

## **THE ENVIRONMENTAL EFFECTS OF EFFLUENT DISPOSAL AT GOLD MINES IN ZIMBABWE: A CASE STUDY OF TIGER REEF MINE IN KWEKWE**

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### **ABSTRACT**

This study examines the environmental effects of effluent disposal at gold mines in Zimbabwe with particular reference to Tiger Reef Gold Mine in the Kwekwe district. The methods of data collection included questionnaire surveys and interviews directed at key informants to solicit information on the environmental impacts of the environment and human health. Field tests and observations were also undertaken on parameters, such as cyanide and mercury concentrations, and these were compared with the recommended standards of the World Health Organization (WHO) and the Standards Association of Zimbabwe (SAZ). The conclusions drawn from the study are that waste water management practices at Tiger Reef Mine are associated with negative impacts on the environment as well as human health. There is also lack of monitoring and enforcement of the relevant environmental management legislation by the relevant authorities in the country in order to control the negative impacts. It is recommended that the mine needs to adopt a holistic approach in waste effluent water treatment by using strategies, such as closed circuit treatment, microbial activities, and cyanide bio-degradation.

**Key words:** effluent disposal, cyanide concentration, mercury concentration,

### **INTRODUCTION**

The mining sector plays a crucial role in the economies of many countries, especially through both backward and forward linkages. Significant contributions can be noted in the form of employment creation and foreign currency earnings that are essential for socio-economic development. According to Zimtrade (2006), over the years, mining accounted for 4% of Zimbabwe's GDP. Gold production, in particular, is one of the significant sectors in terms of foreign currency earnings and contributes about 30% of the total foreign currency earnings Zimtrade (2006). It is estimated that, on average, gold exports account for 15% of all exports. However, such a trend has been undermined by several constraints that include rising costs of production, lack of foreign currency, ageing processing technology, complexity of the remaining ores as well as depletion of free milling ores (Ajusa, 2003). As a result of these problems, gold production, which normally accounts for 52% of total

mineral production in Zimbabwe, suffered a huge slump between 1999 and 2008, according to the Chamber of Mines (2008)

Focus in the mining sector should not be only on the economic aspects, but on sustainable environmental management, which is part of the integrated global efforts for environmentally friendly production processes (Ajusa, 2003). According to Ermitte (2004), mine effluent is a term used to describe waste water from mines that includes waste rock or tailings depositories, slimes dams, and/or draining into an adjoining body of water, including streams, lakes aquifers, wetlands, and oceans. The Ministry of Mines (1990) asserts that effluent is waste water or other fluid originating from industrial activity, whether the water is treated or untreated and whether it is discharged directly or indirectly into the environment. 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). Disposal of such large quantities of waste poses tremendous challenges for the gold mining industry and may significantly impact the environment.

A major environmental problem relating to mining is the uncontrolled discharge of contaminated water commonly known as effluent disposal (EEB, 2000). It is widely acknowledged that this phenomenon is responsible for costly environmental and socio-economic impacts. Effluent disposal from gold mines is characterized by raised levels of toxic heavy metals, especially sodium of cyanide, silver, mercury, and arsenic. Their availability in effluent water is not only associated with ground and surface water contamination, but is also responsible for the degradation of aquatic environments, animal species, as well as death and infection of human beings (Adler & Rustler, 2007). Assessments by the Environmental Protection Agency in 1987 concluded that “problems relating to mining effluent may be second only to stratospheric ozone depletion in terms of ecological risks. Release of mine effluent to the environment can result in irreversible destruction of ecosystems. In many cases the polluted sites may never be restored fully because pollution is so persistent that remedial measures may be difficult to apply” (EEB, 2000). Mining companies, scientists, and governments are blamed for being reluctant to discuss mine water effluent and its impacts publicly, yet it is a state of a problem of such magnitude that it will affect the environment and health of the present, as well as generations to come.

Although Zimbabwe has made significant progress in shifting policy framework to address mine water effluent and the mining industry has changed its practices to conform to new legislation, vulnerability in the current system still persists (Wohurst, 2003). Institutional fragmentation, overlapping or vaguely defined roles and responsibilities regarding the management, and control over mining waste are common in Zimbabwe, like most developing countries (Godfrey, 2007). In general, waste management falls within the mandate of environmental authorities or agencies, while mining activities are being addressed by mining authorities with little guidelines on managing mine waste. Mining developments and activities in Zimbabwe are thus highly characterized by profit motives at the expense of environmental protection (Ajusa, 2003). The Midlands

Province of Zimbabwe, in general, is characterized by both small scale to medium scale gold mining activities. The rampant illegal gold panning in the area cannot be overlooked. Although these activities are vital for socio-economic development, their associated environmental impacts need to be examined. Considerable priority has been given to the precious metal (gold) at the expense of all other considerations. This research is an attempt to bring into the lime light the potential environmental effects of the effluent disposed at gold mines using Tiger Reef Mine as a case study.

