ABSTRACT

Chiyadzwa under Marange tribal trust land which is located between Save and Odzi South of Mutare city is rich in diamonds. There are 5 diamond mines which are currently operating in Chiyadzwa whose mining activities have brought a myriad of environmental problems . In light of the above the research sought to establish the types of contaminants and analyse the causes of water pollution on both upper Odzi and Save catchment areas.

The research was carried out using both qualitative and quantitative methods. A case study method was used in carrying out this research. Both questionnaires and interviews were used to gather information on mine disposal methods, water quality problems and the mines environmental permits. Water samples were collected for chemical, BOD, COD, turbidity and conductivity analysis from October to December 2013 on 7 sampling points on each river. Point 7 on both rivers was the control. This was located 10km from the mines discharge points. Water samples were send monthly to GK laboratory in Harare for analysis.

The study undertaken has shown a protracted increase in water quality problems in both Save and Odzi Rivers due to the mining operations. Heavy siltation was noticed on both Save and Odzi Rivers as well as the tributaries which feed the mighty rivers. The effect of contaminated effluent as a result of Ferrosilicon was evidence since there was heavy metal presence of (Iron, Nickel, Aluminium, and Manganese) as well as high conductivity, BOD and COD. All these parameters were found to be in the red and yellow categories on sampling points below the discharge points.

In light of these water quality problems emanating from the mining operations, standard or appropriate slimes dams should be constructed by all the 5 operating mines in Chiyadzwa. Notably there is need to carryout comprehensive Environmental Impact Assessments and Social Impact Assessments on all the mining projects in Chiyadzwa to avert the water quality problems which are being envisaged.

DECLARATION

I **NJAYA ANTONY** declare that this project report is my original work and affirm that it had not been submitted to this or any other University in support of any application for a post graduate degree or any other qualifications.

Signed……………………………………………………………… Date…………………………………………………

APPROVAL

This dissertation entitled- The impacts of Chiyadzwa - Marange Diamond mining activities on water quality. A case of upper Save and Odzi catchment area in Manicaland Province Zimbabwe by **Antony Njaya** meets the regulations governing the award of the degree of Masters of Science in Safety, Health and Environmental Management Degree of the Midlands State University and is approved for its contribution to the knowledge and literal presentation.

Supervisor- Professor J.D. Masaka **Signature**..

Date..................

DEDICATION

I would want to dedicate this research project to my wife Nyaradzo my children Tatenda, Kudzai and Tadiwanashe for their moral and financial support.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to all individuals and diamond mining companies in Chiyadzwa for their meaningful contributions towards the success of this project. Special thanks go to my supervisor Professor J.D Masaka my dissertation supervisor for the unwavering guidance, encouragement and constructive criticism that assisted me to make this dissertation a reality. I would also want to thank Dr Azania Mufundirwa of Mbada Diamonds for the assistance rendered in carrying out this dissertation.

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CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Mining operations cause massive environmental degradation which if undertaken without due care may cause irreparable damage of the environment altering the natural ecosystem to levels which may fail to support human, animal and natural vegetation life. It is against this background that various monitoring programmes are implemented where legal mining operations are being established. These include among others; water quality monitoring, soil analysis, dust, noise, vibration and the general environmental management programmes (social impact assessments). Environmental water quality also called ambient water quality relates to water bodies such as lakes, rivers and oceans. Water quality standards for surface waters vary significantly due to different environmental conditions, ecosystems and intended human uses (De Vlaming, 2000). Toxic substances and high populations of certain microorganisms can present a health hazard for non-drinking purposes such as irrigation, swimming, fishing, rafting, boating and industrial uses. These conditions may also affect animals, which use the water for drinking or as a habitat. Modern water quality laws promulgated by the United States Environmental Protection Agency (USEPA) and European Environmental Agency (EPA) were created for the purpose of protecting humans' health, aquatic life as well as flora and fauna to ensure environmental sustainability.

The USEPA protocol for conducting freshwater toxicity tests have been used in California USA to evaluate ambient water quality since 1986.Testing covered from conducting broad watershed surveys for assessing the distribution of toxicity to conducting detailed studies for identifying chemical causes and sources. Using cerio-daphnica dubia tests pulses, of chazinon toxicity were detected over a ten year period throughout California's central valley in waters receiving drainage from dormant orchards (Ern.CBC,2001). In the 1980s toxicity to C.dipha, caused by methyl parathion and carbofuran in drainage from rice fields was detected in the sacraments river source (de Vlaming, 2000).

According to the European Environment Agency (EEA) water pollution can take many forms and have different effects. These include, sediment runoff from the land which can make water muddy blocking sunlight and as a result kill aquatic life .Metals such as zinc , lead , chromium , mercury , and cadmium are extremely toxic. Faecal contamination from sewage makes water unsafe for human consumption and aesthetically unpleasant and unsafe for recreational activities such as swimming boating and fishing.

In Canada, metal mine effluent is monitored and reported and meet authorised limits for dissolved arsenic copper, lead , nickel , zinc, cyanide, radium-226, TDS Solids, pH and toxicity as set out by the Federal Metal Mining Effluent Regulations (MMER) under the Fisheries Act of 1985. Water supplies continue to dwindle because of resource depletion and pollution whilst demand is rising fast because of population growth industrialisation, mechanisation and urbanisation (Falkenmark, 1994). This situation is particularly acute in the more arid regions of the world where water scarcity and associated increases in water pollution limit social and economic development and are linked closely to the prevalence of poverty, hunger and diseases (Falkenmark, 1994). World governments and other agencies such as the World Bank set standards to define parameters for effluent. The standards require mine owners to monitor effluent discharges and if the water exceeds the allowed limits for effluent, contaminated water should be treated to permissible levels before discharging it into receiving water bodies.

There is some desire among the public to return water bodies to pristine or pre-industrial conditions. Most current environmental laws focus on the designation of particular uses of a water body. Related to the above, in the beginning in the later 1950s and through the 1960s, the USA congress reacted to increasing public concern on the impact of human activity on the environment. Advocates of this approach argued that without a specific policy federal agencies were neither able nor inclined to consider the environment impacts of their actions in fulfilling the agency's mission (IIED, 2002).

Over 70% of the water used in both rural and urban areas in South Africa is surface water drawn from rivers, streams, lakes, ponds and springs (DWAF, 2004). Similarly the general public in Chiyadzwa and Lower Save areas, rely on the surface water sources which mainly comprise of local rivers and streams that interconnect. The activities of diamond mining companies in Chiyadzwa, may alter the natural water bodies of the area. The community downstream has been complaining of water pollution into their daily water sources, which are Save and Odzi. Recent studies by the Zimbabwe Lawyers' Association (2012) on the impact of Marange Diamond Mining operations on water quality revealed that water quality had deteriorated to the extent that most ecosystem services (potable water, livestock watering and irrigation) that used to be derived from these natural ecosystems had been lost (ZELA 2012). This study shall further establish the state of the water within Odzi and Save with regards to pH, TDS, heavy metals and turbidity.

Apart from the adverse aspects of mining highlighted above, diamonds mined in Marange are projected to dominate the world market for the next five years. Zimbabwe is expected to earn about 700 million US dollars from the sale of precious stone in 2013 with the record 16.9 million carats set to be produced from Marange Diamond fields. According to the report released by the Companies Diamond Industry Series in August 2013, Zimbabwe will satisfy up to 30 % of the world diamond demand by 2015 as leading diamond groups such as Alrosa (Russia) and De Beers are likely to reduce production by venturing into underground mining (Sunday Mail 8-14 September, 2013). Zimbabwe's mining sector has continued to be the lead in economic performance, contributing an estimated 16% to GDP in 2012, up from 13% in 2011. The sector also continued to lead in export earnings, rising to USD 2 billion in 2012 from 1.5billion in 2011. The major drivers of this growth in export earnings were diamonds, platinum and gold. Overall, mineral production has maintained its upward trend, meeting most Medium Term Plan projections of 2012 (MTP). The year 2013 looks no different assuming the current momentum is maintained, thus GDP is expected to grow by 5% (Mutambara, 2013).

If mining is done using cleaner production methods, it may trigger sustainability since it can strengthen the economic linkages which may stimulate economic growth and poverty eradication. According to the Environmental Mining Council of British Columbia (2001), for the sake of current and future generations there is need to safe guard the purity and quality of water against irresponsible mineral development. Such irresponsible mineral development can result in a reduction of the quality of water through increased pollution and sedimentation loads leading to a reduced quantity of water being available for use by current and future generations. This falls in line with the principle of Sustainable Development (IIED, 2002).There is need to ensure that the best pollution prevention strategies are employed, especially in case where the environment risks can be managed. The emergence of global environmental issues such as climate change, ozone depletion and trans-boundary air pollution problems associated with acid rain have forced countries to realize that environmental problems cannot continue to be tackled in a piece meal fashion since ecosystems transcend national or political boundaries (Marsh 2012).

There is now an international moral consensus about each individual’s right to a clean environment. The realization of the global nature of the environment has been the driving force behind the emergence of institutional and legal mechanisms designed to tackle international problems and challenges. According to Serageldin (1995) national capital stocks (national wealth) rather than income is used as the criteria for assessing economic and environmental performance. The concept is that national wealth or capital stock of a nation, is the sum of (a) man made capital (b) natural capital (c) human capital and (d) social capital. The four components of national wealth are interlinked to a high degree and they are supplementary in contributing to economic activities. In this context, sustainability as an opportunity is defined as follows: Sustainability is to leave future generations as many if not more opportunities as we have had ourselves. It is a more positive and practical approach to sustainability than the Brundtland view. The new approach recognizes the legitimate use of resources for economic activities providing that capital stock, defined in the four forms of capital, is at least the same if not larger at the end of the process than at the start. Accounting for gains and losses in capital or national wealth over time, including real loses in natural resources enable one to estimate the kinds and extent of opportunities in the future and thus to gauge progress towards or away from goal of sustainability. Fig 1.1 is an illustration of the sustainability matrix .

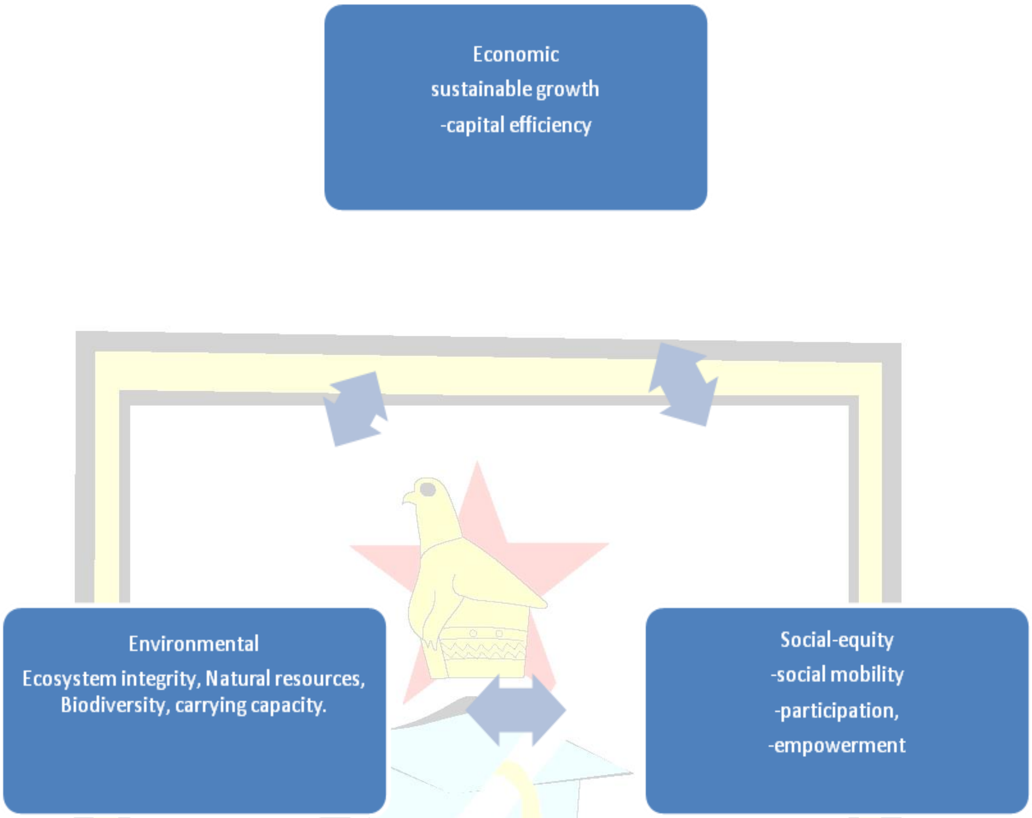


Fig 1.1 Sustainability Matrix (Serageldin and Steer 1994)

In light of the above, Smyth and Dumanski (1995) further implored sustainability, and establish the objectives of sustainability as the harmonisation of the complimentary goal of providing environmental, economic and social opportunities for the benefit of present and future generations, while maintaining and enhancing the quality of land resources that is soil and water. In this context sustainable land/environment management can be defined as a combination of technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously, maintain or enhance production services, reduce the level of production risk, protect the potential of natural resources and prevent degradation of soil, land and water, be economically viable as well as socially acceptable (Masaka, 2013). From the above definition it is critical to note that the mining activities currently happening in Chiyadzwa should satisfy the five fundamental aspects raised by Smyth and Dumanski to a greater extent to ensure sustainability. The fact that there are numerous social complaints as a result of diamond mining as well as environmental outcries stimulated the need to carry out this research. It is against this background that this research is seeks to establish the consequences of mining operations in Chiyadzwa and their subsequent interference with water bodies and the various adverse effects to the chemical composition of the water in Odzi and Save.

1.2 Diamond process overview

Ore generation starts by bush clearing and massive excavation of ore to depths of about fifty meters. In-field screening of mined liberated material, run of mine (ROM) and conglomerate is done and stockpiled. The treatment plants comprise of the following sections; ore receiving, primary screening, de-gritting and a Dense Medium Separation (DMS) concentration section. Concentrate from the DMS Plant is jet pumped to the final recovery section. The plants are run on a continuous basis. Below is the diamond processing flow diagram.

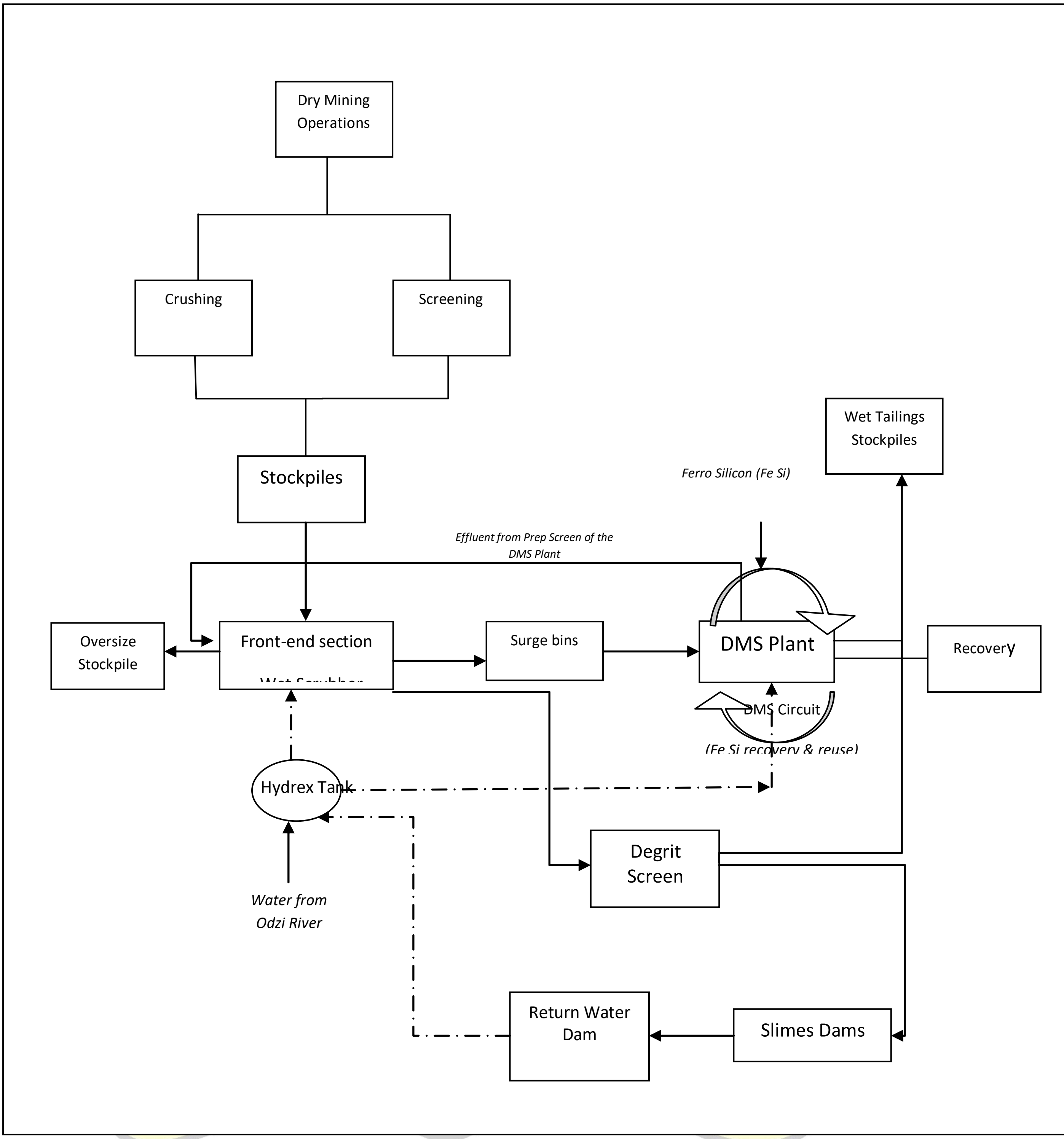


Fig 1.2: Diamond processing flow chart.

