illegal gold mining have more adverse effects on both the aquatic environment and water users which transform into a number of health hazards to humans and nature.

5.1 RECOMMENDATIONS

The responsible authorities should like EMA and the rural district council should minimize pollution of the river by stoppage of the use of river water in gold processes. This can be substituted by taking the processes further inland and use the mine water to separate the gold. The mining dumps which are sources of acidity should be neutralized for example by lime neutralisation thus reducing acid mine drainage which causes low pH river water. Dependants of Runde river as a source of water should adopt better ways of water purification in order to remove the heavy metals in the water resulting from the mining activity. More boreholes should be sunk in villages along the river as they normally depend on river water during the dry season.

APPENDICES

1) STATISTICAL ANALYSIS FOR COPPER

DRY SEASON

Analysis of variance

Variate: COPPER_mg_l

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	2	0.328693	0.164347	43.59	<.001
Residual	12	0.045240	0.003770		
Total	14	0.373933			

WET SEASON

Analysis of variance

Variate: COPPER_mg_l

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	2	0.320213	0.160107	89.95	<.001
Residual	12	0.021360	0.001780		
Total	14	0.341573			

2) STATISTICAL ANALYSIS FOR MERCURY

DRY SEASON

Analysis of variance

Variate: MERCURY_mg_l

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	2	1.542E-04	7.710E-05	8.19	0.006
Residual	12	1.129E-04	9.410E-06		
Total	14	2.671E-04			

WET SEASON

Analysis of variance

Variate: MERCURY_mg_l

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	2	8.603E-05	4.302E-05	32.36	<.001
Residual	12	1.595E-05	1.329E-06		
Total	14	1.020E-04			

3)STATISTICAL ANALYLIS FOR pH

DRY SEASON

Analysis of variance

Variate: Ph

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	2	5.69365	2.84683	30.17	<.001
Residual	12	1.13244	0.09437		
Total	14	6.82609			

WET SEASON

Analysis of variance

Variate: PH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	2	1.83481	0.91741	18.70	<.001
Residual	12	0.58868	0.04906		
Total	14	2.42349			

4) STATISTICAL ANALYSIS FOR IRON

DRY SEASON Analysis of variance

Variate: IRON_mg_l

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	2	0.046253	0.023127	15.91	<.001
Residual	12	0.017440	0.001453		
Total	14	0.063693			

WET SEASON

Analysis of variance

Variate: IRON_mg_l

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	2	0.050680	0.025340	15.87	<.001
Residual	12	0.019160	0.001597		
Total	14	0.069840			

5) STATISTICAL ANALYSIS FOR TURBIDITY

DRY SEASON

Analysis of variance

Variate: TURBIDITY_mg_l

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	2	67.272	33.636	29.01	<.001
Residual	12	13.913	1.159		
Total	14	81.185			

WET SEASON

Analysis of variance

Variate: TURBIDITY_NTU

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	2	384.869	192.435	188.23	<.001

Residual	12	12.268	1.022
Total	14	397.137	

Comparisons of seasons

Analysis of variance

Variate: mercury

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	1	0.082810	0.082810	62.50	<.001
Residual	8	0.010600	0.001325		
Total	9	0.093410			

Analysis of variance

Variate: iron

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	1	6.400E-06	6.400E-06	8.53	0.019
Residual	8	6.000E-06	7.500E-07		
Total	9	1.240E-05			

Analysis of variance

Variate: copper

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	1	0.054760	0.054760	37.64	<.001
Residual	8	0.011640	0.001455		
Total	9	0.066400			

Analysis of variance

Variate: TURBIDITY_ntu

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	1	227.5290	227.5290	1002.33	<.001
Residual	8	1.8160	0.2270		
Total	9	229.3450			

Analysis of variance

Variate: Ph

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREATMENT	1	1.09561	1.09561	12.63	0.007
Residual	8	0.69408	0.08676		
Total	9	1.78969			