Tiger Reef Mine is in the Midlands Province of Zimbabwe within the green belt and 16 km northwest of the city of Kwekwe along the Kwekwe Gokwe Road (Fig.1). Its total area is approximately 54 km<sup>2</sup> and is bounded to the north by the Sebakwe River. The mine is a typical medium gold producing mine. Tiger Reef Mine employs up to 400 workers under normal conditions whose duties are specialized, such as geologists, artisans, engineers, chemists, assayers, human resource managers' surveyors as well as number of general workers. The objectives of this study are to establish the types of effluent disposed at the mine, to assess the environmental impacts of the waste, and to evaluate the current practices in managing the waste in order to come up with environmentally sound strategies for disposing the waste.

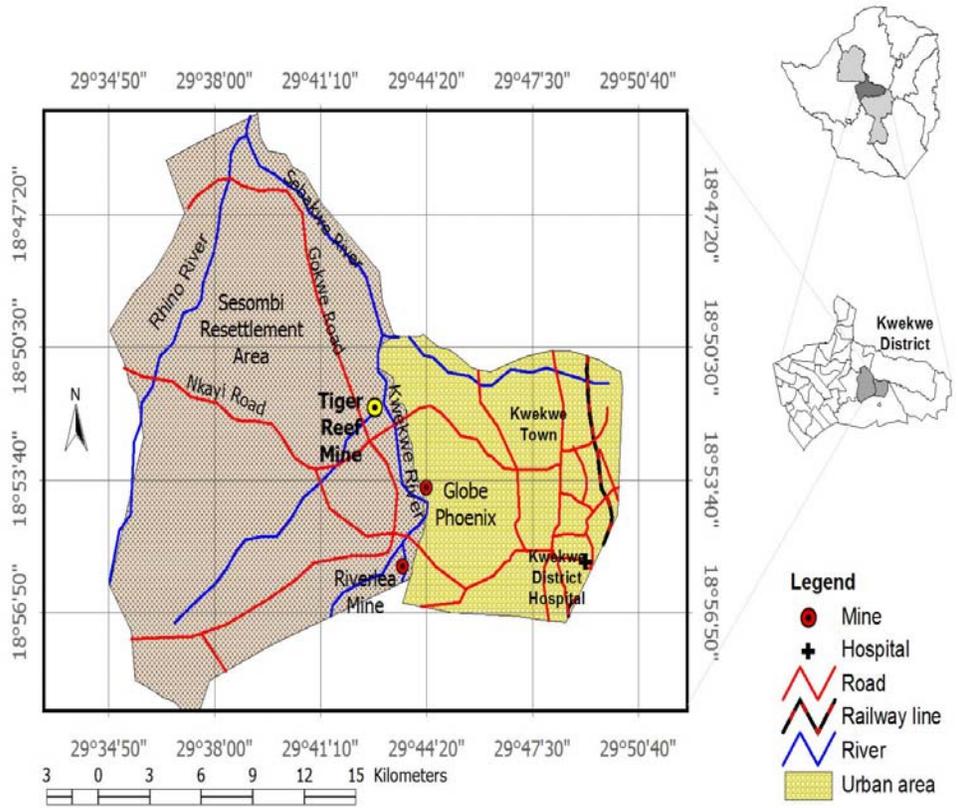


Fig. 1 The location of Tiger Reef Mine in the Midlands Province of Zimbabwe

## METHODOLOGY

A multi-methods approach was used in this research that included the use of questionnaires, interviews, sample tests, and field observations. Questionnaires were directed at the residents of the mine and surrounding areas to obtain information on the effects of the effluent generated by the mine. Table 1 shows the personnel and reasons for interviews undertaken by key informants at the mine.

**Table 1: Personnel and reasons for interviews**

Personnel to be interviewed	Reasons for interview
Mine manager	Information on activities at the mine in and their impact on the environment and human health
Safety, health, and environmental officer	The health impacts of effluent disposal and the measures put in place to mitigate the impacts
Engineering manager	Information regarding the technical design of slimes dams, heap leach pads, and tailings dams impoundments
Environmental Management Agency officials	Information on the environmental policy in place to monitor and regulate mine activities
Plant manager	To get information regarding major chemicals, reagents, and heavy metals used in the plant and the management of effluent water, especially after it has gone through various plant processes.

Sample testing and field observations were used to define the levels of chemical constituencies of effluent disposed from the mine. Various elements were tested, including those chemicals that are used in gold production, such as sodium of cyanide and mercury. In selecting sampling locations, the researcher selected representative points. This implies a location that characterizes or approximates the quality or condition of the water body, or a location in process waters where specific parameters are measured that adequately reflect the actual conditions of those waters (ZINWA, 2000). Table 2 shows parameters for analysis and corresponding sample sites.

**Table 2 Sampling sites and selected parameters**

Parameter	Sample Site/ Identification	Results	Maximum recommended Threshold Levels mg/litre (WHO Standards/SAZ Standards)
Cyanide	1. Turura stream	0.23	0.02
	Borrow pit	0.105	0.02
Mercury	1. Discharge from stump mills	2.13	0.05
	2. Down stream	0.13	0.05
pH	1. Borrow pit	2.5	6.5 -7.5
	2. Down stream	3.0	6.5- 7.5

Samples were site specific in order to determine the effluent quality at its point of release into the environment. The selection of sampling locations was done at several locations, which were down stream, tailings dam impoundments, and actual point discharges at the stump mills. Samples were collected manually as the method is relatively less costly. This method, however, increases the probability of variability due to human sample handling as well as inconsistency in collection.