1.2.1 Front End

Ore is tipped into the receiving hopper of the vibrating grizzly at predetermined rate, for example 70tonnes per hour for Plant A and B. The grizzly feeder has grizzly bar openings of 55mm width and is positioned above the receiving hopper to scalp off the +55mm grizzly (over-size) fraction. Oversize material that does not get into the grizzly feeder is stockpiled and retaken into the process.

The material that passes through the grizzly bar openings is drawn out of the ore receiving hopper by a heavy-duty belt feeder. The belt feeder draws material out of the hopper at a constant rate and is linked to the primary feed conveyor via a weightometer. This allows the speed of the belt feeder to be varied to maintain a constant feed tonnage into the Plant.

1.2.2 The Scrubber

The belt feeder delivers the material onto a wide primary conveyor. The primary feed conveyor discharges into a long roller-supported scrubber lined with thick replaceable rubber liners within its shell. The scrubber has been included in the circuit for more flexibility, should the material from the infields screening change. Although the Plant should be treating very competent liberated material ore there is still the possibility that the Plant will be fed with material that contains clay, the scrubber will then, be able to process the material and remove the clay.

1.2.3 Primary sizing

The scrubber discharges onto a banana primary sizing screen. The primary sizing screen is a double deck vibrating screen fitted with polyurethane panel apertures to cut at 25 and 3.5mm. The -55 and +25mm material from this screen is conveyed to a stockpile. The -25+3.5mm material from the primary screen is conveyed to the DMS modules via surge bin. The -3.5mm material is slimes material which is pumped to the de-gritting section via the primary screen effluent pumps, the effluent pump have a standby stream to allow for more flexibility and continuous front-end feed.

1.2.4 De-gritting Circuit

Effluent water is received from the primary screen. This effluent is passed through degrit separators; which have a standby stream for more flexibility. The overflow from these separators reports to the degrit screen under pans while the underflow reports to the degrit screens for further water recovery. The solid materials leaving the screens are discharged onto the -25mm final tailings stockpile. The effluent from the degrit screen underpan is pumped to the slimes dam.

1.2.5 DMS Section

The DMS’ receive -25+3.5mm material from the front end circuits via a surge bin. The feed passes from a feed preparation screen where fines are removed from the system through washing with water and pumped back to the scrubber. The remaining material goes into the Mixing Box where it is mixed with ferrosilicon (FeSi). The medium and gravel mixture is then pumped to two cyclones via a densifier pulp distributor. The sinks and floats are discharged onto their respective screens where the FeSi medium is washed off and returned to the process for re-densification via tube densifier and a magsep.

The washed material either reports to the recovery in the case of sinks or to final tailings in the case of floats. The concentrates (-25+3.5mm) is jet pumped from 20T Sinks Hoppers to the recovery dewatering panel. The concentrate is fed from the dewatering panel to an attritioner. The concentrates is fed onto a dewatering screen and finally ends up in the sort house for sorting.

1.2.6 Recovery

Concentrate from the concentrate bin is pumped to the Recovery building by a jet pump. The concentrate is taken to the dewatering screen where water is removed, before the concentrate goes to the attritioner. At the attritioner, the concentrate is washed after which it is dewatered and sent to the classifying screen.

At the classifying screen, concentrate is separated according to size, resulting in four streams, namely; 3 – 6 mm, 6 – 12 mm, 12 – 16mm and +16mm.

The four classes of material go to 4 separate bins, prior to going into the X-ray machines. Thermo luminescent materials are ejected from the system to the vault, while the remaining material is dried at the dryers. The material passes through pemrolls where magnetic material is separated from non-magnetic one. The former is removed from the system as magnetic tailings (irons) while the latter goes for hand sorting.

1.2.7 Slimes dams

Slimes are impoundment designed to trap the solid constituents of plant effluent, thereby releasing clarified water. Material is discarded by the off-take pipes and allowed adequate resident time to allow for settlement. The resultant is decanted through the penstock to the return dam where it is pumped back to the plant.

1.3 Statement of the Problem

Save and Odzi Rivers used to be the source of life for several villages starting from Marange and stretching several kilometres downstream to Chisumbanje. The rivers provided fish, drinking water for humans and livestock and domestic chores such as laundry. Villagers also used the water for horticultural activities, bathing and acted as one of the few recreational facilities for young boys and girls who flocked the mighty rivers for swimming escapades and fishing. In some areas food is grown alongside the rivers, more so due to the fact that Marange is a semi-arid region which experiences perennial droughts. Renowned and highly successful irrigation schemes at Chakohwa, Nyanyadzi and Birchnough Bridge also drew water from both Save and Odzi Rivers (Pazvakawambwa and van der Zaag 2001).

However, since the commencement of commercial diamond mining activities in Marange in September 2009, the anthropogenic activities have altered the life pattern of most villagers who are persistently complaining on the high levels of water pollution (ZELA ,2012). A scientific study commissioned by the Zimbabwe Environmental Law Association and carried out by the University of Zimbabwe also confirms the fears of villagers and non-governmental organizations who have long suspected that companies were polluting Save River. The study concluded that the water in Save and Odzi Rivers is contaminated by e-coli, total viable count and coli form bacteria to such an extent that communities cannot use the water for drinking purposes anymore in light of the above it is critical to note that mining by its nature consumes, diverts and can seriously pollute water resources (Miller,1999). There is potential for massive contamination of the area surrounding mines due to the various chemicals used in the mining process as well as the potentially damaging compounds and metals removed from the ground with the ore. Diamond mines in Marange use Ferrosilicon in Diamond processing. Ferrosilicon is an alloy which contains Iron, Aluminium, Chromium, Nickel and Manganese. These heavy metals when deposited in water they cause irreparable damage to both aquatic animals and plants. subsequently this affects people living within the contaminated waters. Agriculture remains the engine of economic development in most developing countries and a more sustainable agriculture is more likely to provide long term benefits required to achieve sustainable development and poverty reduction. The foundation for sustainable agriculture is the maintenance of biological production potential, particularly maintenance of land and water quality including genetic diversity (Smyth and Dumanski 1995).

The five pillars of sustainability as promulgated by Smyth and Dumanski, (1995) are critical. However the situation in Chiyadzwa if not properly managed, may propel a myriad of environmental problems which will affect aquatic life flora and Fauna, agricultural and social activities and the health of both people and animals. The fact that the number of mines are increasing and the water and soil resources remain the same , the situation in Chiyadzwa may cause the dwindling of the natural resources due to water contamination.

1.4 Objectives of the Study

1.4.1 General Objective

- To examine the effects of Chiyadzwa - Marange diamond mining activities on surface water quality in the upper Odzi and Save Catchment Areas.

1.4.2 Specific Objectives

- To identify the causes of water pollution on both upper Odzi and Save catchment areas and type of contaminants.
- To assess the levels of chemical contamination due to diamond mining activities.
- To analyse the effects of diamond waste disposal methods in Marange - Chiyadzwa to water quality.

1.5 Justification of the Study

The study will be of paramount importance to the diamond companies in Chiyadzwa as it will highlight the various impacts, emanating due to their mining activities. Such important information on chemical effects from the processing activities to the water quality will be generated through water sampling and testing. The results after a scientific analysis will be used to promulgate mitigatory measures which can be implemented to control and avert water pollution. The study is also being conducted to determine the levels of contamination in both Save and Odzi rivers and will be of significance to government policy makers, Ministry of Mines, Ministry of Environment and Natural Resources, Rural and Urban councils and other relevant stakeholders. It is also critical to note that the study will also further explore the gaps of previous studies on the same to show the extent of the damage, as a result of contaminated water in Save and Odzi Rivers.

1.6 Study Area

Chiyadzwa community is located 130 km south east of Mutare City. The area which falls under natural farming region 5/6 is boarded by Save and Odzi River hence it is confined between Save Tribal Trust Land and Mutambara Tribal Trust Land. The area receives little rainfall. The vegetative cover is dense on other areas. Predominantly the area is covered by Mopanie, Acacia Karoo and Baobab trees. Chiyadzwa area which is now declared a diamond and protected area stretches from Birchnough Bridge to Odzi Bridge which is located along Mutare and Harare road. The area covers 757 000 hectares of land. Plate1.1 shows the location of the land under study.

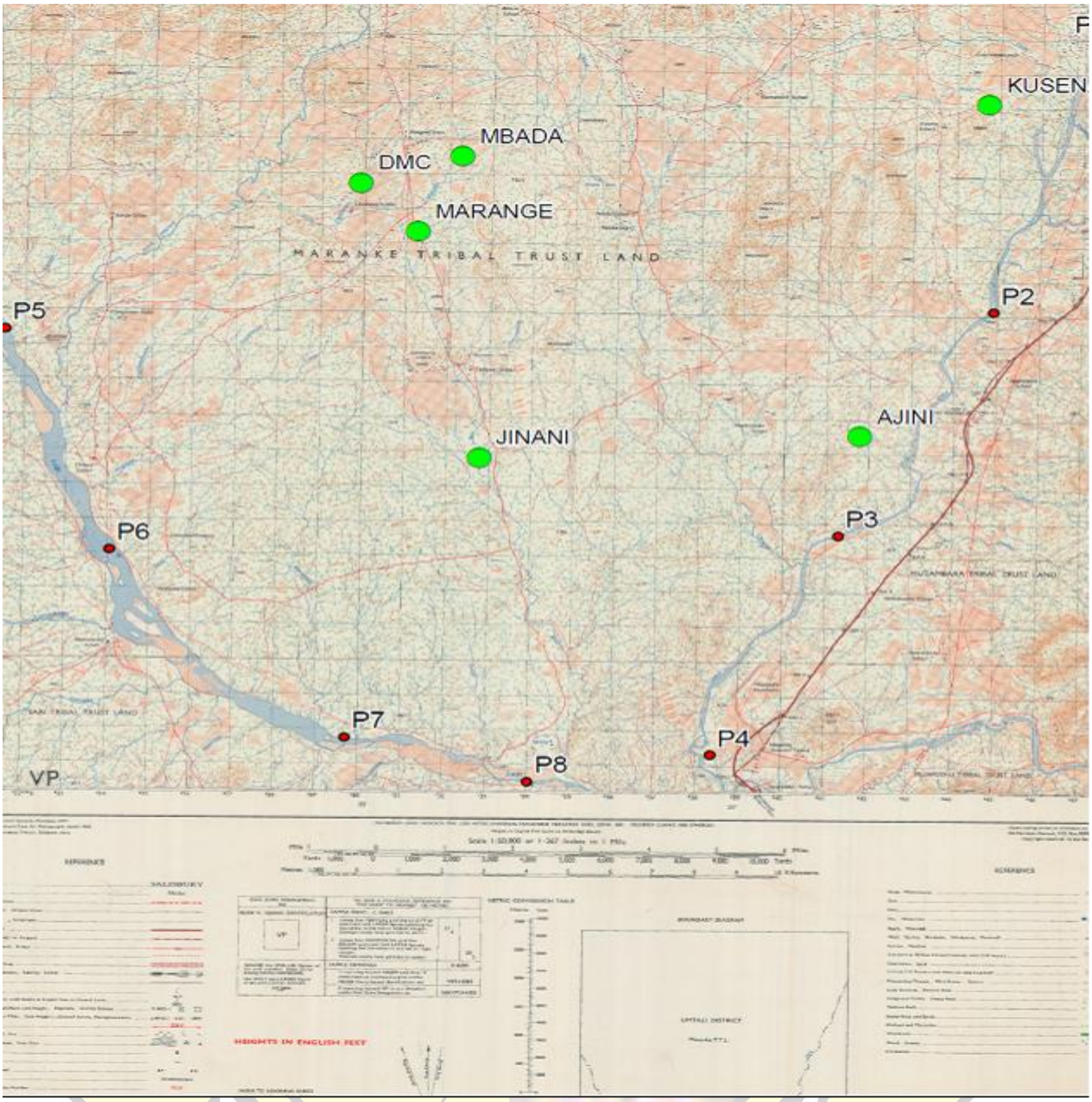


Plate 1.1 Chiyadzwa Mining Area.

Sampling sites were strategically located to determine the nature of the environmental impacts of mining activities in the Marange area. There are 5 mining companies operating in the Marange area namely: DMC, Mbada Diamonds, Anjin, Jinani and Marange Resources. Communities have raised concern about effluent water which contaminates both Save and Odzi Rivers. Notably reference/control points were identified on both the Save and Odzi River, and these points represent conditions in the rivers before the impacts from mining activities. The reference point or control was sampling point 7 on both Save and Odzi Rivers . The reference sampling point was situated 10 km away from the mine discharge points which marked sampling point 1 on both Rivers . The other sampling points were selected to measure the water quality at different points downstream of the mining effluent discharge areas up to Birchnough Bridge.

CHAPTER 2 : LITERATURE REVIEW.

2.1 Water Quality and its importance.

UNESCO, 2008 states that the term water quality describes a broad spectrum of items related to how we identify water concerns and how we collectively address them. The most widely used definition of water quality is “the chemical, physical and biological characteristics of water, usually in respect to its suitability for a designated use” (UNESCO 2008) . Water quality standards are put in place to protect the various designated uses of a water body. Water bodies are then monitored by states to ensure that these standards are being met and that a water body supports its designated uses. When water quality assessment reveals that a water body does not support its designated uses, then it is considered impaired by the United States Environmental Protection Agency (EPA). Impairments result from two major categories of water pollution: point source or nonpoint source pollution. Point source pollution originates in effluent that is discharged regularly (such as daily) from industrial and municipal wastewater treatment plants through permanent conduits such as pipes or ditches. Nonpoint source pollution originates from diffuse sources scattered across.

Contaminants that may be in untreated water include microorganism such as viruses, protozoa and bacteria; inorganic contaminants such as salts and metals, organic chemicals from industrial processes and petroleum use; pesticides and herbicides; and radioactive contaminants. Water quality depends on the local geology and ecosystem, as well as human uses such as sewage dispersion, industrial pollution, use of water bodies as a heat sink, and overuse (which may lower the level of the water) (UNESCO 2008).

The United States Environmental Protection Agency (EPA) limits the amounts of certain contaminants in tap water provided by US public water systems. The Safe Drinking Water

Act authorizes EPA to issue two types of standards, primary standards which regulate substances that potentially affect human health, and secondary standards which prescribe aesthetic qualities that is those that affect taste, odor, or appearance (UNEP, 2008).

The U.S. Food and Drug Administration (FDA) regulations establish limits for contaminants in bottled water that must provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk.

Environmental water quality, also called ambient water quality, relates to water bodies such as lakes, rivers, and oceans. Water quality standards for surface waters vary significantly due to different environmental conditions, ecosystems, and intended human uses. Toxic substances and high populations of certain microorganisms can present a health hazard for non-drinking purposes such as irrigation, swimming, fishing, rafting, boating, and industrial uses. These conditions may also affect wildlife, which use the water for drinking or as a habitat. Modern water quality laws generally specify protection of fisheries and recreational use and require, as a minimum, retention of current quality standards (UNEP, 2008).

Water quality management contributes both directly and indirectly to achieving the targets set out in all eight Millennium Development Goals (MDGs), although it is most closely tied to specific targets of the goal 7, thus to ensure environmental sustainability. Indicators on water quality can be used to demonstrate progress toward the targets (UNEP 2008). There are a number of UN initiatives that are assisting to raise the water quality issues. These include among other things:

- Clean water for a healthy world - World Healthy Day World Water Day is held annually on 22 March as a means of focusing attention on the importance of freshwater and advocating for the sustainable management of freshwater resources. Each year, World Water Day highlights a specific aspect of freshwater. In 2010 World Water Day was dedicated to the theme of water quality.
- Thematic priority area on water quality - UN-Water Thematic Priority Area on Water Quality was established in September 2010 to enhance integration, collaboration and coordination on water quality and support Governments and other stakeholders to address water quality challenges.
- Water taskforce on wastewater management – UN The taskforce was created in 2009. It was established to highlight issues surrounding wastewater management, increase awareness by governments, and strengthen UN-system collaboration on activities related to wastewater management (UNEP 2008).