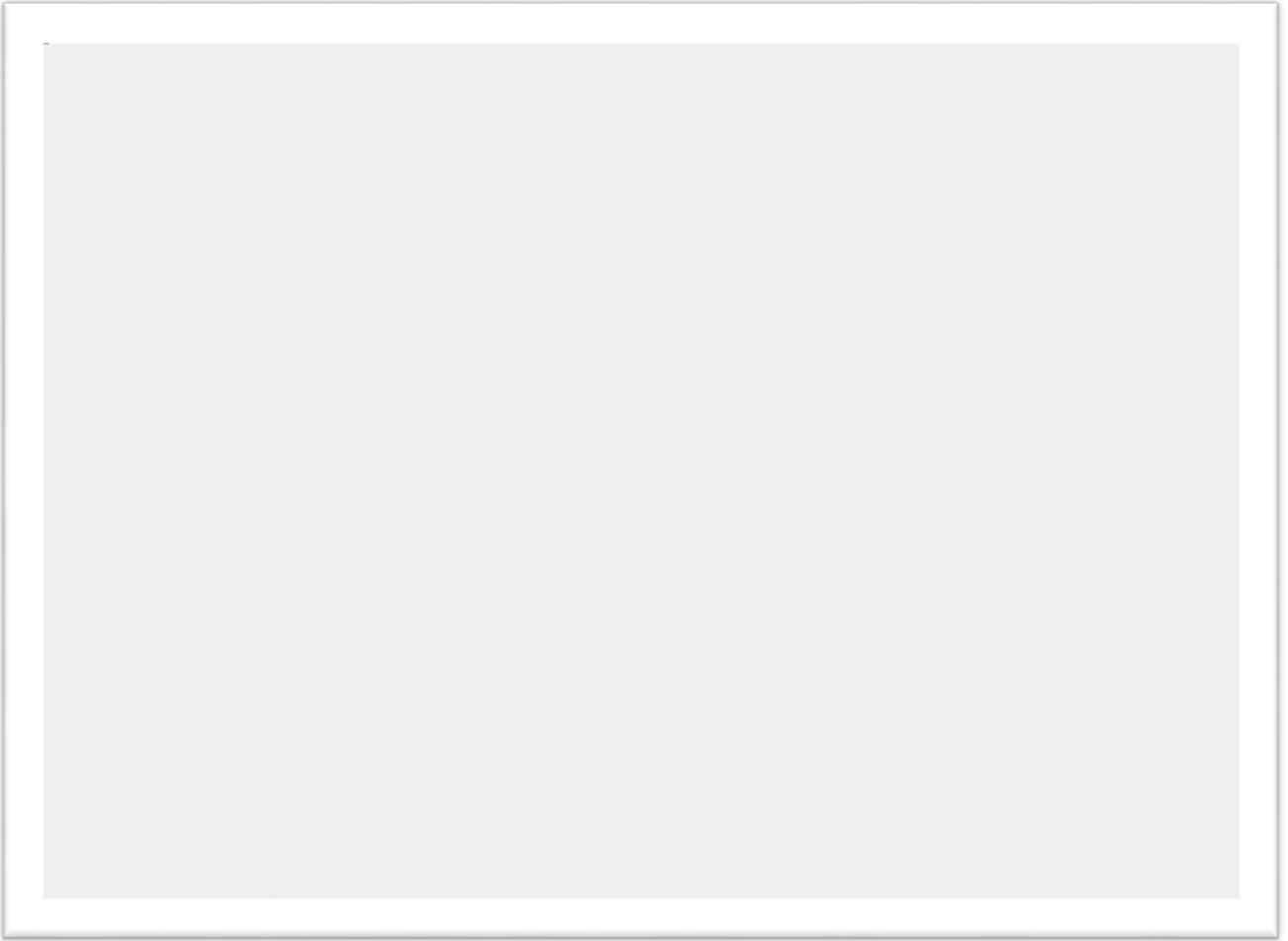
Sluice Box annexure 1 (water from washing the soil is directed into the river)



Sieve plate annexure 2



One of the highly producing shaft at least 20 meters deep(*termed hasha*) annexure 3



Annexure 4 study site

REFERENCES

- 1Anon, DISASTERS GLOBAL BIODIVERSITY MINING blessing or curse ?
- Anon, No Title. , pp.1–14.
- 2Bhebhe, D., 2006. Environmental damage caused by gold panning in Gwanda district {Zimbabwe}. , (051).
- 3Carpenter, L. & Conrad, J., 2012
- 4 Guidelines for Drinking-water Quality.
- 5 Environmental and Social Impacts of Mining.
- 6In, B.I.I.I.F.T., Element Concentrations Toxic to Plants , Animals , and Man.
- 7Kuyucak, N., 2002. Role of Microorganisms in Mining : Generation of Acid Rock Drainage and its Mitigation and Treatment. , 2(3), pp.179–196.
- 8Mudyazhezha, S. & Kanhukamwe, R., 2014. ENVIRONMENTAL MONITORING OF THE EFFECTS OF CONVENTIONAL AND ARTISANAL GOLD MINING ON WATER QUALITY IN NGWABALOZI. , 4(10).
- 9Nkuli, G., 2008. EFFECTS OF MINING ACTIVITIES AT BULYANHULU GOLD MINE (BGM) ON THE WATER QUALITY OF BULYANHULU RIVER : SHINYANGA - TANZANIA. , (June).
- 10Nyakungu, T. & Mbera, S., 2013. Assessment of the Impact Waste Water Disposal on Cations in Ruwa River , Zimbabwe. , 4(6), pp.55–61.
- 11Poulin, J. et al., 2008. Mercury Assessing the environmental burden of disease at national and local levels. , (16).
- 12Salem et al., 2000. Heavy Metals in Drinking Water and Their Environmental Impact on Human Health. *Icehm*, pp.542–556.
- 13Schulte, E.E., 2004. Fertilizer Sources of Iron. , p.2. Available at: <http://corn.agronomy.wisc.edu/Management/pdfs/a3554.pdf>.

14Sheet, F., Turbidity measurement.

15Shoko, D., 2002. Small-scale mining and alluvial gold panning within the Zambezi basin: an ecological time-bomb and tinder box for future conflict among riparian states. *Managing Common Property in an Age of Globalisation: Zimbabwean Experiences*, pp.46–66.

16Takizawa, Y., 1972a. Minamata Disease in Japan. *Environmental Toxicology and*, I, pp.6–10.

17Takizawa, Y., 1972b. SA NE M SC PL O E – C EO PL O E – , I.

18WHO, 2013. Mercury Exposure and Health Impacts among Individuals in the Artisanal and Small-Scale Gold Mining (ASGM) Community. *Preventing Disease through Healthy Environments*, (January), pp.1–7. Available at:
http://www.who.int/ipcs/assessment/public_health/mercury_asgm.pdf.

19 mining facts.org 2012 Fraser Institute

20 International Convention on Water and Environment, 1992

21 United Nations Development Program, 2006

22 National College of Sciences 2011