According to the Zimbabwe National Water Authority (ZINWA) (2000), samples must be preserved once collected and must be analyzed within the time limit established for the required parameter in order to maintain the integrity of the sample. In this regard, cyanide as well as mercury samples needed cool dry conditions (4 degrees Celsius) and needed to be tested within 14 and 28 days, respectively. The results of the sample testing were rated against local and international standards, especially Australian standards, World Health Organization, and Zimbabwean Standards using the Waste Water and Effluent standards of 2000. ZINWA Operational Guidelines for Water Pollution control in Zimbabwe were also used in order to weigh the tests results against set safe thresholds.

Various statutory instruments, standards, and acts, both local and international, were widely used, especially those with an environmental regulatory effect as well as sustainable protection of the environment. The list included the Standard Associations of Zimbabwe, the Environmental Management Act Chapter 20:27 of 2002, Mining (Management and Safety) Regulations, 1990 Chapter 165 Statutory Instrument 109 of 1990 as well as Water (waste and effluent) Disposal Regulations of 2000 at the local level. Internationally, the World Health

Organization standards and the Australian Standards were also incorporated in a bid to increase the scope of the study.

## **DATA PRESENTATION AND ANALYSIS**

The gold mining activities, especially rudimentary mines as well as stump mills, use mercury to dissolve and attract gold from the ore. The wet slurry effluent is a cause of concern considering the presence of mercury, which is bio-cumulative when disposed in aquatic environments (Dales, 1995). The types of effluent from Tiger Reef Gold Mine may be grouped into two types, namely acid wash effluent and tailings effluent, and these can be further divided into cyanidization tailings effluent and mercury tailings effluent.

### **Concentration of mercury**

Table 3 explains the concentrations of mercury in effluent water. The samples were collected from different points from effluent water discharged from the stump mill. This is an activity which uses mercury in the amalgamation of gold. With a standard threshold level of 0.01, one can see that the concentration of mercury is above stipulated limits. The concentrations are above SAZ and ZINWA limits as indicated by readings 2.13, 1.14, 0.13mg/liter for the sample sites selected. This leads to the assertion that water sources within the community are polluted with heavy metals, hence any use of open water is likely to pose mercury concentrations in the blood stream or its bio-accumulation in the case of animals. This was achieved through sample testing of effluent from the various sites of effluent disposal from the mine. The quest was to analyze the properties as well as the chemical constituencies of the disposed water, hence establishing the effluent type. The chemical properties of the effluent water were mainly concerned with those chemicals and heavy metals used at the mine.

**Table 3: Mercury concentrations (ml/liter) for the effluent water sample from the stump mill**

parameter	Sample site	Mercury concentrations (mg/liter)	Recommended threshold levels. SAZ/WHO.ZINWA Standards (mg/liter)
mercury	Seepage from water pond (a)	2.13	0.02
	Tailings impoundments (b)	1.14	0.02
	Stream down the mill (c)	0.13	0.02

The result of the assessment is that there is increasing level of water pollution to the immediate environment as a result of the activities of effluent disposal. Hence, there is need for improvement in effluent water treatment. Application of a more effective and environmentally friendly treatment system or improvement on the current system would be a solution to the current effluent water treatment limitations.

Artisanal mining releases mercury into two forms, that is, metallic mercury and mercury vapor. Although inhalation is a serious occupational and economic hazard, the conversion of re-deposited mercury vapor into methyl mercury, a reality available and highly toxic form of mercury, represents a critical health risk to residents consuming methyl mercury contaminated form of effluent. Due to the behavior of mercury in aquatic ecosystems, mercury levels in carnivorous fish, a crucial protein resource for many riparian communities, can be high.

Chronic exposure of mercury can also result in muscular tremors. Mild cases of mercury poisoning have many psycho-pathological symptoms, like depression and exaggerated emotional responses, which can be mistaken for alcoholism, fever, and malaria. Exposure to acute levels can produce dysfunctional kidneys, urinary tract infection, vomiting, and, potentially, death (Dales, 1995). In the Tiger Reef and the Kadoma-Chakari region of Zimbabwe, the fate of mercury, in amalgamation tailings that are subsequently subjected to cyanidation, was identified as a major cause for concern in terms of environmental pathways for exposure (Global Mercury Project, 2006). In this region, just like many other developing regions endowed with gold deposits, amalgamation tailings are often treated with cyanide to extract residual gold, with subsequent waste being typically discharged directly into nearby water ways. Mercury is known to form strong complexes with cyanide, resulting in mobilization of a portion of mercury in solution, which is discharged with effluent. As cyanide mercury complexes are highly soluble, this may contribute to the downstream transport of mercury in aquatic systems. More so, it has been suggested that mercury, in this form, may be more susceptible to transformation to biologically available form (especially methyl mercury) thereby enhancing the potential for its incorporation into the food chain (Campbell, 1998).