Water quality standards are also important because they help to protect and restore the quality of the Nation's surface waters, consistent with the requirements of the relevant water legislation which include the ZINWA Act (Zimbabwe), Clean Water Act (USA). The standards herein mentioned help to identify water quality problems caused by, and not limited to improperly treated wastewater discharges, runoff or discharges from active or abandoned mining sites, sediment, fertilizers, and chemicals from agricultural areas, and erosion of stream banks caused by improper grazing practices (UNEP, 2008).

According to the EMA Act (20:15) and the Clean water Act (USA), the standards herein mentioned also support efforts to achieve and maintain protective water quality conditions, which include:

- total maximum daily loads (TMDLs), waste load allocations (WLAs) for point sources of pollution, and load allocations (LAs) for non point sources of pollution,
- water quality management plans which prescribe the regulatory, construction, and management activities necessary to meet the water body goals,
- NPDES water quality-based effluent limitations for point source discharges,
- water quality certifications or licensing for activities that may affect water quality and that require environmental(federal for USA) and(EMA for Zimbabwe) license or permit,
- quarterly and annual water quality reports , such as the reports required under CWA 305(b)(federal USA) or(EMA for Zimbabwe), that document current water quality conditions, and
- CWA 319 management plans (federal USA) (for Environmental Management Plans EMP (EMA Act Chap 20:15) for the control of non point sources pollution.

2.2 The major water pollutants.

The World Water Development Report 3, UNEP (2007), defines pollution as “chemicals or substances in concentrations greater than would occur under natural conditions". Major water pollutants include microbes, nutrients, heavy metals, organic chemicals, oil and sediments which can raise the temperature of water.

2.1 Point sources.

Point sources refers to "contaminants that enter a waterway from a single, identifiable source, such as a pipe, trench or ditch (www.nature.com) . Examples include discharges from, mine and industrial processing plants and sewage treatment plants. The U.S. Clean Water Act (CWA) defines point source for regulatory enforcement purposes (www.nature.com).

Accordingly the CWA definition of point source was amended in 1987 to include municipal storm sewer systems, as well as industrial storm water, such as from construction sites.

2.2 Non -point sources.

Non Point source pollution refers to “diffuse contamination that does not originate from a single discrete source" (www.nature.com). Non point source pollution is often the cumulative effect of small amounts of contaminants gathered from a large area. Common examples include leaching out of nitrogen compounds from fertilized agricultural lands and nutrient runoff (www.nature.com).

Below are the major sources of water pollution which can be point or no-point source:

2.2.3. Bacteria, viruses, protozoa and parasitic worms.

These are mainly found in human and animal wastes.

2.2.4 Organic Wastes

Organic waste is derived from animal manure and plant debris that can be decomposed by aerobic bacteria.

2.2.5. Inorganic chemicals

The sources include , water soluble, acids, compounds of toxic metals such as lead , arsenic and selenium (Se) and (3) salts such as sodium chloride (NaCl) in ocean water and fluorides found in some soils. These are mainly generated from industrial effluents and household wastes (Swanepoel, 1989).

2.2.6 . Organic Chemicals

Organic chemicals include among other things, oil, gasoline, plastics, pesticides, cleaning solvents, detergents. The pollutants are mainly derived from industrial effluents, household cleansers, surface runoff from farms and homes especially in towns and cities (Swanepoel, 1989).

2.2.7 Plant Nutrients.

The components include, water soluble compounds containing nitrate, phosphate and ammonium ions. These are mainly generated from sewage, manure, and runoff from agricultural farmlands (Bird, 2007).

2.2.8. Sediment.

Soil, silt and effluent from runoff as a result of heavy rainfall causes turbidity and high sedimentation.

2.2.9. Radioactive Materials.

Radioactive isotopes of iodine, radon, uranium, cesium and thorium account for the pollution (Bird ,2007). Radioactive materials are mainly generated at nuclear and coal-burning power plants, mining and processing of uranium and other ores and nuclear weapons production.

2.3 Effects of pollutants to ecology

Water pollution has been extensively established as a contributor to health problems in humans and marine animal ecosystems (Swanepoel, 1989). It is critical to note that the effects of pollution can be catastrophic, depending on the kind of chemicals, concentrations of the pollutants and where there are polluted.

2.3.1 Death of aquatic (water) animals

The main problem caused by water pollution is that it kills life that depends on water bodies. Dead fish, crabs, birds and sea gulls, dolphins, and many other animals often wind up on beaches, killed by pollutants in their habitat (living environment). Fish are easily poisoned with heavy metals which include lead, iron, chromium, copper, mercury, aluminium, magnesium and manganese. These heavy metals can later be consumed by humans when they eat the water species such as fish and cause serious health problems (Wyk ,et al 2009).

2.3.2 Disruption of food-chains

Pollution disrupts the natural food chain. In the food chain each organism can be in a producer, consumer, predator, and prey relationship. The oxygen and the water cycle sustain these organisms. When an ecosystem gets polluted, the natural balance in the system is disturbed and this affects the organisms in different ways. Thus plants and animals can die.Pollutants such as lead and cadmium are eaten by tiny animals. Later, these animals are consumed by fish and shellfish, and the food chain continues to be disrupted at all higher levels (Morris and Baartejes,2010).

2.3.3 Disease / Microbiological

In many communities in the world, people drink untreated water (straight from a river or stream). Pollution caused by effluent discharge in water bodies may cause water born diseases such as typhoid, dysentery and cholera. This practice is mainly prevalent in Africa and Asia due to excessive poverty. More so swimming in and drinking contaminated water causes skin rashes and health problems like cancer, reproductive problems, typhoid fever and stomach sickness in humans (www.shareasale.com/r.c.fm/).

2.3.4 Suspended Matter

Some pollutants (substances, particles and chemicals) do not easily dissolve in water. This kind of material is called particulate matter. Some suspended pollutants later settle under the water body. This can harm and even kill aquatic life that lives at the floor of water bodies (www.eschool.com/pollution/waterpollution/important-waterpollution-facts.html). Many industries and farmers work with chemicals that end up in water. These include chemicals that are used to control weeds, insects and pests. Metals and solvents from industries can pollute water bodies. These are poisonous to many forms of aquatic life and may slow their development, make them infertile and kill them. Sewage, fertilizer, and agricultural run-off contain organic materials that when discharged into waters, increase the growth of algae, which causes the depletion of oxygen. The low oxygen levels are not able to support most indigenous organisms in the area and therefore upset the natural ecological balance in rivers and lakes. The availability of organic compounds such as nitrates in the water bodies can cause massive eutrofication culminating in low oxygen availability to water organisms and animals (Swanepoel, 1989).

2.3.5 Oil Spillage

Oil spills usually have only a localized affect on wildlife but can spread for miles. The oil can cause the death of many fish and stick to the feathers of seabirds causing them to lose the ability to fly (Swanepoel, 1989).

2.4 The Kreb Cycle

Organisms derive the majority of their energy from the Kreb's cycle also known as the TCA cycle. The Kreb's cycle is an aerobic process consisting of eight definite steps. In order to enter the Kreb's cycle pynuvate must be converted into Acetyl- CoA byruvate dehydrogenise complex found in the mitochondria. In the presence of oxygen organisms are capable of using the Kreb's cycle. Without the oxygen the electron transport would not work. it only happens when oxygen is present (Winston ,2011).

The Kreb's cycle occurs in the cell mitochondria for animals and in the chloroplasts of plants. All organisms that use oxygen generate energy through the Kreb's cycle. In other words the process converts carbohydrates fats and proteins into CO_2 and converts H_2O into serviceable energy. The process occurs after gycolysis and oxidative. Oxygen deficiency in water due pollution may result in low BOD in rivers, dams, lakes and seas. This negatively affect the ability of aquatic animals and plants to produce energy through the Kreb's cycle (Winston ,2011).

2.5 Osmosis Potential and Gradient

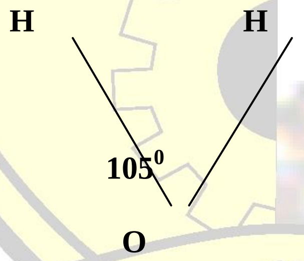
According to (Wyk,et al 2009) osmosis is " the movement of water molecules from a region of higher water potential to a region of lower water potential through a partially permeable membrane"**.** When there is a lot of water in a solution, we say that the solution has a high water potential**,** it is less concentrated and is a dilute solution. A more concentrated solution has less water and low water potential. Pure water has the highest water potential.

(Wyk,et al 2009) further states that ,if two solutions are separated by a partially permeable membrane, more water diffuses from the solution with the higher water potential into the solution with the lower water potential. The water diffuses down a water potential gradient. In other words the process entails the movement of water molecules from a hypotonic solution (more water, less solutes) to a hypertonic solution (less water, more solutes) across a semi permeable membrane. In light of the above too many negatively charged salts in water conduct more electricity charges and these determine potential difference which is related to the higher concentration of salts H^+. Thus there will be high salts in water than in fish resulting in dehydration and death of fish (Wyk,et al 2009).

2.6 The Chemistry of water.

According to Zumdahl (1997), water is one of the most important substances on Earth. it is essential for sustaining the reactions that keep us alive, but it also affects our lives in many indirect ways. water helps to moderate the Earth's temperature, it cools automobile engines, nuclear power, plants and many industrial processes. It provides a means of transportation on the earth's surface and a medium for the growth of a myriad of creatures we use as food and much more.

One of the most valuable properties of water is its ability to dissolve many different substances. Liquid water consists of a collection of water molecules. an individual water molecule is bent or V-shaped with an H-O-H angle of approximately 105 degrees.



The O - H bonds in the water molecule are covalent bonds formed by electron sharing between the oxygen and hydrogen atoms. However the electrons of the bond are not shared equally between these atoms. Oxygen has a greater attraction for electrons than hydrogen. Thus the oxygen atom gains a slight excess of negative charge and the hydrogen atoms becomes slightly positive. Due to this unequal charge distribution, water is said to be a polar molecule. It is this polarity that gives water its great ability to dissolve compounds (Zumdahl, 1997).

The positive ends of the water molecules are attracted to the negatively charged anions and that the negative ends are attracted to the positively charged cations. This process is called hydration. The hydration of its ions tends to cause a salt to fall apart in water or to dissolve. The strong forces present among the positive and negative ions of the solid are replaced by strong water ion interactions (Zumdahl , 1997).

It is very important to recognise that when ionic substances (salts) dissolve in water they break up into the individual cations and anions. The solubility of ion substances in water varies greatly. The differences in the solubilities of ionic compounds in water typically depend on the relative attractions of the ions for each other (these forces hold the solid together) and the attractions of the ions for water molecules (which cause the solid to disperse (dissolve) in water. When an ionic solid dissolve in water ions become hydrated and are dispersed (move around independently) (Zumdahl 1997:134).The polarity also allows water interact with an electric field.

2.7 The Chemistry of Iron.

Iron is a water contaminant that takes two major forms. The water-soluble form is known as the ferrous state and has a + 2 valence state. In non-aerated well waters ferrous iron behaves much like calcium or magnesium hardness in that it can be removed by softeners or its precipitation in the back end of the RO system can be controlled by the use of a dispersant chemical in an RO feed water. In aqueous solutions iron (II) salts are generally light green because of the presence of the Fe $(H_2O)^{2+}$. Although the Fe $(H_2O)_6^{3+}$ ion is colourless aqueous solutions of iron (III) salts are usually yellow to brown in colour due to the presence of Fe (OH) $(H_2O)_5{}^{2+}$ which results from the acidity of Fe $(H_2O)_6{}^{3+}$ ($K_a = 6 \times 10^{-3}$) : Fe $(H_2O)_6{}^{+3}$ [aq]) $\rightleftarrows$ Fe (OH) $(H_2O)_5{}^{2+}$ (aq) + H^+ (aq) (Zumdahl , 1997) .

The water insoluble form which has been alluded above , is known as the ferric state and has a +3 valence state. Typically, RO manufacturers will recommend that combined iron levels be less than 0.05 ppm in the RO feed. If all iron is in the soluble ferrous form, iron levels up to 0.5 ppm in the feed can be tolerated if the pH is less than 7.0 (though an iron dispersant is recommended). The introduction of air into water with soluble ferrous iron will result in the oxidation to insoluble ferric iron. Soluble iron can be found in deep wells, but can be converted into the more troublesome insoluble iron by the introduction of air by being placed in tanks or by leaky pump seals. Soluble iron can be treated with dispersants or can be removed by iron filters, softeners or lime softening (Zumdahl , 1997).

Insoluble ferric iron oxides or ferric hydroxides, being colloidal in nature, will foul the front end of the RO system. Sources of insoluble iron are aerated well waters, surface sources, and iron scale from unlined pipe and tanks. Insoluble iron can be removed by iron filters, lime softening, softeners (with limits), ultra filtration (with limits) and multimedia filtration with polyelectrolyte feed (with limits) (Zumdahl, 1997).

2.8 The Chemistry of Manganese

Manganese can exist in all oxidation states from +2 to +7 although +2 and +7 are the most common. Manganese (II) forms an extensive series of salts which are common anions. In aqueous solution Mn^{2+} forms Mn $(H_2O)_6{}^{+2}$ which has a light pink colour which is widely used as an analytical reagent in acidic solution. Manganese is a water contaminant present in both well and surface waters, with levels up to 3 ppm. Manganese, like iron, can be found in organic complexes in surface waters. In oxygen-free water, it is soluble. In the oxidized state, it is insoluble and usually in the form of black manganese dioxide (MnO_2) precipitate. An alert level for potential manganese fouling in a RO aerated RO feed waters is 0.05 ppm(Zumdahl , 1997).

Drinking water regulations limit manganese to 0.05 ppm due to its ability to cause black stains. Dispersants used to control iron fouling can be used to help control manganese fouling. The MnO_4 behaves as a strong oxidising agent with the manganese becoming:

$Mn2^+$: MnO_4^- (aq) + 8 H^+ (aq) + $5_e \longrightarrow$ Mn^{2+} (aq) + 4 H_2^4 O (l) (Zumdahl , 1997).

2.9 The Chemistry of Aluminium.

Aluminium, when introduced into water, disassociates into trivalent aluminium and sulfate. The hydrated aluminium ion reacts with the water to form a number of complex hydrated aluminium hydroxides, which then polymerize and starts absorbing the negatively charged colloids in water. Fouling by aluminium-based colloid carryover can occur, with alert levels for the RO designer ranging from 0.1 to 1.0 ppm aluminium in the feed water. Aluminium chemistry is complicated by the fact that it is amphoteric. Aluminium at low pH's can exist as a positively charged trivalent cation or as an aluminium hydroxide compound. Aluminium at high pH's can exist as a negatively charged anionic compound (Zumdahl, 1997). Typically, the range of least solubility for aluminium compounds is in the pH range of 5.5 to 7.5. Aluminium has metallic physical properties, such as high thermal and electrical conductivities and a lustrous appearance, but its bonds to non-metals are significantly covalent.

Thus $Al(H_2O)_6^{+3}$ (aq) $\rightleftharpoons$ $Al(OH)(H_2O)_5^{2+}$ (aq) +H^+ (aq).

Research which was carried out in DRC and Sierra Leone by UN on alluvial diamond mines showed that Aluminium can be a risk when it is found in water (UN, 1993). People that work in factories where aluminium is applied during production processes may endure lung problems when they breathe in aluminium dust. The effects of aluminium have drawn attention, mainly due to the acidifying problems. Research also carried at Diavik mine in Australia indicated that Aluminium may accumulate in plants and cause health problems for animals that consume these plants (Wiggins and Shields, 1995).

According to (Wiggins and Shields,1995) , the concentrations of aluminium appeared to be highest in acidified lakes. In these lakes the number of fish and amphibians is declining due to reactions of aluminium ions with proteins in the gills of fish and the embryo's of frogs. High aluminium concentrations do not only cause effects upon fish, but also upon birds and other animals that consume contaminated fish and insects and upon animals that breathe in aluminium through air. The consequences for birds that consume contaminated fish are eggshell thinning and chicks with low birth-weights. Another negative environmental effect of aluminium is that its ions can react with phosphates, which causes phosphates to be less available to water organisms.

Similar studies in Diavik Canada have showed that, high concentrations of aluminium may not only be found in acidified lakes and air, but also in the groundwater of acidified soils. There are strong indications that aluminium can damage the roots of trees when it is located in groundwater (Wiggins and Shields ,1995) .

2.10 Effects of Iron concentration on respiration.

Research carried out in Australia and Canada diamond mine in 2002 has shown that, iron metabolism is crucial in the biology and pathophysiology of the lower respiratory tract (Rossi and Freeman 1985). As with many other factors involved in inflammation, it is very important that an appropriate iron balance is maintained. Local deficiency of iron could impair growth and proliferation of cells responsible for the inflammatory response and tissue repair (lymphocytes and fibroblasts) and the synthesis of mediators (for example, arachidonic acid derivatives) (www.bmj.com).

In contrast, excessive accumulation of iron, especially in free form—that is, not bound to one of the specific iron-binding proteins—facilitates the generation of potentially toxic hydroxyl radicals and increases the ability of intracellular bacteria such as mycobacterium to grow (www.bmj.com).

According to (Greenwood ,1980) Iron metabolism in the lower respiratory tract has taken advantage of bronchoalveolar lavage, a technique by which it is possible to obtain the cells and fluid lining the alveoli. Determination of iron content in the alveoli-interstitial region shows that 80% is present in the cells and 20% in the epithelial lining fluid of the lung. Since alveolar macrophages constitute the major cell population in this region, and because the iron content of lymphocytes, neutrophils, and monocytes is very low in comparison with alveolar macrophages, these cells are of special interest. Iron is a dietary requirement for most organisms, and plays an important role in natural processes in binary and tertiary form (Wiggins and Shield 1995) .

Iron forms chelation complexes that often play an important role in nature, such as hemoglobin, a red colouring agent in blood that binds and releases oxygen in breathing processes. Organisms take up higher amounts of binary iron than of tertiary iron, and uptake mainly depends on the degree of saturation of physical iron reserves. Iron is often a limiting factor for water organisms in surface layers. When chelation ligands are absent, water insoluble tertiary iron hydroxides precipitate (www.bmj.com). Iron usually occurs in soils in tertiary form, but in water saturated soils it is converted to binary iron, thereby enabling plant iron uptake. Plants may take up water insoluble iron compounds by releasing H^+ ions, causing it to dissolve. Micro organisms release iron siderochrome, which can be directly taken up by plants. Iron may be harmful to plants at feed concentrations of between 5 and 200 ppm. Iron compounds may cause a much more serious environmental impact than the element itself. (http://www.lenntech.com/periodic/water/iron/iron-and-water.htm#ixzz30qRHe8k9)

2.11 Influence of pH on cell metabolism.

The decline in freshwater fish populations in parts of southern Norway and Canada (Diavik mine) is associated with increasing acidity in rivers and lakes (Vanclay 2005) . The salmon has been eliminated from many rivers, and hundreds of lakes have lost their trout populations. The death and loss of aquatic life is as a result of increased acidity of the water bodies. Water acidity in seas and oceans is mainly due to, acid precipitation, mining effluent discharge and massive oil spillages. Similar observations of acid rain and related effluent discharge from mines and industries have accounted for the disappearance of freshwater fish populations in the United States, Canada and Sweden (Vanclay 2005).

(Vanclay 2005) states that very high (greater than 9.5) or very low (less than 4.5) pH values are unsuitable for most aquatic organisms. Young fish and immature stages of aquatic insects are extremely sensitive to pH levels below 5 and may die at these low pH values. High pH levels (9-14) can harm fish by denaturing cellular membranes.

Changes in pH can also affect aquatic life indirectly by altering other aspects of water chemistry. Low pH levels accelerate the release of metals from rocks or sediments in the stream. These metals can affect a fish’s metabolism and the fish’s ability to take water in through the gills, and can kill fish fry www.nature.com/nature/journal/v259/n5542/abs/259391ao.html).

Similarly, a research which was carried out by Plymouth Marine Laboratory in 2006, indicated that shellfish, crabs, lobsters and a host of other familiar species could become extinct around Britain and Europe because seas are becoming steadily more acidic.

It is critical to note that aquatic plant species, such as corals and certain plankton, are so sensitive to the rising acidity that they could be in rapid decline within decades. Others, such as crabs, mussels and lobsters, are more resistant, but they too will be in danger by the end of the century. In fact affected organisms build their shells or skeletons from calcium carbonate, a mineral they extract from sea water but which is attacked by carbonic acid (pml.ac.uk - Shellfish) .

CHAPTER: THREE RESEARCH METHODOLOGY

3.1 Introduction

This chapter focuses on research methodology, the description of the various methods and research instruments that were used to collect and analyse data. Data sources such as primary data and secondary data were also used in the research methodology.

3.2 Research Design

Research design refers to the detailed outline of how an investigation will take place and typically include how data is to be collected, what instruments will be employed, how the instruments will be used and the intended means for analyzing data collected, (Yin, 1984). The water quality analysis employed systematic sampling, where samples were collected from the two respective rivers Save and Odzi rivers. Sample points were marked 10 kilometres apart. A total of 14 samples were marked along the rivers, 7 on each river. Sampling point 7 was the control point on both rivers and this was located 10km upstream to avoid contamination from the mine effluent discharge. The other 6 sampling points were located downstream from the point of mine discharge to Birchnough Bridge. The water samples were collected for 3 consecutive months starting from October 2013 to December 2013. The following parameters were checked under chemical analysis, namely: metals (iron, copper, manganese, aluminium and nickel), pH conductivity COD, BOD, and turbidity. These are the major constituents of ferrosilicon a substance added in diamond processing. Ferrosilicon is an alloy with the major constituents being, iron, copper, manganese, aluminium, chromium and nickel. Sampling was not done on the onset of rains to avoid dilution of water since this could affect the water sampling results. The advantage of this sampling method was that it ensured for the consistent coverage of the entire sampling stretch without any difficulties, unlike with random sampling.

In getting the view of the people, stratified random sampling was used where the study population was divided into groups based on the 5 mining operations in Chiyadzwa. Three questionnaires were distributed to each company to solicit information on effluent and water management strategies. The self administered questionnaires were distributed to three levels of employees namely, senior management, middle management and lower level employees. The questionnaires were both open ended and closed.

3.2: TARGET POPULATION

According to Kothari, (1985) target population (framework) for a research is the entire set of units for which the research data are to be used to make inferences. Thus, the target population defines those units for which the findings of the research are meant to generalize. It can also be defined as the eligible population that is included in research work. For this study the target populations were all the 5 diamond mines operating in Chiyadzwa, Chiyadzwa community, EMA and Rural Council officials.

3.3: SAMPLE SIZE

Sample according to Neale et al. (2006:11) "is a subset of the population being studied". It represents the larger population and is used to draw inferences about that population. It is a research technique widely used in the social sciences as a way to gather information about a population without having to measure the entire population. Sample size is the number of observations used for calculating estimates of a given population. The size of sample used in this research was 14 water sampling points on both Save and Odzi of which 7 samples were collected from each river.

3.3 Research Instruments

If one wants to know how people feel, what they experience, what their emotions and motives are like, their opinions and the reasons for acting the way they do should be asked and observed (McMillan, (1992). The researcher therefore sought this information by using questionnaires, interviews and field observations including secondary data.

3.3.1. The Questionnaire

A pretested questionnaire was used to collect data from the selected key informants from the community of Chiyadzwa. Pretesting was done with 5 respondents from the population that was going to be used during the study. This enabled the focusing of questions on the issue of water quality and other related issues and checks the effectiveness of the questions. The copies of the questionnaire were distributed to the three levels of employees to each representative company. The technique guaranteed a high (100%) return of the questionnaires.

In addition, the questionnaire was made up of open-ended questions and closed-ended questions. Open-ended questions are those which require someone to explain or express the answer by writing in the spaces that would be provided on the questionnaire. The closed-ended questions have specific answers that one ticks or chooses in the given options or answers that would be provided on the questionnaire (Neale et al 2006). The advantage of open-ended questions is that, they give room for respondents to write out their own answers expressing themselves fully.

However, open-ended questions took more time for the respondent to write a response than just choosing an offered response. Closed-ended questions on the other hand, made the respondent to select a single response from the list. This was a disadvantage for respondents who would think otherwise from the given possible answers on the questionnaire. Generally, the open-ended questions were an advantage as they made respondents to keep to the aims of the study as they only provide the required actual facts to the study.

However, using the questionnaire as a method of collecting primary data helped the researcher to obtain a wide range of information within a limited period of time. There was greater flexibility as data analysis was easy on the close-ended questions as compared to the open-ended questions which needed to be analysed by reading carefully the responses.

3.3.2. Field Observations

Field observations were undertaken to investigate and assess the situation on the ground on the points of discharge. The field observations were vital as they aided the researcher with the actual evidence and facts on the problems on water quality.

3.3.3. Secondary Data Sources

Secondary sources of data are accounts of an event that were not actually witnessed by the reporter. They are merely a testimony from the ones who would have witnessed it. These may include journals, magazines, newspapers and textbooks (Neale et al 2006). For the study, secondary data obtained was for consulting and reviewing on public documents that included EMA and Mutare Rural Council.

Secondary data gave guidelines on the water quality issues by giving information about the study area especially the statistics on the area, which included compliance level, water permits and standards. An advantage of using secondary data was that it saved time as it was just reviewing from recorded data which was relevant to the study. This enabled the researcher to cover some ground using the data as it was of quality and reliable (Neale et al 2006).

Some of the limitations of this method were that, some of the data was also irrelevant to the researcher's needs thereby consuming time for the researcher as he read the information during the selection of relevant information.

3.3.4. Reliability and Validity

Leeds (1997) indicates that validity is concerned with the soundness, effectiveness of the measuring instruments. Reliability is the consistency with which a measuring instrument performs. However, reliability is concerned with the degree of fit between construct and data. Phillips in Baley (1982) notes that, a measurement of a given phenomenon is viewed as valid if it successfully measures the phenomenon it sets out to measure. The validity of a questionnaire relies on the relevance or content validity, of the questionnaire to the researched topic.

During the construction of the questionnaire, an examination of the items was done by the researcher to ensure that the questions in the questionnaire focussed on the required information. In addition, to ensure reliability and validity of the questionnaire, the researcher also approached senior scholars who assisted in the phrasing and elimination of some of the questions in order to meet the objectives of the study.

3.4 Methods of Data Collection

A stratified random sample is a blend of mutually exclusive homogeneous samples that are chosen in proportion to their contribution to a heterogeneous population. The discharge points on the rivers were used to determine the water sampling points. The upper sampling points on each river were 10 km upstream and these were the control points (sampling points 7). At each river site, water samples were collected and sent to the laboratory for analysis. The samples were sent for chemical analysis. The following parameters were checked under chemical analysis, namely: metals (iron, copper, manganese, aluminium and nickel), pH, conductivity COD, BOD, and turbidity. These are the major constituents of ferrosilicon a substance added in diamond processing. Ferrosilicon is an alloy with the major constituents being, iron, copper, manganese, aluminium, chromium and nickel.

3.4.1 Chemical Analysis

3.4.1.1 Metals (Iron, Copper, Nickel, Manganese and Aluminium).

The metal constituents of the samples were analyzed using multi-acid digestion and this uses a combination of HCl (hydrochloric acid), HNO_3 (nitric acid), HF (hydrofluoric acid) and HClO4 (perchloric acid). While multi-acid (4 acid) digestion is a very effective dissolution procedure for multi-element analysis at trace levels of detection, there can be a loss of volatile elements (e.g. B, As, Pb, Ge, Sb) during this type of digestion and some refractory minerals (especially oxide minerals) which are partially digested. The metal analysis was completed off through the use of the Atomic Absorption Spectroscopy (AAS). Atomic Absorption Spectroscopy in analytical chemistry is a technique for determining the concentration of a particular metal element within a sample (Mackereth et al (1978).

3.4.1.2 pH

The pH of samples was measured using a pH meter. The electrode or sensor of the meter sends a signal to the digital meter based on the acidity, alkalinity or ionic potential (ORP) of the solution. The signal is a very weak voltage measured in millivolts. The meter converts the signal to pH and displays the result. The major factor that affects accuracy of the pH meter is calibration (Mackereth et al (1978).

3.4.2.3 Conductivity

Conductivity defines the amount of dissolved ions in a sample. Solutions of dissolved ions (dissolved salts) in water passed the electric potential of a battery through them and allow the light bulb to light. An electrolytic sample contains cations and anions. The more cations and anions present, the higher the conductivity (Chapman,1997) . Conductivity was measured using the conductivity meter, that is, the electrode system (Chapman,1997) . Conductivity meter results were affected by the calibration status of the meter. However if the laboratory calibrates the meter as to the manufacturer's specification, then the results will be accurate. Another factor that could affect the conductivity of the sample was hardness, which may cause scaling of the electrode. Scaling will coat the electrodes, diminish electrical current flow and negatively impact on the reading. There is therefore need to ensure electrodes are always free from scales Mackereth et al (1978).

3.4.2.4 Turbidity

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality (Chapman ,1999).

3.4.2.5 COD and BOD

Biochemical Oxygen Demand (BOD) is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. BOD is determined using the titrimetric methods (Mackereth et al 1978) . For BOD, dissolved oxygen (DO) concentrations in a sample measured before and after the incubation period, and appropriately adjusted by the sample corresponding dilution factor. This analysis was performed using 300 ml incubation bottles in which buffered dilution water is dosed with seed microorganisms and stored for 5 days in the dark room at 20°C to prevent production via photosynthesis. In addition to the various dilutions of BOD samples, this procedure required dilution water blanks, glucose glutamic acid (GGA) controls, and seed controls (Chapman 1997).

Chemical Oxygen Demand (COD) test is commonly used to indirectly measure the amount of organic compounds in water. Titrimetric measurement for COD involves the use of potassium dichromate, which is a strong oxidising agent. BOD and COD results may be affected by laboratory (titrimetric) errors if procedures are not adequately followed (Bartrum and Balance,1996).

3.4.3. Factors influencing Results

3.4.3.1 Sampling Mechanisms

The way samples were collected influenced the final results of the analysis. Consequently samples were collected from same points every month and these were put in sterilised bottles to avoid contamination. Samples were also collected at specific times of the day that is in the morning.

3.4.3.2 Contamination

Contamination may occur during collection and transportation. This is particularly serious with microbial samples as contaminating microbes can grow. Thus all containers were sterilised and clearly labelled.

3.4.3.2 Lab Errors

Failure to follow procedures in culture preparation and sample analysis may influence results negatively. It is therefore necessary to follow procedures during sample analysis

3.4.3.3 Quality control

Quality control was assured by the use of procedural blanks and standards. In each case a known concentration of the standard solution was assayed after every five samples to verify the analytical quality of the result since there is no standard reference material available. In all the cases for sediments, water and fish, a preparation / reagent blank was prepared for every 20 samples and all the concentrations were below the detection limits. Each sample was analyzed in triplicate for repeatability with a relative standard deviation < 5 % for all the metals analyzed (DK Laboratory control standards ,2012)

3.5 Data analysis and Presentation

All the quantitative data was entered in the Microsoft-Excel Program. Data processing, analysis and interpretation of the information collected through questionnaire survey, interviews and observations were done using SPSS 11.5 and MS-Excel 2007. The results were then represented in the form of tables, graphs, and charts.

Analysis of water sample results was done and was assessed against published EMA (S.I 6 of 2007) and World Health Organization (W.H.O.) guidelines because the waters of these rivers are used for domestic uses. These standards are presented in Table 1.

Table 1 Water quality standards.

		W.H.O. guidelines drinking water	**Zimbabwe Effluent standards (SAZ 558: 1999) Requirements**			
Parameter	Units		Blue	Green	Yellow	Red
pH	-	6.5- 8.5	6 – 9	5-6; 9-10	4-5; 10-12	0-4; 12-14
Turbidity	NTU	5	≤ 5			
Conductivity	uS/cm	-	≤ 1000	≤ 2000	≤3000	≤ 3500
Sus . Solids	mg/l	-	≤ 25	≤ 50	≤ 100	≤ 150
TDS	mg/l	1000	≤500	1500	2000	3000
Chlorides	mg/l (Cl)	250	≤250	≤ 300	≤ 400	≤ 500
B.O.D	mg/l	-	≤ 30	≤ 50	≤ 100	≤ 120
Nitrates	mg/l (NO^{3+})	50	-	-	-	-
Nitrites	mg/l (NO^{2-})	3	≤ 3	≤ 5	≤ 8	≤ 10
Potassium ions	mg/l	-	-	-	-	≤ 500
Sodium ions	mg/l		≤ 200	≤ 300	≤500	<1000
Manganese ions	mg/l	0.1	≤ 0.1	≤ 0.3	≤ 0.4	≤ 0.5
COD	mg/l	-	≤ 60	≤ 90	≤ 150	≤200
Copper	mg/l	1	≤ 1.0	≤ 2.0	≤ 3.0	≤5.0
Zinc ions	mg/l	1.5	≤ 0.5	≤ 4.0	≤ 5.0	≤15
Iron ions	mg/l	0.3	≤ 1	≤ 2	≤ 5	≤ 8

Nickel ions	mg/l	0.07	≤ 0.3	≤ 0.6	≤ 0.9	≤ 1.5
Lead ions	mg/l	0.01	≤ 0.05	≤ 0.1	≤ 0.2	≤ 0.5
Total Viable Count	Counts 100ml	> 2000				
E-Coli						
Total coliforms	Counts/100ml		≤1000	>1000	>1500	≤2000

CHAPTER FOUR: DATA PRESENTATION, INTERPRETATION ANALYSIS AND DISCUSSION.