However, in cases where cyanide is not used at Tiger Reef, mercury tailings are often discharged into local drainages, crude impoundments, or old pits. In the nearby aquatic systems, mercury associated with tailings may be transformed to a biologically available form (methyl mercury), which biomagnifies up trophic levels of the food chain, resulting in elevated mercury concentration, particularly in the tissues of carnivorous fish (Global Mercury Project, 2006). Chronic exposure to moderate levels of methyl mercury results in symptoms, including visual constriction, numbness of the extremes, impairment of hearing as well as impairment of speech. There has been a marked increase in the number of pregnant women in the Tiger Reef mining area due to the slowly improving economic situation in Zimbabwe following the meltdown between 2000 and 2008. However, the mercury derived effluent is easily transferred from a pregnant woman to the fetus with

subsequent effects, ranging from sterility and spontaneous abortion to mild and severe neurological symptoms (Dales, 1995).

Mercury derived effluent is a result of the release of effluent from rudimentary gold extraction processes, especially artisanal and small scale mining. Artisanal and small scale mining (ASM) denotes small scale as well as large-scale mining activities characterized by a lack of long term mine planning and the use of rudimentary techniques, be they illegal, or legal formal or informal as is the case at Tiger Reef Mine (Hinton, 2006). The process generally uses mercury to extract secondary gold from highly weathered ores or sediments (that is free gold that is easily concentrated by gravity processes). Viega (2005) notes that the process also involves extraction of gold that is associated with 'hard rock' or primary ores, hence blasting with dynamites may be required. In the Tiger Reef area of Zimbabwe and especially in the Kadoma-Chakari Region, ore extraction is highly manual involving digging of tunnels of up to 50 meters deep with basic tools, like picks, shovels, hammers and chisels. Ore is sent to nearby independently operated stump or ball mills for crushing. Ore is generally passed over a copper plate where mercury is spread directly in an attempt to increase gold recovery. According to Dales (1995), this practice is known as 'whole ore' amalgamation, resulting in enormous mercury losses to the environment, in most cases more than 10 parts of mercury per one part of gold produced.

At times, whole ore amalgamation employs copper plates in lieu of slices, where mercury is spread across the surface of plates and amalgamates with copper. As gold bearing ore is passed over the plates, gold amalgamates with mercury onto the copper plate and is later scrapped off the surface by hands. Due to scouring by coarser particles in the ore, substantial amounts of mercury are lost to the environment through mine tailings or simply discharged in water ways as running water, though it will be slurry like in nature (Hinton, 2006). Amalgamation is a process wherein mercury alloys with gold in a pulp of gold bearing and water (Botz, 2002). Depending on the operation, amalgamation can take place in mills, copper plates sluices, or by pouring of concentrates recovered from sluicing. The undesirable mineral portion is separated from gold mercury amalgam by panning either in water boxes or pools and ponds excavated into the ground. The heavy mineral rich amalgamation tailings frequently contain more than 500 ppm of residual mercury, which creates 'hot spots' when discharged into water bodies (Dales, 1995).

On average, it is conservatively estimated that at least 1 to 2 grams of mercury are lost for every gram of gold produced by artisanal miners (Viega, 2005). With artisanal miners producing an average of 500-800 kilograms of gold annually, it has been estimated that 800 to 1,000 tons of mercury are annually emitted by artisanal miners globally (Viega, 2005). Highest emissions are from China (200 to 250 tons released), followed by Indonesia (100 to 150), and between 10 to 30 tons in each of Brazil, Bolivia, Colombia, Venezuela, Philippines, and Zimbabwe (Viega, 2005). This, therefore, implies that effluent from gold mines is a potential

environmental problem which, if not approached properly, may lead to costly environmental and socio economic impacts.

UNEP (2002) asserts that the ratio of mercury lost to gold produced are used to establish emission. The highest ratio recorded was in Takawana, Indonesia, where 1 kg of mercury is added to the ball mill for every 30 to 40 kgs of ore processed. This resulted in a mercury lost: gold produced ratio of between 60 and 90%, therefore translating to an annual emissions of 20 to 30 tons from this area alone (UNEP, 2002). Similarly, in Zimbabwe in the Tiger Reef and Kadoma areas mercury lost: gold produced is 1:3, respectively, leading to 3 to 5 tons lost per annum.

Awareness of the environmental and human risks associated with mercury use is low in the Tiger Reef artisan mining area. An assessment carried out by the same organization in Papua Guinea in 2004 showed that some awareness of mercury risks range from 2% to 75%, although even those miners who expressed some level of awareness could not accurately name symptoms or effects of exposure. More so, in Sudan, in Ingessara district, almost 75% believed that mercury poses no risks (Dales, 1995). Women do much of the indoor amalgamation as well as collection of stump mill ores, panning, and processing, not mentioning the use of water domestically, yet they are less aware of mercury risks than their male counterparts (Campbell, 1998).