4.1 Introduction

This chapter focuses on data presentation, analysis, interpretation and discussion. The data collected will be presented in form of charts, tables and graphs. A thematic approach will be used in the analysis, interpretation and presentation of data.

4.2 Demographic Data

Gender distribution in this research was male dominated on all the key informants who were interviewed or supplied with questionnaires. Table 4.1 gives a summary of the gender distribution.

Table 4.1 Distribution of research instruments by gender.

Group	**Gender**			
	Males	**%**	**Females**	**%**
EMA/ Rural District Council.	2	100	0	0
Headmen	2	100	0	0
Chief	1	100	0	0
Village Heads	7	87.5	1	12.5
Diamond Mining Representatives	5	100	0	0

From Table 4.1 above, 100% of the mining companies, headmen, chiefs and company representatives were males. On the other hand 12.5% village heads were females. Interview and questionnaire instruments ware fairly distributed although they favoured males to a great extent. This pattern had no impact on research findings. Both males and females indicated that there were water quality problems which were emanating from diamond mining activities in Chiyadzwa. These include among other things, death of fish, dirty water which affected agricultural, domestic and recreational use of water.

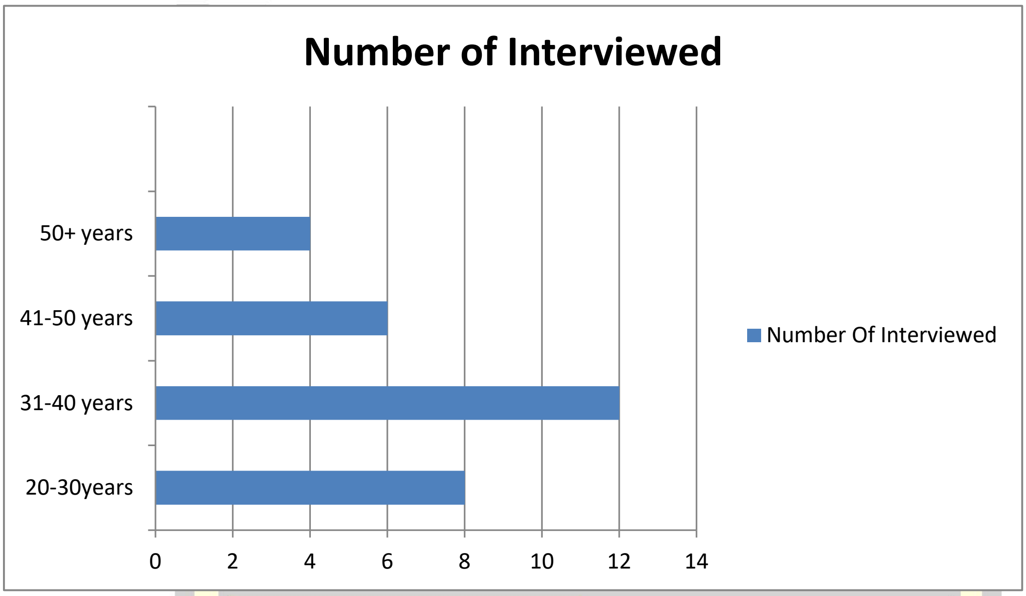


Fig 4.1: Distribution of interviewees by age.

The subjects interviewed were above 20 years. This assisted the researcher in making a trend analysis from the period before the diamond mining to the current era of diamond mining. It was also observed that different age groups had similar the effects of poor water quality to the Marange community.

4.3 Mining activities which influence water quality

The research study identified the mining activities which affected water quality in both Save and Odzi Rivers. The aspects identified by all respondents were, discharge of dirty water into Save and Odzi and their tributaries and failure of mine slimes dams to capture effluent from the processing plants. Plate 4.2 confirms effluent discharge by one of the diamond mines into Save River. The EMA officials pointed out that there was low compliance level in

Chiyadzwa diamonds mines on water and effluent management. It was indicated that all the 5 operating companies' effluent permits were in the Yellow to Red categories. This showed that companies are heavily polluting the mines. It was also indicated that there was high restrictions in accessing the mines making it difficult or almost impossible to audit and inspect the mine premises of the companies operating in Chiyadzwa. EMA and Rural District council also indicated that fining the operating companies is not deterrent and neither does it stop them from polluting the environment.

Plate 4.1 Effluent Discharge from one of the diamond mines (Source: self)

4.4 Environmental Management Agency (EMA) and WHO water quality parameters and Standards.

Tables 4.2 (a) and 4.2(b) show the water quality parameters which were measured against the EMA S.I 6 of 2007 and WHO standards. The licence colours are blue, Green, Yellow and Red. The physiochemical parameters which were all measured (heavy metals) are major constituents of FeSi which is added during diamond mineral processing (Fig 1.1). All the heavy metals which were measured (Iron, Aluminium, Nickel, and Manganese) were in the red and yellow categories of EMA (S.I 6 of 2007) and WHO water quality standards. The only exceptional heavy metal which was within the legal limit was copper which was in blue category. this shows that there is no copper contamination in the two Rivers which is caused by diamond mining companies.

Low concentration of heavy metals was recorded on sampling points 5 and 6 which were located downstream. The low concentrations could be attributed to dilution as the water flows down stream. However COD and BOD levels were significantly high in sampling point 5

Table 4.2(a)Water Analysis Table - Effluent Water (Save River October 2013 - December 2013)

	SAMPLING POINTS																					**LICENCE COLOUR**			
Parameters	**1**			**2**			**3**			**4**			**5**			**6**			**7**						
	O	**N**	**D**	**O**	**N**	**D**	**O**	**N**	**D**	**O**	**N**	**D**	**O**	**N**	**D**	**O**	**N**	**D**	**O**	**N**	**D**	**Blue**	**G**	**Y**	**R**
pH	4.9	4.2	4.7	4.5	5.6	4.9	6.7	4.6	5.6	4.3	6	5.2	6.3	6.9	7.7	7.2	6	7.8	7.4	7.5	7.7	6 – 9	5-6; 9-10	4-5; 10-12	0-4; 12-14
Conductivity-µS/cm	2286	3587	2586	2115	3480	3584	3125	2123	2141	2137	1126	2756	2127	1126	1665	729	967	690	338	270	336	≤ 1000	≤ 2000	≤3000	≤ 3500
Copper-mg/l	0.32	0.01	1.32	0.02	0.01	1.17	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0	0.01	0.01	0.01	≤ 1.0	≤ 2.0	≤ 3.0	≤5.0
Iron-mg/l	32.29	39.3	21.5	2.01	41.2	24.5	6.26	7.39	6.32	8.22	7.41	8.82	2.5	2.99	2.4	2.04	2.43	1.2	2.21	0.55	0.8	≤ 1	≤ 2	≤ 5	≤ 8
Manganese-mg/l	5.1	8.2	4.1	5.4	8.5	3.9	5	3.9	3.7	4.4	3.2	5.2	1.4	0.3	0.2	0.1	0.02	0.2	0.1	0.1	0.01	≤ 0.1	≤ 0.3	≤ 0.4	≤ 0.5
Nickel-mg/l	1.19	1.16	0.95	2.3	1.9	0.67	3.1	2.2	4.5	2.7	2.4	2.6	1.2	0.8	0.32	0.21	0.4	0.2	0.01	0.01	0.04	≤ 0.3	≤ 0.6	≤0.9	≤ 1.5
Aluminium-mg/l	8.57	36.6	9.8	8.1	33.6	23.1	31.2	20	17.4	11	9.4	9.8	1.65	1.27	4.3	1.37	2.6	4.2	1.55	2.15	4.9	< 5	-	-	-
Turbidity-ntu	232	24.2	9000	33	25.1	4000	43.3	51.6	9.4	45.1	37.2	10.2	36.4	1.19	3.25	2	1.66	3.2	2.17	1.35	4.82	< 5	-	-	-
BOD-mg/l	216	428	720	182	108	2080	144	112	179	168	142	113	216	77	55	42	26	28	18	27	11	≤ 30	≤ 50	≤ 100	≤ 120
COD-mg/l	188	212	147	288	124	1100	268	128	100	336	132	160	944	188	88	216	276	108	32	50	80	≤ 60	≤ 90	≤ 150	≤200

Table 4.2 (b) Water Analysis Water Analysis Table - Effluent Water (Odzi River October 2013 - December 2013)

	SAMPLING POINTS																					**LICENCE COLOUR**			
Parameters	**1**			**2**			**3**			**4**			**5**			**6**			**7-Control**						
	O	**N**	**D**	**O**	**N**	**D**	**O**	**N**	**D**	**O**	**N**	**D**	**O**	**N**	**D**	**O**	**N**	**D**	**O**	**N**	**D**	**Blue**	**G**	**Y**	**R**
pH	4.5	4	4.6	4.8	4.9	5.5	6	5.2	4.3	5.8	5.2	4.8	7.1	6.9	7.4	6.4	6.7	7.4	7.4	7.7	7.5	6 – 9	5-6; 9-10	4-5; 10-12	0-4; 12-14
Conductivity-µS/cm	3282	3525	3788	4273	3125	3626	2285	3138	2412	3296	3514	2136	2320	1141	1155	901	837	437	302	142	155	≤ 1000	≤ 2000	≤3000	≤ 3500
Copper-mg/l	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0	≤ 1.0	≤ 2.0	≤ 3.0	≤5.0
Iron-mg/l	7.22	9.52	11.4	10.6	9.69	13.2	6.67	10	1.02	7.04	9.3	8.5	3.51	1.52	1.53	1.33	0.47	0.84	0.29	0.23	0.4	≤ 1	≤ 2	≤ 5	≤ 8
Manganese-mg/l	8.6	4.1	4.9	8.1	3.7	4.7	9	4.2	4.7	8.9	4.6	4.8	0.3	0.6	0.4	0.4	0.2	0.2	0.1	0.2	0.1	≤ 0.1	≤ 0.3	≤ 0.4	≤ 0.5
Nickel-mg/l	3.1	5.1	6.2	9	11	8.3	12	7	4.3	5.2	3.1	3	2.4	0.8	0.6	0.2	0.1	0.2	0.02	0.01	0.1	≤ 0.3	≤ 0.6	≤ 0.9	≤ 1.5
Aluminium-mg/l	7.45	6.3	5.83	6.07	6.46	6.73	7.98	5.72	6.67	7.15	6.54	6.31	5.2	1.69	1.34	1.19	1.78	4.27	1.63	1.66	1.8	< 5			
Turbidity-ntu	37.9	40.8	11.59	40.2	42.62	39.78	53.7	35	22.9	44.4	21.6	18.9	25.7	11.5	16.7	12.3	5.75	3.4	4.41	1.84	1.9	< 5			
BOD-mg/l	177.4	224	111.6	212	167.3	122.4	104.8	121	114	132	115	100.4	78	98	54	46	11	20	13.2	22.1	22	≤ 30	≤ 50	≤ 100	≤ 120
COD-mg/l	252	116	236	288	112	228	308	336	206	258	132	154	120	111	118	67	16	24	39	24	44	≤ 60	≤ 90	≤ 150	≤200

The results shown on Tables 4.2 (a) and4.2(b) above confirm all the research objects. The five operating diamond mines, DMC, Marange Resources, Anjin, Jinan, and Mbada Diamonds discharge contaminated effluent to both Save and Odzi Rivers polluting the waters.

From the above Tables 4.2 (a) and 4.2(b), it has been established that mining activities causes high pH, conductivity, turbidity, BOD, and COD. Generally sampling points 1-4 and to some extent sampling points 5 and 6 which were located near and at Birchnough Bridge downstream we in the Red, Yellow and Green licence colours. this confirms pollution by diamond mines in Chiyadzwa.

4.5 pH levels in Save and Odzi Rivers

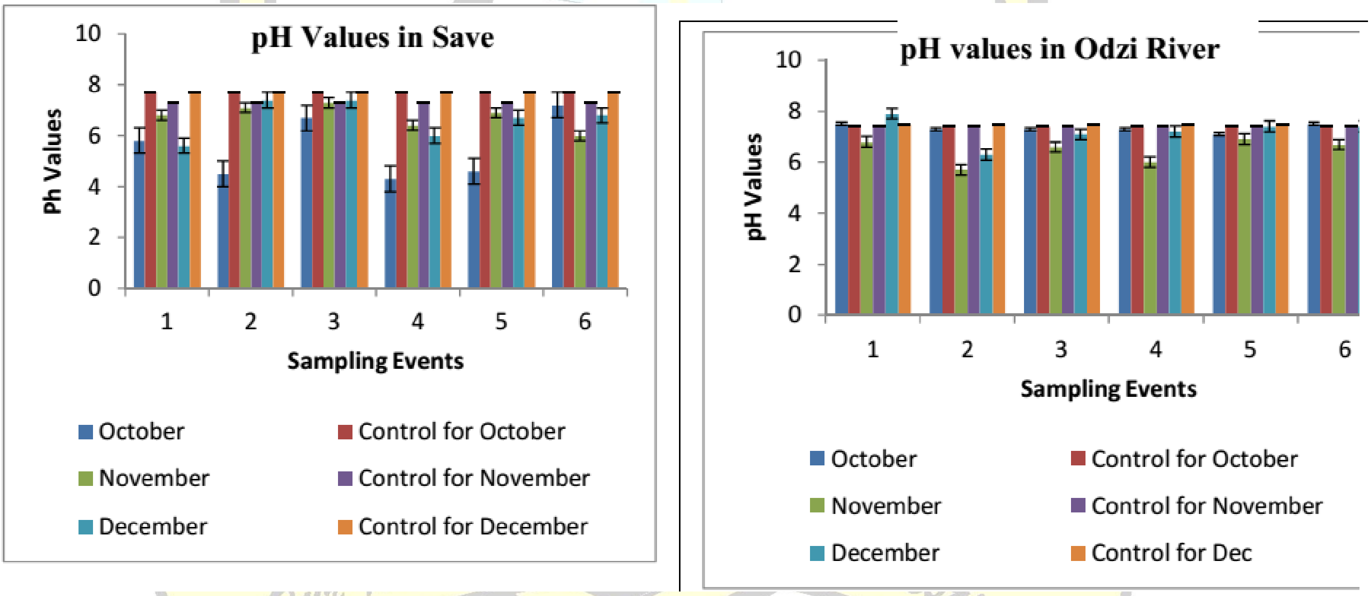


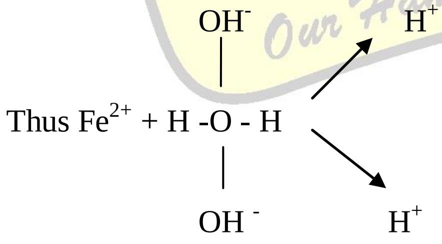
Fig 4.3 pH concentration in Save and Odzi

pH is the concentration of H ions in a substance and acidic waters tend to keep minerals in solutions. Fig 4.3 shows that there is a significant difference between the pH values before discharge (control) and the points after discharge of mine effluent. p.H values below 6.5 were recorded in Save and Odzi in October , November and December on sampling points 1,2 ,3 and 4. The sampling points were also in red according to S.I 1 06 of 2007 see table 4.2(a) and

4.2(b). Points 1 , and 3 were receiving direct effluent discharge from DMC through Singwizi River and point 1 and 3 in Odzi were receiving direct effluent discharge from Anjini and Marange Resources.

The processing plants for Anjini and Marange Resources are barely 50 and 20 metres from Odzi River respectively, hence there is massive discharge of effluent into Odzi river which accounts for the pH levels which are beyond the legal limit as compared to the acceptable pH levels as shown by the control point samples (sampling point 7) from October to November which were 6. 7, 7.7 and 7.5 in Save River and 7.4, 8.5 and 7.5 in Odzi River respectively. The control point sample results were within the EMA and WHO legal limits which is blue catergory (Table 4.2(a) and 4.2(b).