### **Cyanide concentration**

Figure 4 shows cyanide concentration from effluent water discharged from the cyanidation plant. Cyanide refers to a singularly charged anion consisting of one carbon atom and one nitrogen atom joined with a triple bond. Although it is lethal to life, cyanide is still used for gold production on the basis of reagent availability, effectiveness, cost, and capability to dissolve gold from low grade iron. The most toxic form of cyanide is free cyanide, which includes the cyanide anion itself and hydrogen cyanide, HCN, either in gaseous or aqueous state. Cyanide is extremely dangerous to birds and mammals drawn to cyanide solution collection ponds as a source of water. Ponds can leak or overflow posing threats to underground drinking water supplies and wildlife as well as species in lakes and streams. Sample results indicate that the concentration of cyanide is above stipulated levels. This means that the current effluent management practices are not effective in achieving total destruction of cyanide in effluent water. The results may indicate high groundwater pollution due to leakages through unlined tailing dams, slimes dams as well as return water ponds.

**Table 4. Average cyanide concentration (mg/liter) for effluent water at selected sites**

parameter	Sample site	Sample results mg/litre	Threshold levels(SAZ, ZINWA ,WHO Standards (mg/litre)
Cyanide	(a) after tailings impoundment	2.17	0.01
	(b) turura stream	0.23	0.01
	(c)seepage from borrow pit	0.105	0.01

The presence of cyanide concentrations of 2.17mg/litre after tailings impoundment means no adequate neutralization is carried out. This implies high cyanide pollution, hence high chances of polluting water sources in the immediate environment.

Cyanidation effluent is a result of the release of effluent from a gold processing plant where there is maximum use of cyanide for gold extraction. Cyanide of sodium and potassium cyanide solutions is usually used to extract the precious metal from the ore. The cyanide containing solution (effluent) is deposited at slimes dams and the tailings dam, depending on the scale of production of waste at a particular mine. The principal reasons for the prominent place of cyanide in gold ore processing includes its wide availability, its efficiency at extracting gold, its relatively rapid extraction kinetics, and the strength and solubility of its gold cyanide complex (Middler, 2001). In addition, cyanide is used in mining technology called heap leaching, which is a cheap way to extract gold from its ore. Gold miners spray a cyanide solution (which reacts with gold) on huge open piles of crushed ore. They, then, collect the solution to leach pads and overflow ponds, and extract gold from it by recycling it a number of times.

There is also leaching of amalgamation tailings with cyanide in the Tiger Reef area. According to the Global Mercury Project (2006) cyanide of mercury contaminated ores create dangerous cyanide mercury complexes that are, then, lost to the wider environment, resulting in high mercury levels in local streams and other adjacent aquatic environments. In Zimbabwe, miners crush gold ore primarily with wet stump mills, creating slurry, which passes over copper plates covered with mercury. After squeezing and burning the amalgam, the mercury contaminated tailings are usually treated with cyanide for additional gold recovery, leading to additional mercury cyanide complexes. The process of submitting mercury contaminated tailings to cyanidation constitutes a dangerous and improper combination of technologies in gold recovery. This is because Hg becomes soluble and bio-available, thereby making it easier for it to be methylated (Flying & McGill, 1995).

### **The environmental effects of cyanide effluent**

Fish and other aquatic invertebrates are sensitive to cyanide exposure as it blocks the absorption of oxygen by cells and causes the species to suffocate. While aquatic life is killed by cyanide concentrations in the microgram per liter (ppb) range, birds and mammal deaths result from cyanide concentrations in the milligram per liter (ppm) range. Concentrations of free cyanide in the aquatic environment ranging from 5.0 to 7.2 micrograms per liter reduce swimming performance and inhibit reproduction in many species. Other adverse effects include delayed mortality, pathology, and susceptibility to predation, disrupted respiration osmoregulatory disturbances, and altered growth patterns (Flying & McGill, 1995). Observations in Ecuador showed cyanide levels in cyanide tailings of between 400 and 100 ug/liter of free cyanide (Middler, 2001). Concentrations of 20 to 700 ug/liter free cyanide cause death of many species and, during nitrification, negatively affect reproduction physiology and levels of activity in many fish species that can render the fish species non-viable. It is necessary to note that aquatic plant species are not affected by cyanide at concentrations that are lethal to most species of fresh water fish and invertebrates. According to Middler (2001), cyanide often forms a variety of cyanide related compounds in a solution and these include thiocyanite, cyanite, ammonia, and nitrate. Cyanite is a primary by product of cyanide treatment in which chemical oxidation processes are employed. It is, however, less toxic and does not persist in the environment for long periods of time. Thiocyanite is formed through the interaction of cyanide with sulphur containing compounds, especially sulphide minerals like pyrite and pyrrotite, which characterize gold deposits rock (Middler, 1998). Thiocyanite is a potential problem for it is toxic and it has the ability to form ammonia. More so, it has high chemical consumption, especially in water treatment processes (Kann, 2002). At the same time, the formation of ammonia is a threat to the sustainability of aquatic ecosystems because it is toxic and it has the ability to consume oxygen in streams during nitrification (Middler, 1998). Toxicity of its breakdown products nitrate and ammonia cannot be overlooked. Ammonia is, thus, the breakdown of cyanide and forms through the hydrolysis of cyanite (Kann, 2002).

Gold mining is interrelated and interconnected to agriculture and aqua cultural areas. According to Lindback and Murray (1996) chemicals used in gold processing, especially mercury and cyanide are leached into river sources and transported downstream to nearby environments, contaminating the environment, killing fish, and poisoning the drinking water. In Ecuador, especially the mining districts of El Oro, mercury makes its way into agricultural areas, enters soil near schools and further downstream, thereby polluting shrimp farming industry as well as the estuarine region and mangrove areas where methylation could be achieved. Appleton (2006) has shown that artisanal gold mining has caused agricultural areas in Ecuador to be contaminated with mercury while other studies, Eagler (2006) suggests that Hg uptake probably occurs through stomata by atmospheric mercury deposition.

According to the local people in the Tiger Reef area, soil contaminated with gold mining tailings is useless for growing any kind of agricultural crops and even local vegetation becomes stunted in such soils. The shrimp

farmers say that when water from the rivers enters through the pond gates, shrimps behave abnormally and then die (Eagler, 2006). It is, therefore, not an exaggeration to pinpoint that the mobilization of sediments/effluent from mining into the aquatic environment is the main source of pollution. Farmers in the area have decided not to use the river for any other purpose neither for agricultural irrigation nor for the recharge of water (as is common in shrimp farming). While some banana and shrimp plantations in Ecuador have been abandoned because of such a situation, others have constructed large canals to bring safe or less contaminated water from other areas. This shows that the interaction of chemical compounds in the complex mix of cyanide is a primary issue that needs to be addressed in further studies of the fates and transformations of mining waste as well as water and soil quality monitoring in adjoining areas.

In addition, mining activities in Zimbabwe, especially gold production, are likely to increase due to the present situation whereby efforts are underway to increase foreign investment in the mining sector. This may mean that without further studies, the effects of mining on the social and economic lives of the whole local community in the affected areas are devastating. It is against such concerns that the government and other interested parties are called to pitch in and address these issues and find cleaner alternatives to traditional practices.

Field observations of small scale mining, in parts around the Tiger Reef area, have revealed that it is not only the aquatic and terrestrial ecosystems that are negatively affected by the mercury released through amalgamation, but the air is contaminated with hydrogen cyanide due to low pH of cyanidation solutions, as well as emissions of acids and heavy metals into the atmosphere during processing. More so the fact that the socio-economic and health effects of mining effluent waste, especially mercury, is not known especially at grass root level and it constitutes as one of the biggest problems. Therefore, as mining activities are likely to increase, small scale miners need an intervention that will help them construct cleaner and efficient techniques of gold recovery. This can be achieved through further research, transfers of technology, and policy changes towards sustainability in gold mining. It is, therefore, against this background that the researcher wants to find out management practices currently in place in as far as effluent waste from gold mines is concerned.

### **Current effluent waste management practices**

The mining industry has an obligation to prevent release of toxic metals into the environment thereby ensuring that humans, birds, animals, and aquatic life are not endangered by the storage and discharge of waste waters (Telmer, 2006). Release of heavy metals that included arsenic, copper, zinc, cadmium, and manganese into the receiving environment following collapse of tailings at Aznalcollar in Spain in 1998 proved the detrimental effects of effluent disposal from gold mines (Telmer, 2006). On the same note, in 1995 there was release of cyanide into river streams following collapse of the tailings dam at Omar in Guerra. In 2000, the dam collapse at Baia Mine in Romania released cyanide and zinc into the environment leading to a significant negative environmental impact. It is against this background that mines are encouraged to manage effluent from their activities in order to avoid fatalities that result from casual handling of waste water from gold processing

plants. The following are current management practices in place, though their application vary geographically as well as with levels of technology available

### **Assessment of the environmental effects of effluent disposal**

From the results collected, (92%) respondents agreed that water flows through their community. This response is crucial in the sense that it highlights the possibility of occurrence of water pollution considering the fact that the study area is geographically located in a dry part of the country.

### **Sources of water**

Data collected indicated that 72% (258 degrees) confirmed that the mine contributes greatly to flowing water within this community, although sewage bursts and natural river flows constituted about 19% and 9%, respectively. This, therefore, indicates that Tiger Reef Mine extensively discharges effluent water into the local community. This is a form of an environmental hazard considering the chemicals that are used in gold extraction in this case mercury as well as cyanide. This is likely to impact the local community in that they can eventually use the water for varying domestic purposes considering that the area is regularly dry. Local communities tend to be affected either directly or indirectly, depending on the type of usage as well as regularity of use.

It is also necessary to note that receiving aquatic environments are likely to be affected whereby the effluent water may be transported into nearby aquatic environments resulting in death of aquatic life or, simply, biological accumulation of mercury in fish.

### **Uses of the effluent water**

Communities the Tiger Reef area use effluent water for different domestic purposes. These uses range from gardening and flushing toilets to bathing according to one's proximity to effluent water. The high usage of effluent water may be a result of failure of both the mine and the city council to provide Tiger Reef residence with adequate fresh tapped water. The ever increasing arid conditions associated with prolonged water scarcity may mean that any source of water is subjected to use, hence affecting human health, plants, and animals.