The realtionship between pH and iron as shown in Fig 4.4 was so significant as reflected by the R^2 of 0.109 and 0.1138 for Save and Odzi Rivers respectively . This shows a strong correlation between pH levels in water and the heavy mineral presents. The pH levels were also above the EMA and WHO standards of water quality in the rivers see table 4.2(a) and 4.2(b). In light of the above , the water in Save and Odzi is acidic because of the H^+ ion which moves independently when water reacts with the Fe^{2+} (goethite insoluble) or Al^{3+} (gibbsite insoluble). The Fe^{2+} or Al^{3+} are pollutants which emanate from the ferrosilicon which is used to increase the density of water (SG) to 2.6 in diamond processing.



$$\text{Thus } Fe^{2+} + \overset{OH^{-}}{\underset{OH^{-}}{H\text{-}O\text{-}H}} \begin{matrix}\nearrow H^{+}\\ \searrow H^{+}\end{matrix}$$

The independent H^+ which is liberated when iron reacts with water causes the acidity in water in both Save and Odzi Rivers hence there is a significant relationship between pH and iron(Fig

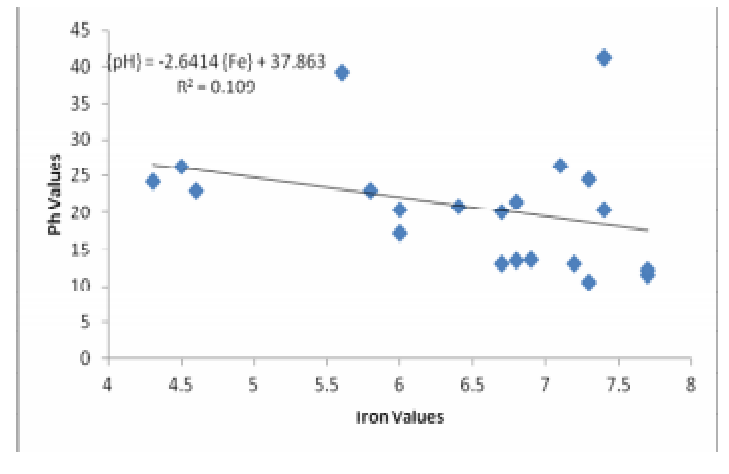
4.4) . In light of the above the mines operating in Chiyadzwa -Marange are polluting the water causing it acidic. The research study findings conforms to other studies, (Vanclay 2005) states that very high (greater than 9.5) or very low (less than 4.5) pH values are unsuitable for most aquatic organisms. Young fish and immature stages of aquatic insects are extremely sensitive to pH levels below 5 and may die at these low pH values. High pH levels (9-14) can harm fish by denaturing cellular membranes.

Changes in pH can also affect aquatic life indirectly by altering other aspects of water chemistry. Low pH levels accelerate the release of metals from rocks or sediments in the stream. These metals can affect a fish's metabolism and the fish's ability to take water in through the gills, and can kill fish fry (www.nature.com/nature/journal/v259/n5542/abs/259391ao.html).

Similarly, a research which was carried out by Plymouth Marine Laboratory in 2006, indicated that shellfish, crabs, lobsters and a host of other familiar species could become extinct around Britain and Europe because seas are becoming steadily more acidic.

4.6 Relationship between Iron and pH in Save and Odzi Rivers.

Relationship between pH and Iron in Save River Relationship between pH and Iron in Odzi River



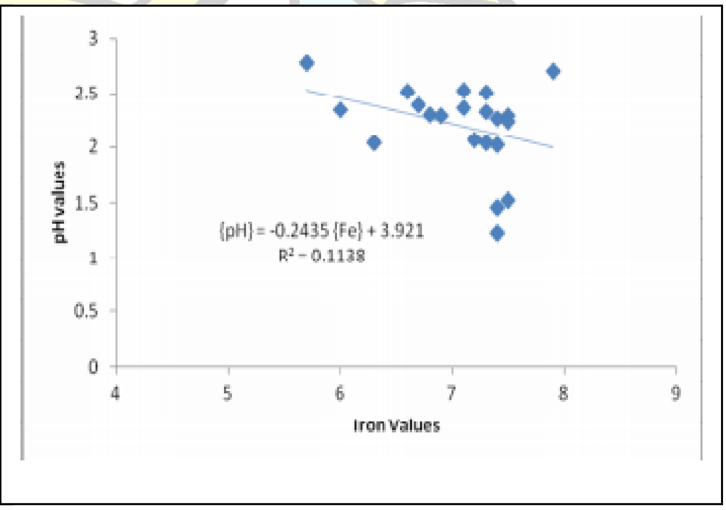
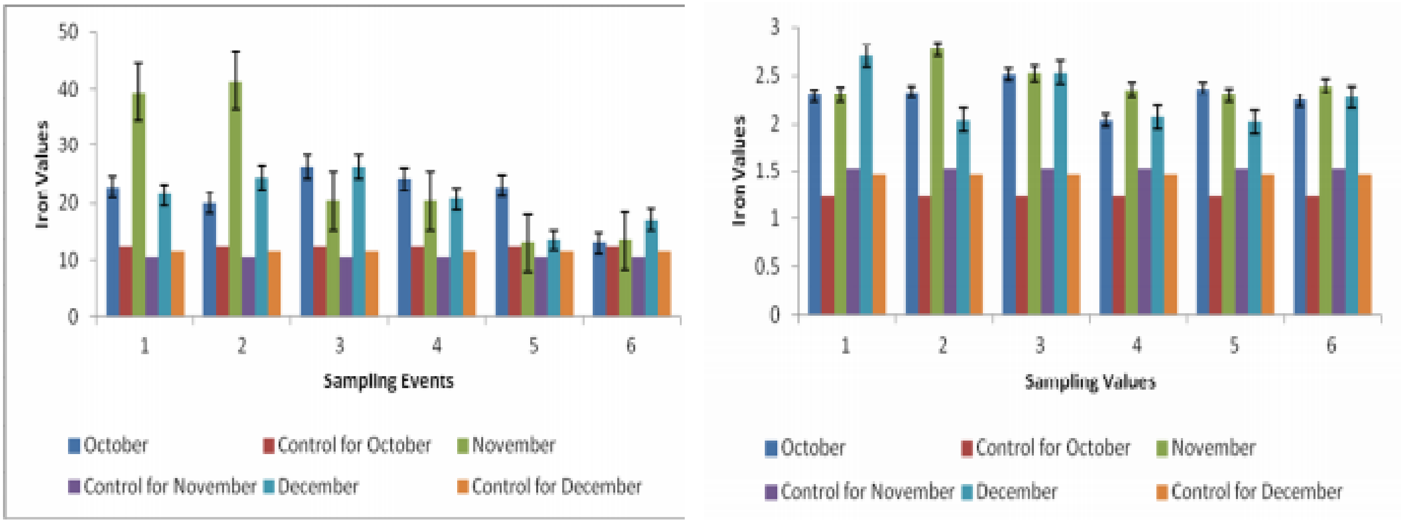


Fig 4.4 Relationship between pH and iron in Save and Odzi Rivers.

The pH values of around 7 indicate good water quality. All the other sampling points affected by mine discharges, sampling points (1,2,3,4) on both rivers recorded pH values of > 8 and < 6, the worst affected being sampling points 1, 2 and 3 Save River with pH values of 4.2,4.3 ,4,5 and 4.6 (Save River) and 4, 4.5 and 4.6 (Odzi river) respectively (Table 4.2 (a and b). The results clearly indicated that discharges and runoff from the mining areas contained contaminants which pushed the water pH to acidic levels. The acceptable limits for pH according to W.H.O and EMA (S.I 106 of 2007) drinking water standards are 6.5-8.5. Contrary to these standards, several sites receiving mine drainage from diamond mines failed to meet these important criteria.

It is critical to note that aquatic plant species, such as corals and certain plankton, are so sensitive to the rising acidity that they could be in rapid decline within decades. Others, such as crabs, mussels and lobsters, are more resistant, but they too will be in danger by the end of the century. In fact affected organisms build their shells or skeletons from calcium carbonate, a mineral they extract from sea water but which is attacked by carbonic acid (pml.ac.uk - Shellfish. In light of the above the loss of aquatic life in Odzi and Save can be attributed to the pollution caused by the five operating diamond mines.

4.7 Iron levels in Save and Odzi Rivers.



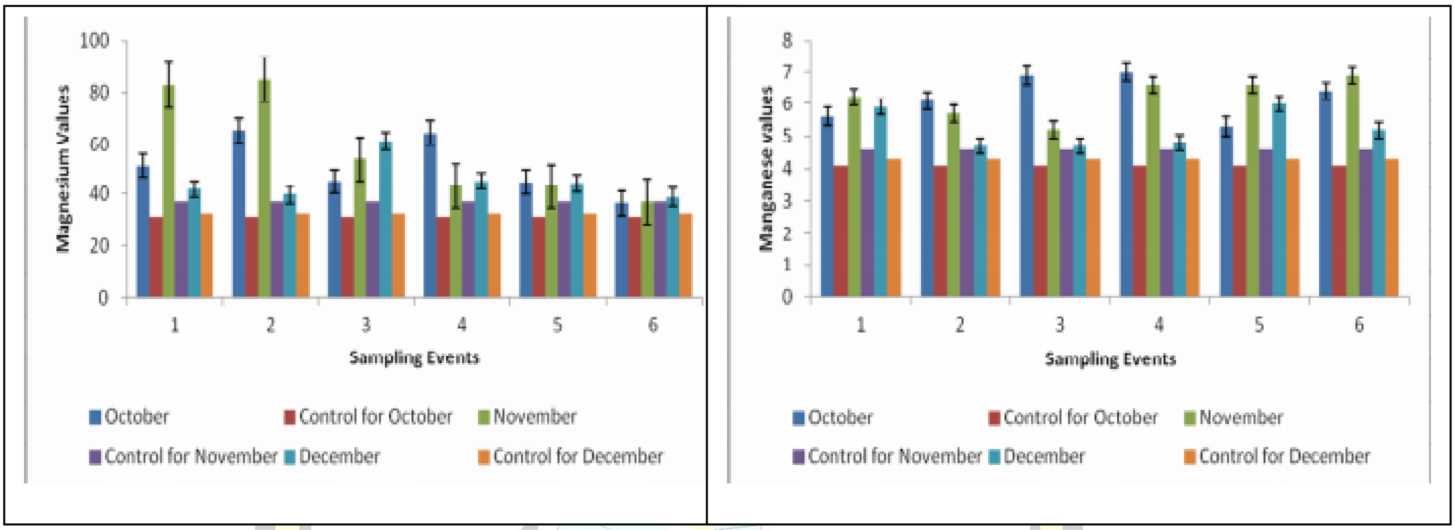
Availability of Iron in Save River

Availability of Iron in Odzi River

Fig 4.5 Iron concentrations in Save and Odzi Rivers.

The concentrations of Iron (Fe) were much higher than W.H.O. limits as well as effluent standards S.I.106 of 2007 (EMA) and placed the affected sites (Sites 1, 2, 3, 4, &) into the RED and Yellow categories see plate 4.2(a) and 4.2(b) . This means that local communities are at risk of iron poisoning, which is an iron overload caused by excessive iron intake. The first indications of iron poisoning by ingestion are pains in the stomach, as the stomach lining becomes ulcerated. This is often accompanied by nausea and vomiting. The pain then abates for 24 hours as the iron passes deeper into the body and damages internal organs, particularly the brain and the liver, and metabolic acidosis develops. Thus the research findings confirms the research that was carried in DRC and Sierra Leone. It was noted that ,water pollution of that nature kills life that depends on water bodies. Dead fish, crabs and birds and many other animals often wind up on river banks or shores , killed by pollutants in their habitat (living environment). Fish are easily poisoned with heavy metals which include lead, iron, chromium, copper, mercury, aluminium, magnesium and manganese. These heavy metals can later be consumed by humans when they eat the water species such as fish and cause serious health problems (Wyk ,et al 2009).

4.8 Manganese levels in Save and Odzi Rivers



Manganese availability in Save River Manganese availability in Odzi River

Fig 4.6 Manganese concentrations in Save and Odzi Rivers.

Fig 4.6 shows Manganese in Save and Odzi Rivers. Concentrations were highest at sampling points 1, 2, 3and 4, and were above the stipulated W.H.O. standards and EMA standards. The highest were 8.5 and 8.2 in Save River see table 4.2(a) and 4.2(b). The rising concentrations of these elements are a cause for concern because they are cancer causing agents and there is need to construct lined slimes dam to capture all the processing water from diamond mining activities. The failure to recover the FeSi after diamond extraction by the mines and allowing it to flow into the rivers is causing environmental damage and putting people at risk of exposure to carcinogenic agents (cancer causing).

4.9 Relationship between Manganese and pH in Save and Odzi Rivers.

Relationship: pH and Manganese Save River   Relationship: pH and Manganese Odzi River

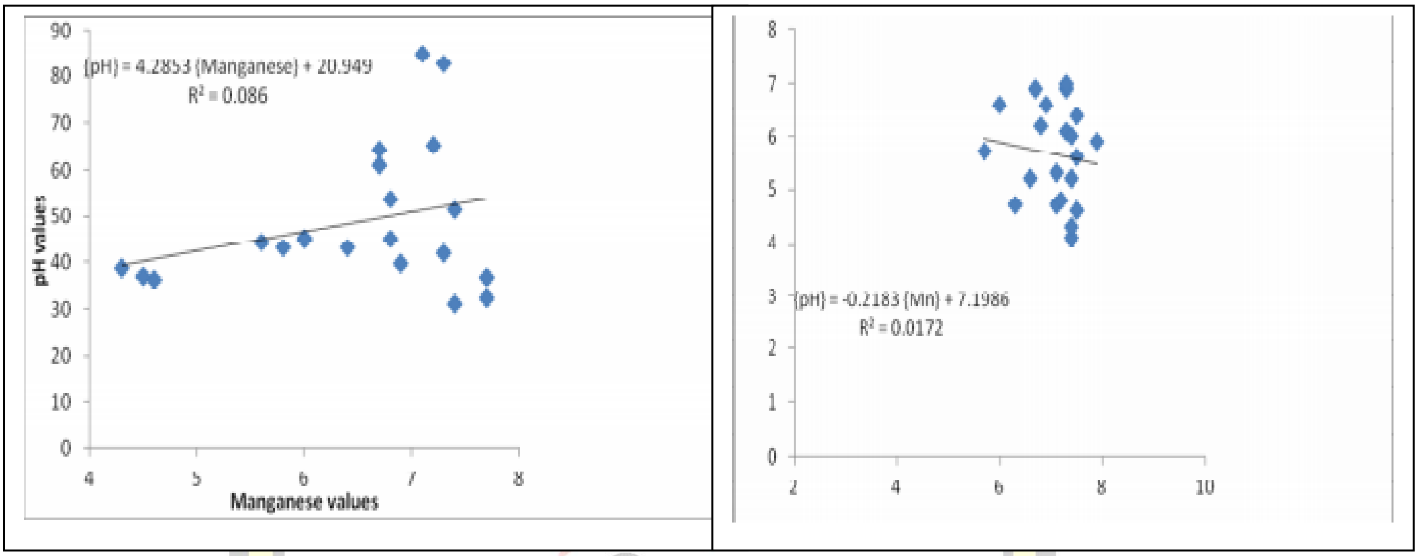
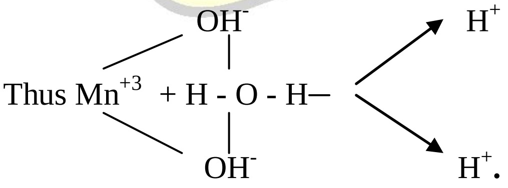


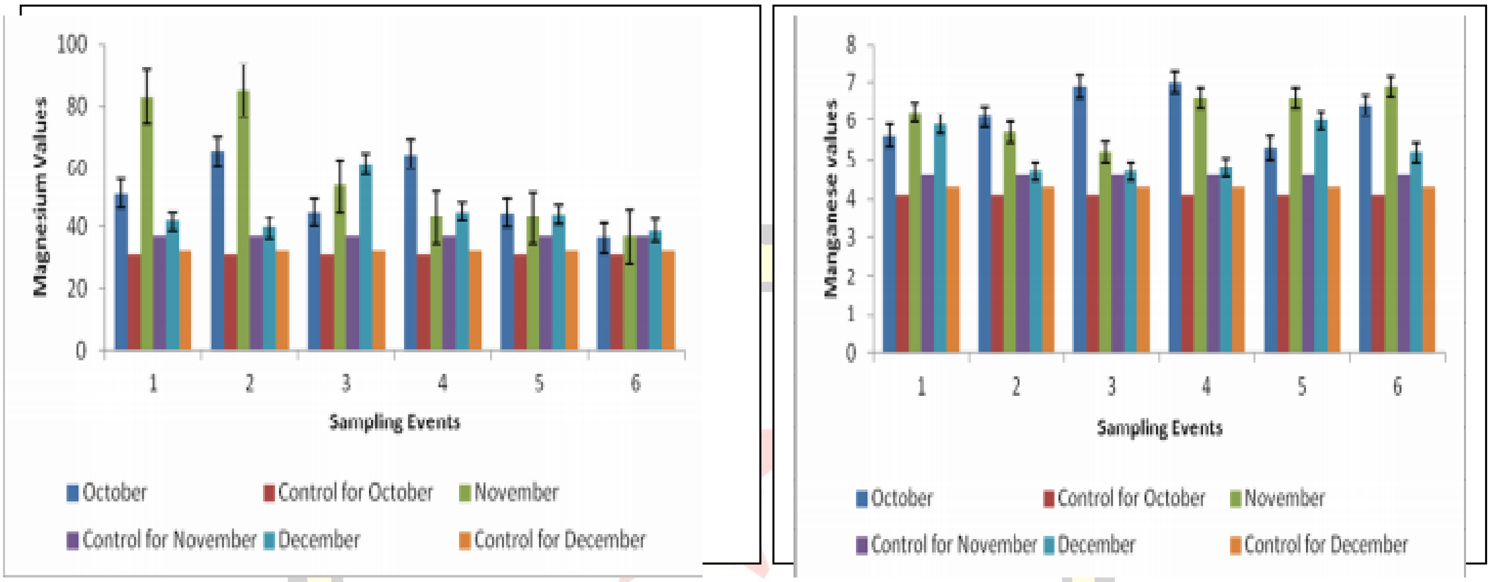
Fig 4.7 Relationship between Manganese and pH in Save and Odzi Rivers.