The community may have realized the dangers involved in using effluent water for domestic purposes, especially drinking as well as cooking. They have resorted to the use of the water for gardening as indicated by 21.9% usage of effluent water for this activity. Flushing of toilets constitute about 12.5% of total usage by the people and (18.8%) of the people use the water for bathing. Such uses of mine water expose residents to diseases and other effects associated with polluted water, especially mercury poisoning, which tends to have long term effects to human beings because of its bio-cumulative nature. Gold panners in the area confirmed using the effluent water in their activities. The mining activities at Tiger Reef are directly supporting the very environmental destructive activities of gold panners through releasing water into the external environment where it can be accessed by these illegal gold panners.

All the respondents confirmed that the area under study faces serious challenges in terms of domestic water. In this regard, it is, therefore, not an exaggeration to see local communities resorting to use of any source of water at their disposal. Their water alternatives are limited, hence they are prone to the negative effects of polluted effluent water. 84.4% of the respondents indicated that residents use water from open and unprotected pits around this locality. Considering the fact that there are high pollution levels in effluent water and that there are no boreholes to provide residents with cleaning water, it was difficult to study levels of underground water pollution as well as ascertaining flow patterns. Underground flow patterns may be contributing to the movement of effluent water right into the open heap leach pits, thereby negatively affecting the health of the local community.

All the respondents confirmed the absence of boreholes in the area implying that the mine is not supplying the local community with alternative source of water in order to supplement domestic water supplies during times of need. The absence of boreholes mean that the mine does not have the capacity to test the quality of underground water, which is directly affected by their mining activities.

Environmental management practices in the mining industry largely hinge upon concerted efforts between the environmental regulatory authorities and the mining organizations themselves. In Zimbabwe, various statutory instruments are in place and they are essential in giving guidelines and monitoring the activities of mines towards sound environmental sustainability. Major statutory acts, like the Environmental Management Act Chapter 20:27, Mines and Minerals Act, the Water Act, and Public Health Act, are used for monitoring all pollution in Zimbabwe, especially water pollution.

The Environmental Management Act is an environmental law that regulates and guides appropriate management of the environment. It is an important tool for achieving environmental sustainability through the prevention of pollution and environmental degradation. It views the environment in a holistic way, to include the biophysical, economic, social, technological, and political aspects. The Act helps the Ministry of Environment to regulate, monitor, and co-ordinate all environmental management, protection, and the control of pollution. Where a law is in conflict or inconsistent with this act, the Environmental Management Act shall prevail. This law is administered in addition to and not in substitution for any law, which is not in conflict with this Act. This Act stipulates that any person who causes pollution or environmental degradation shall meet the cost of remedying such pollution and any resultant health effect. Tiger Reef Mine, together with other mines and industries in Zimbabwe, are big polluters of the environment and it may make economic sense to them to pollute and pay the fine since it is cheaper to do so. In terms of environmental quality standards, the Act stipulates that the effluents and other pollutants may not be discharged without an effluent discharge license issued by the Environmental Management Board and waste should be minimized through treatment, reduction, and recycling. The Environmental Management Act stipulates heavy fines and imprisonment terms for the polluter, but due to lack of enforcement of this legislation, the polluters are not punished.

The Public Health Act (Chapter 15.09 of 1996) of Zimbabwe stipulates that waste producers are expected to take responsibility for collection, transportation, storage, and the treatment of waste. It delegates waste management to producers of waste and this has caused problems where no clear waste management standards and procedures exist in providing adequate standards in handling waste in the Zimbabwean mines. Another powerful Act that attaches few restrictions to the exploitation of the mining rights, once a permit has been obtained is the Mines and Minerals Act. Consequently, this Act leaves the way open for negative impacts on the environment through mining activities. The Water Act (Chapter 20.2) controls the discharge of pollutants, but it does not fully address the control of degradation in water catchments in mines.

## **CONCLUSION**

The waste effluent water management practices at Tiger Reef Mine are not environmentally sound because they are associated with negative impacts on human health and the environment. There is no enforcement of legislation that governs mining in the country by the Environmental Management Agency. The negative environmental impacts are, therefore, felt most by local residents who use this effluent water for domestic purposes despite the fact that it is untreated and has heavy toxic metals. Tiger Reef Mine is arid and, therefore, the residents use any water sources at their disposal. Gold panning is also on the increase in the area and this utilizes effluent from the mine, further impacting negatively on the already fragile environment. Although a number of pieces of legislation have been put in place to minimize the impact of mining activities on the environment, these have failed due to lack of enforcement by the relevant authorities. The result has been rampant environmental degradation in the affected mining areas.

## **RECOMMENDATIONS**

The problems emanating from mine effluent can be solved through concerted efforts from government agencies, and the mining companies as well as the general public. The effluent water at gold mines needs to be treated as a closed circuit whereby there is recycling of water back into the system rather than disposing it to the external environment where it can cause negative environmental impacts. In this way, mines can benefit tremendously by cutting costs of procuring chemicals through recycling.

All structures for the containment of effluent water, like slimes dams, return water ponds, and borrow pits as well as tailings dams need to be lined with hard plastic lines (HDPE lining) in order to avoid the seepage and infiltration of water into the groundwater that can pollute groundwater storage. This ensures that there is enough effluent water collected and ready for circulation back into the system. Neutralization of effluent water is recommended whereby there is the use of chemicals to neutralize the strength of the chemicals to levels less harmful to the environment. For example, the neutralization of cyanide can be done using hydrogen peroxide. The adoption of modern treatment practices, such as lime precipitation in effluent water, helps in treating effluent water for eco-justice. As far as heavy metals, like mercury, are concerned, application of a hybrid ion rich in organic sorbent containing particles of oxide akermatite and gypsum has been demonstrated to remove

low concentrations of dissolved heavy metals. Manufacturers of chemicals used in the mining industries also need to develop and put in place strategies for protecting the environment as a result of use of their chemicals. Presently, they are concerned about safety and storage of the chemicals at the expense of residual treatment that have a direct interaction with the environment. Manufactures of toxic chemicals need to supply the purchased chemicals together with neutralizing chemicals to the buyer.

Institutional fragmentation and overlapping or vaguely defined roles and responsibilities regarding the management and control over mining and mining waste should be eliminated. There is need for the development of a single law devoted to mining waste based on sound scientific evidence by the Environmental Management Agency of Zimbabwe. This will also necessitate technological improvement of the mining sector, hence upgrading overall performance of the industry. Public environmental education is essential in Zimbabwe as part of environmental awareness on the impact of mining activities on the environment.

The following are the modern management practices in place in developed countries that could be adopted if funding is made available in less developed countries, such as Zimbabwe, though their application vary geographically as well as with levels of technology available.

- Microbial activities and cyanide biodegradation.

This is one of the most important biotechnologies to emerge in the last two decades for treating process and tailings solutions at precious metal mining operations (Middler and Whettock, 1984). Various scholars have reported investigations into microbial destruction of cyanide. Hundreds of plant and microbial species (bacteria, fungi, and algae) can detoxify cyanide quickly to environmental acceptable levels and into less harmful by products (Middler and Whettock, 1984) and these include actinomyces, bacillus, thiobacillus and pseudomonas. Full scale bacteria processes have been used effectively for many years in commercial applications in North America (Middler and Whettock, 1984).

Cyanide contains two of the most important elements necessary for bacterial growth, namely nitrogen and carbon. Thus cyanide waste can be used for biological purposes (Middler, 2001). Several species of bacteria can convert cyanide, under both aerobic and anaerobic conditions using it as a primary source of nitrogen and carbon. It is known that organisms are capable of oxidizing the cyanide related compounds of thiocyanite and ammonia under varying conditions of pH, temperature, nutrient levels, oxygen, and metal concentrations (Akcil and Koldas, 2006). The biological treatment of cyanide has been shown to be a viable and robust process for destroying cyanide in the mine process water. The classic aerobic biological process involves two separate bacterial oxidation steps to facilitate complete assimilation of waste water (Middler and Whettock, 1984). The first step is the oxidative breakdown of cyanides and thiocynite, and subsequent absorption and precipitation of free metals into the bio film. Thiocyanite cyanide is degraded into a combination of ammonia, carbonate, and sulphate (Middler, 2001). The second step involves the decomposition of ammonia into nitrates

through the nitrification process, with nitrate as the intermediate. Various pseudomonas species are responsible for complete assimilation of the water, including oxidation of cyanide, thiocyanite, and ammonia in the destruction process. Either chemical or biological reactions are utilized to convert cyanide into less toxic compounds. The aerobic and nutrient rich environment promotes the growth of the microbial population, which is capable of uptake, conversion, sorption, and /or precipitation of thiocyanite, cyanide, ammonia, nitrate, and sulphate (Middler, 1998).

In this regard, waste water is regarded as a negative issue, but it can also be seen as a positive aspect if its nutrients are used in irrigation for agricultural soil and aquaculture. Nitrogen, from the cyanide destruction, could probably play an interesting role in this respect, either through the incorporation of inorganic nitrogen or enhancing primary productivity in soil and water. The approach of increasing such valuable nutrients into the soil and water in areas of high mining activity could be an alternative for integrated management.

However, the presence of heavy metals, like mercury, still raises threats of using this biological approach in trying to mitigate against the negative effects of cyanide in effluent water. More over, the result of cyanide degradation in the presence of nitrites, which could not only enhance eutrophication of water, but could also lead to a problem in drinking water, if high nitrates are found. This has led to the use of the water hyacinth in some area in order to reduce nutrient enrichment but more problems were encountered. This proved the failure of the microbial process to address cyanide destruction as it led to the creation of more burdensome environmental problems, hence its limited use as a management issue in this regard.

- Recirculation system

This is done in the limelight of avoiding environmental contamination. The best way of decreasing the cyanide impact on the streams and the external environment is to increase the rate of recycled water. Recycling lowers the waste water levels in both the tailings impoundments and the second waste water ponds, thereby lowering the amount of leakage of waste water into streams.

According to Eisler and Weimeyer (2004) recycling of water, which results from the processing of both low grade and high grade ores, is crucial as the water contains high concentrations of potentially toxic sodium of cyanide (NaCN), free cyanide, and metal cyanide complexes. This is vital as it does not only protect the environment, but it cuts operating costs.

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