Research findings has also shown that there is a strong correlation between manganese in water and p.H as shown on Fig 4.7. The R^2 of 0.086 and 0.0172 respectively entails that an increase in Manganese in water pushes the pH values high. This explains the acidity that was recorded in the water points especially on sampling points 1,2 and 3 which were receiving direct contaminants from the diamond mines.

The reaction of Manganese which is similar to that of Fe^{2+} results in the abundance of H^+ in water causing the water to be acidic. Below is the illustration.



4.10 Aluminium levels in Save and Odzi Rivers.



Aluminium availability in Save River

Aluminium availability in Odzi River

Fig 4.8 Aluminium concentration in Save and Odzi Rivers.

Fig 4.8 is a representation of the Aluminium concentration in both Save and Odzi Rivers. From the water samples collected there was a high concentration of Aluminium in water as compared to the control point (sampling point 7) . The error bars show that the difference between the control and the sampling points below where discharge of mine processing effluent was significant.

Sampling results show that Aluminium concentration were high on areas where DMC, Marange Resources , Mbada Diamonds, Anjin and Jinani discharge effluent. Highest concentration were 36.6,33.6 and 31.2 for Save River and 7.98,7.45 and 6.73 for Odzi River. All the sampling results for the sampling points 1 to 4 and partly 5 were in the red category according to EMA (S.I 106 of 2007) and WHO water standards (Table 4.2(a) and 4.2(b) .

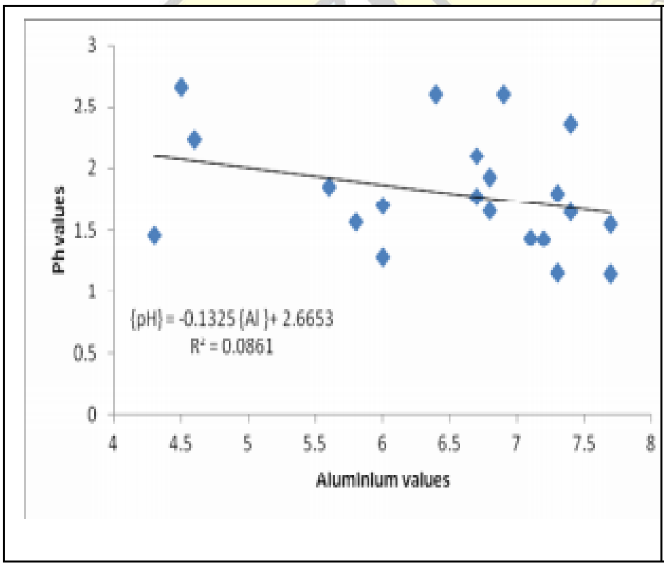
This confirms that diamond mines are polluting both Save and Odzi Rivers since they discharge pollutants into tributary rivers which feeds them.

On the other hand Fig 4.9 shows the R^2 of Save and Odzi Rivers as 0.0861 and 0.29 respectively. This shows that when pH values decreases the concentration of ions H^+ also increase in water causing the water to be acidic. The reaction of Al^{3+} with water is similar to that of Fe^{2+} and Mn^{3+}. The H^+ causes the water to be acidic.

Research which was carried out in DRC and Sierra Leone by UN on alluvial diamond mines showed that Aluminium can be a risk when it is found in water (UN, 1993). People who work in factories where aluminium is applied during production processes may endure lung problems when they breathe in aluminium dust. The effects of aluminium have drawn attention, mainly due to the acidifying problems. Research also carried at Diavik mine in Australia indicated that Aluminium may accumulate in plants and cause health problems for animals that consume these plants (Wiggins and Shields, 1995). The consequences for birds that consume contaminated fish are eggshell thinning and chicks with low birth-weights. Another negative environmental effect of aluminium is that its ions can react with phosphates, which causes phosphates to be less available to water organisms.

In light of the above the research findings confirm that, all the five operating diamond mines pollute Odzi and Save Rivers by discharging contaminated effluent into river bodies.

Relationship: pH and Aluminium Save River



Relationship: pH and Aluminium Odzi River

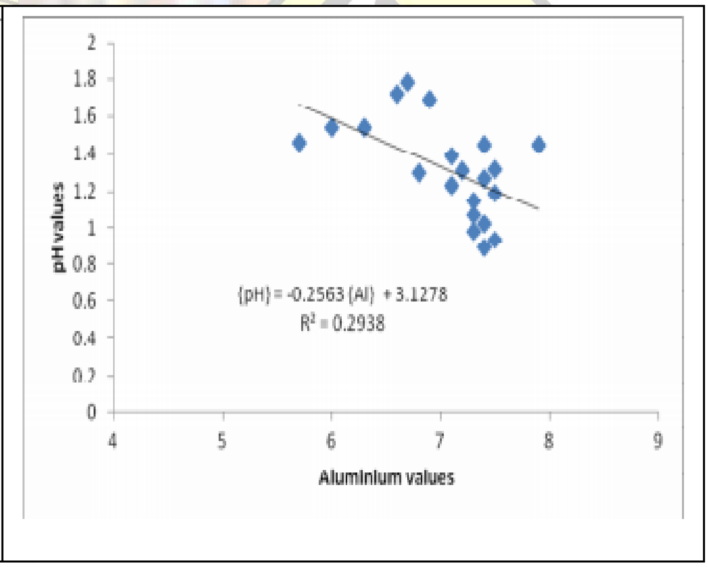


Fig 4. 9 Relationship between Aluminium in Save and Odzi Rivers.

4.11 Nickel levels in water in Save and Odzi Rivers.

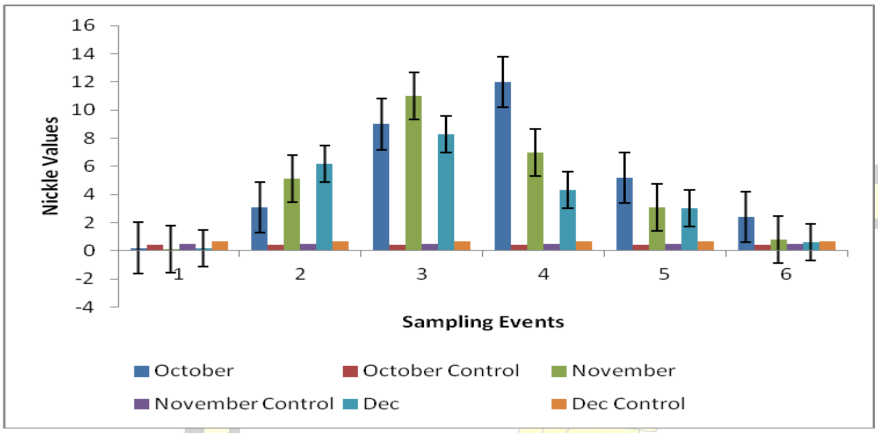
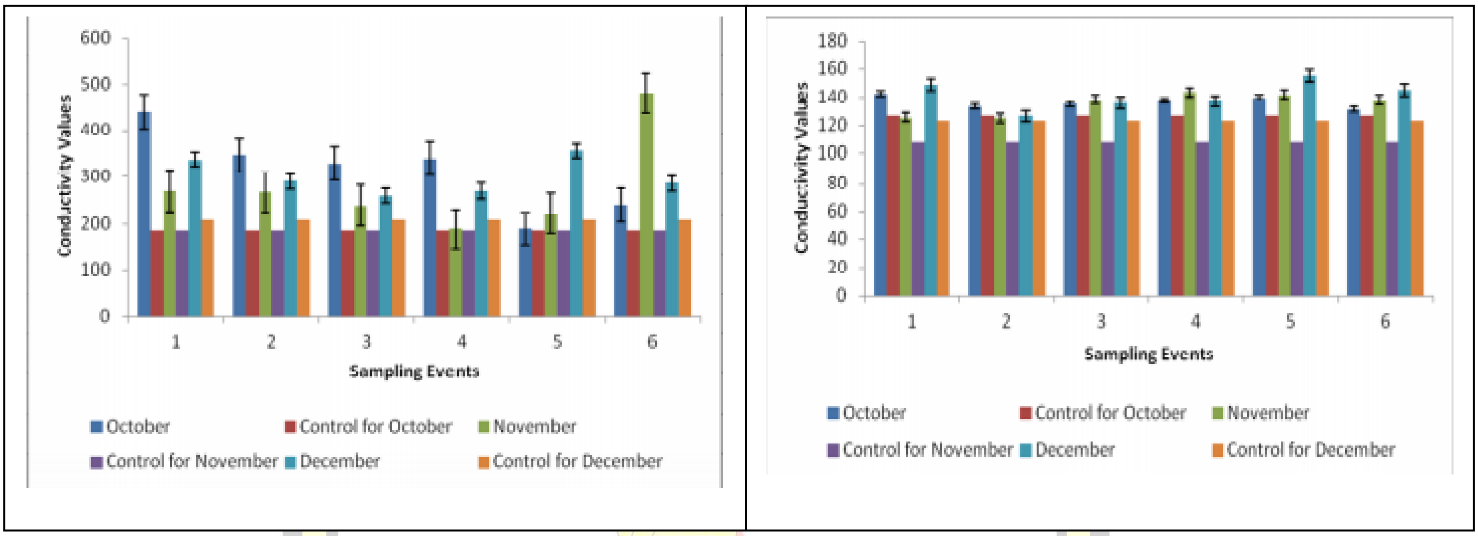


Fig 4.10 Nickel concentrations in Save and Odzi Rivers.

Fig 4.10 shows that were significant in both Rivers. Nickel concentrations were highest at sampling points 1, 2, 3 and 4,in both Rivers and gradually decreases to yellow and green as we go downstream at sampling points 5 and 6 . Thus the 4 sampling sites after the discharge of mine effluent, were all in the Red categories with the exception of few yellow readings. The highest recorded was 11mg/l , which was recorded in November at sampling point 2 (Table 4.2(a) and 4.2(b)) and 4.5 which was recorded in Save River at sampling point 3. The sample results were very high as compared to the ones on sampling point 7. The sampling results of point 7 were all in the blue category according to EMA (S.I 6 of 2007 and WHO water quality standards. Nickel being a constituent of FeSi which is added during diamond processing , the results confirm that diamond mines operating in Chiyadzwa are contaminating both Save and Odzi. This may create a health hazard since Nickel concentrations may put communities around which use water from the two rivers for domestic purpose. Nickel is carcinogenic hence this may result in gene mutation , cancer and miscarriage if consumed to access.

4.12 Conductivity levels in Save and Odzi Rivers



Conductivity Values in Save River

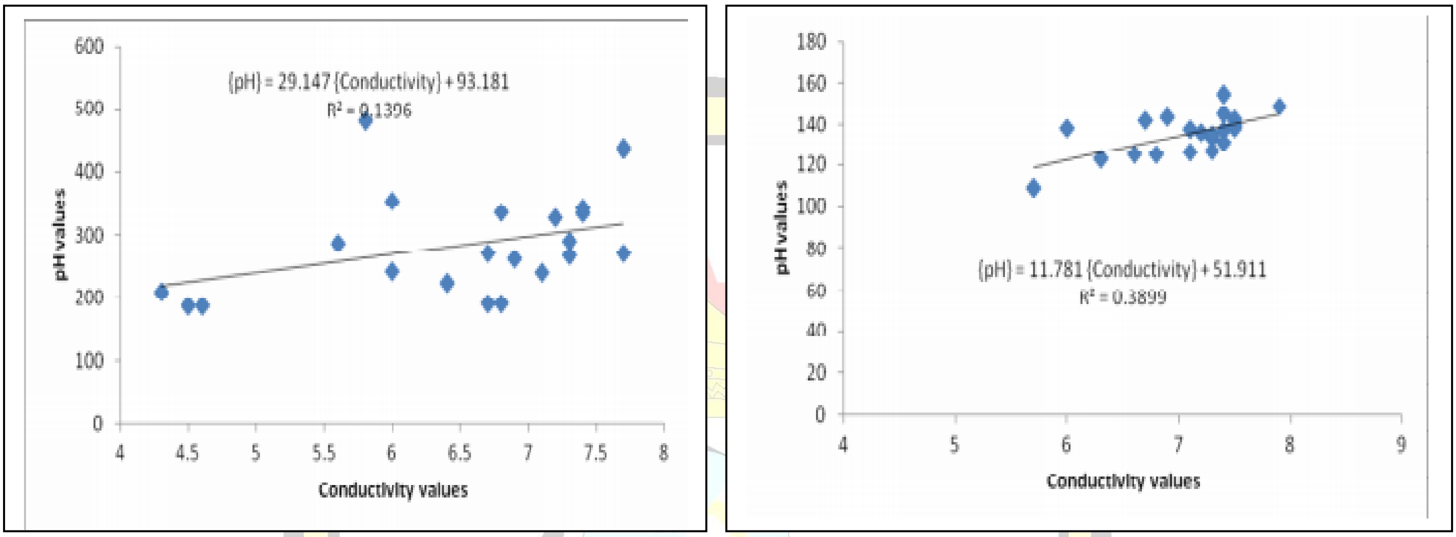
Conductivity Values in Odzi River

Fig 4.11 Conductivity concentrations in Save and Odzi Rivers.

The discharge of effluent into both Save and Odzi Rivers increased the conductivity of water (Fig 4.11). Conductivity values were in the yellow and red catergories for sampling points 1 and 2 ranging from 3500 to 4300 µS/cm on both rivers. The lowwest values were recorded on sampling points 5 and 6 with values below 300 µS/cm in both rivers Fig 4.2(a) and 4.2(b) . Salts which were negatively charged were found in both Rivers. A major increase was noted in October from runoff from all the five operating mines that is DMC, Mbada Diamonds, Marange Resources, Anjini and Jinan. No rains were received during the same period. Temperatures were also high and this increased the concentration of Iron, Aluminium and Manganese as well as pH in the rivers.

The salt charges in water determine the potential difference which is related to higher concentration of salts. (Osmosis Gradient). Studies carried in Diavic show that fish and other aquatic life animals die due to dehydration as a result of high difference in salt concentration in water and the fish bodies. In light of the above too many negatively charged salts in water conduct more electricity charges and these determine potential difference which is related to the higher concentration of salts H^+. Thus there will be high salts in water than in fish resulting in dehydration and death of fish (Wyk,et al 2009).

4.13 Relationship between pH and conductivity in Save and Odzi River.



Relationship: pH and Conductivity Save River   Relationship: pH and conductivity Odzi **River**

Fig 4.12 Relationship between pH and conductivity in Save and Odzi River.

The research study has also shown that there is a positive relationship between conductivity, pH and heavy metal presence in water Fig 4.12. The higher the Fe, Al or Mn the higher the conductivity. Ionic conductivity is a measure of ions dissolved in water measured as electrical resistance between two electrodes. It is also closely related to turbidity.

Research findings has also shown that there is a strong relationship correlation between pH and conductivity (Fig 4.12). The pH levels as skown is influenced by the H^+ availability in a substance hence the more the water is acidic the greater is the availability of the H^+ in water. Thus the R^2 for both Save and Odzi as shown on Fig 4.12 is 0.1396 and 0.3899 respectvely.

4.14 Turbidity concentrations in Save and Odzi Rivers.

Turbidity – Contaminant levels in Save River Turbidity – Contaminant levels in Odzi

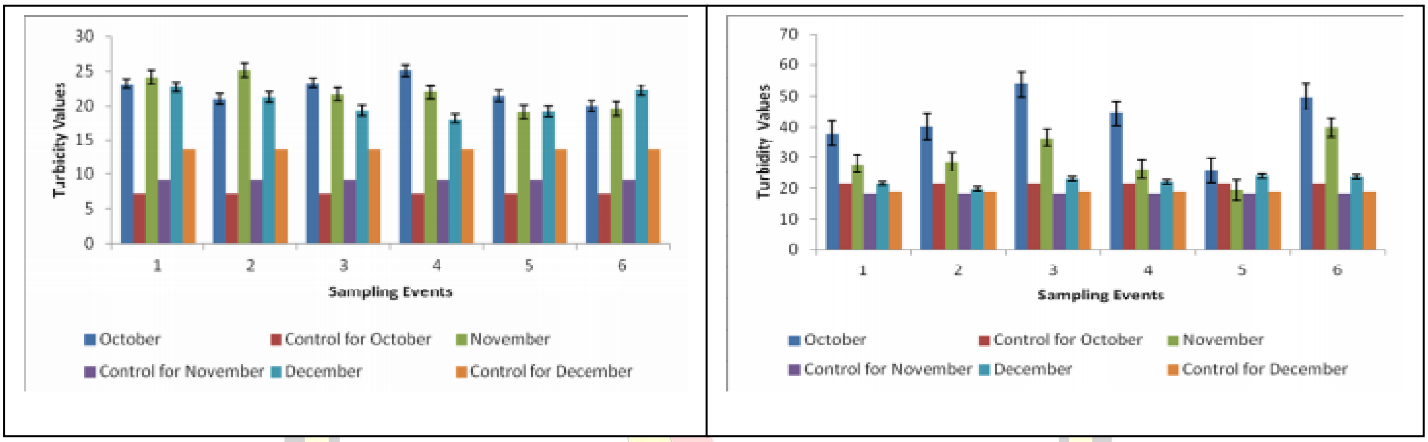


Fig 4.13 Turbidity concentrations in Save and Odzi River.

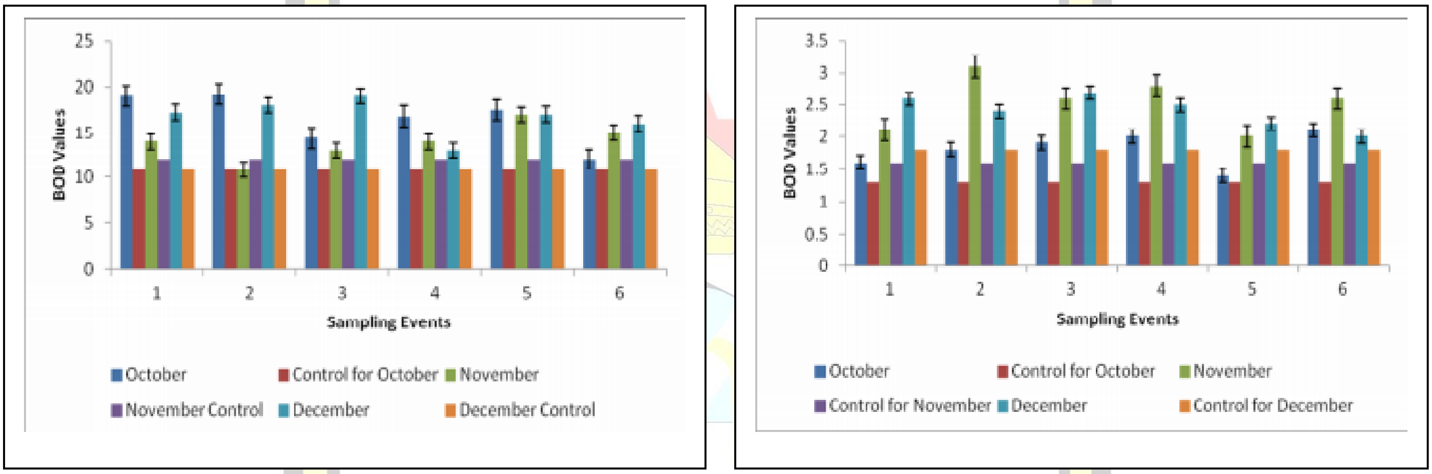
Fig 4,13 shows the turbidity levels in both Save and Odzi Rivers. Downstream of the mining activities the water was red ochre in colour, effectively affecting the health of the river system and ecosystem function. Turbidity which is water clarity was severely affected worse in October, November and December from runoff emanating from the mines. Poor water clarity influences availability of Oxygen in water militating against the respiration of aquatic life for both animals and plants where organisms generate energy through the Kreb cycle.

The water on sampling points 1,2, and 3 were turbid (water was cloudy, opaque, or muddy) because of being of effluent being discharged from DMC, Mbada Diamonds, Marange Resources, Anjin and Jinan mines.

At these sampling points it was evidenced that, livestock and people cannot use the water for drinking and any other domestic uses due to the poor water quality . In Save River effluent is discharged in Makodzi River by Mbada Diamonds and Marange Resources (Plate 4.1) shows effluent discharge from the two mines. The effluent from these two mines feeds into a tributary of Save River called Singwizi River where DMC also heavily discharges just before the point of confluence of the two rivers. The water was very turbid (cloudy, opaque, or muddy) and the river bed was very muddy and sticky.

The control points sampling point 7 were 10km above the mine discharge points. On both points water was clear and this indicated good water quality. All the mines pump clear water upstream for diamond processing and heavily discharge the effluent into the rivers downstream and this shows high level of insensitivity.

4.15 BOD levels in Save and Odzi Rivers



BOD levels in Save River

BOD levels in Odzi River

Fig 4.14 BOD concentrations in Save and Odzi Rivers.

Biological oxygen demand (B.O.D.) is a measure of the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample .The results for B.O.D. as reflected in Fig 4.14 shows that higher values were recorded at sites that were affected by mine drainage (Sites 1 , 2 , 3 and 4), which was indicative of high levels of organic material. This suggests that soils that are washed in the processing stage of diamond extraction, could be contributing to organic loading when they are eventually discharged into the rivers. Several river sites recorded BOD levels of almost >5mg/l which is within the EMA and WHO legal limits .However, sites 1, 2, and 3 and 4 in Save and Odzi Rivers respectively had BOD values of <5mg/l and this indicated oxygen stress or deficits at these sites. These sites which had BOD levels <5mg/l were receiving direct effluent discharge from DMC, Anjin, Marange Resources, Jinani and Mbada Diamonds. Environmental oxygenation is important to the sustainability of a particular ecosystem.

4.16 Relationship between turbidity and BOD in Save and Odzi River.

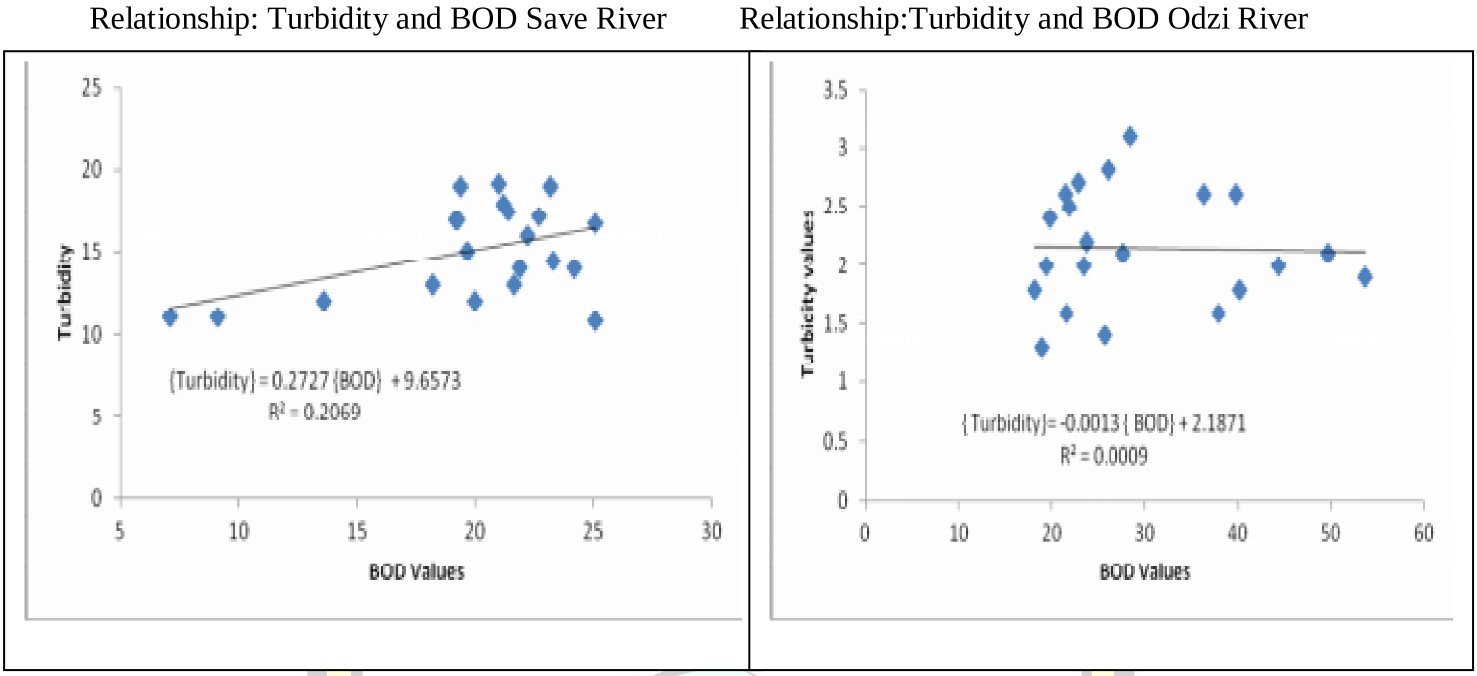

Relationship: Turbidity and BOD Save River Relationship:Turbidity and BOD Odzi River

Fig 4.15 Relationship between turbidity and BOD in Save and Odzi River.

There is a significant relationship between BOD and turbidity. The R^2 values of 0.2069 and 0.009 shows that turbidity significantly influences the BOD of the water. Fig 4 .15 shows that when turbidity increases BOD values also increases . This also shows that, direct inflow of effluent from diamond processing makes the water dirty and turbid as a result this increases the amount of organic components in water. This directly influences the availability of oxygen in the water. Insufficient oxygen (environmental hypoxia) may occur in bodies of water such as rivers, tending to suppress the presence of aerobic organisms such as fish and invertebrates. Deoxygenation increases the relative population of anaerobic organisms. this process alters the ecosystem rendering other species extinct.

The Kreb's cycle occurs in the cell mitochondria for animals and in the chloroplasts of plants. All organisms that use oxygen generate energy through the Kreb's cycle. In other words the process converts carbohydrates fats and proteins into CO_2 and converts H_2O into serviceable energy. The process occurs after gycolysis and oxidative. Oxygen deficiency in water due pollution may result in low BOD in rivers, dams ,lakes and seas. This negatively affect the ability of aquatic animals and plants to produce energy through the Kreb's cycle (Winston,2011).

4.17 COD levels in Save and Odzi Rivers.

COD levels in Save River COD levels in Odzi River

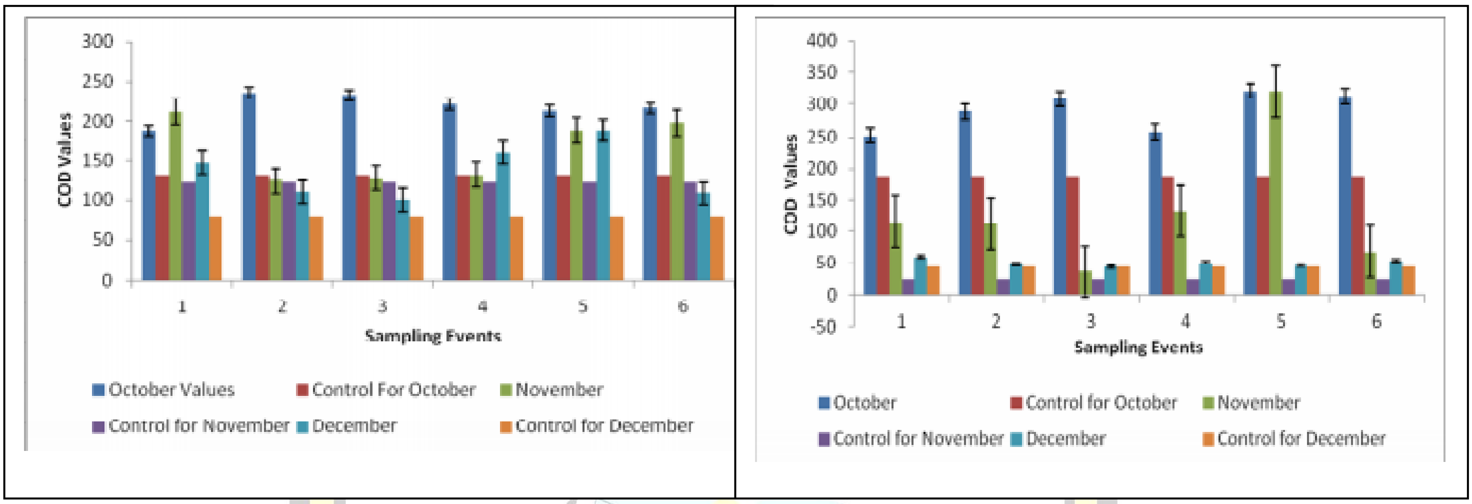


Fig 4. 16 COD concentrations in Save and Odzi Rivers.

The chemical oxygen demand (C.O.D.) is an indirect measure of the amount of organic compounds/pollutants in water. C.O.D is therefore a useful measure of water quality.

The results for C.O.D. showed that sampling points 1, 2 and 3 in both Odzi and Save in October to December had extremely high COD values of 288,336 and 276 mg /l (Save) and 308 , 288 and 252 (Odzi) mg/l Table 4.2 (a-b). All these values were in the red catergory according to WHO and EMA water quality standards (Table 4.2(a) and 4.2(b). All the parameters for sampling points 1, 2, 3, and 4 were either in the yellow or red catergory as compared to the control sampling points which were all in the blue catergory. This indicated direct discharge of chemical organic pollutants into the river from all the five diamond operating mines. Makodzi which subsequently feeds into Singwizi River which feeds into Save River was continuosly flowing with effluent water from Marange Resources, Mbaba Diamonds and DMC. Plate 4.1 shows the water flowing in Singwizi River which feeds into Save River . COD results were mainly in the yellow and red categories as spelt out by S.I 6 of 2007 on all sites directly receiving effluent discharge from DMC, Marange Resources, Anjini, Jinani and Mbada Diamonds see Table 4.2(a) and 4.2(b) showing colour coding according to EMA and WHO standards.

4.18 Relationship between turbidity and COD in Save and Odzi Rivers.

Relationship: Turbidity and COD Save River   Relationship:Turbidity and COD Odzi River

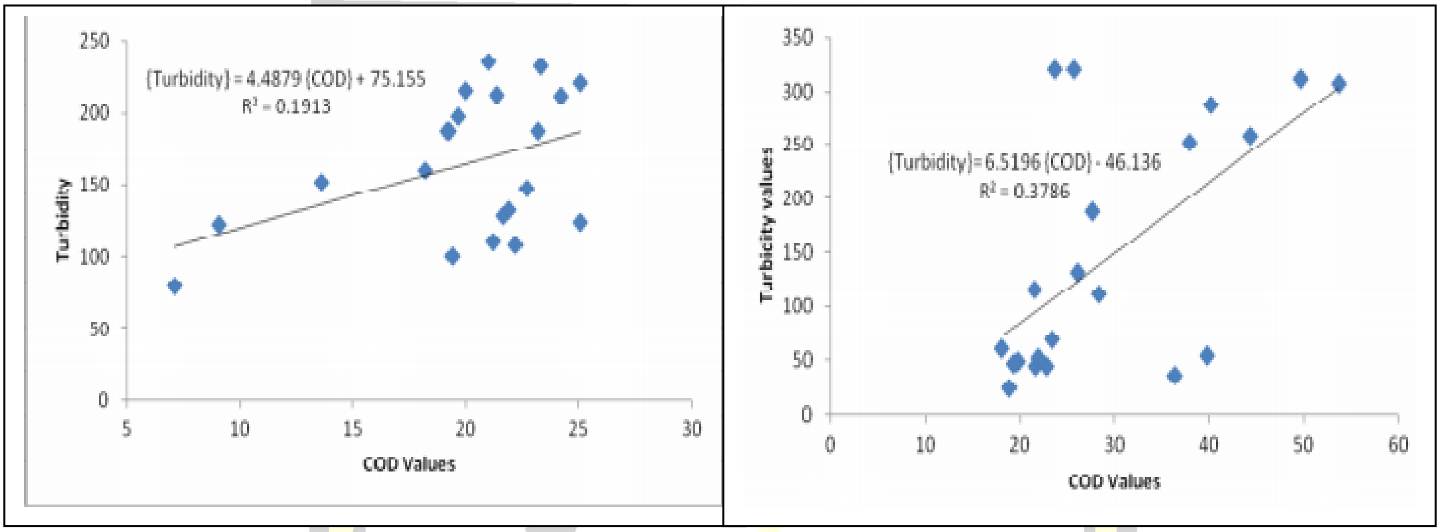


Fig 4.17 Relationship between turbidy and COD.

From the water sample results, of both turbidity and COD , there is a significant correlation betwwen between turbidity and COD as shown in Fg 4.17. The R^2 of 0.1913 and 0.3786 for Save and Odzi Rivers respectively show that the effluent which flows from the five diamond mines carries organic contaminants which causes water to be dirty, turbid as well as contain heavy organic contaminants . This negatively affects the water quality in both Save and Ozi Rivers. This confirms all the stated research objectives. Analysis also confirmed that most of the turbidity in the two Rivers was due to suspended solids. The mud also increased turbidity of the water by affecting its colour. Most of the sampling points failed to meet the required standard by both of W.H.O. and Zimbabwe Effluent standards S.I.106 of 2007, which requires turbidity in water to be less than or equal.

CHAPTER 5 :CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The scientific investigation on the impacts of diamond mining activities on water quality has established major environmental problems which are threatening the might Save and Odzi Rivers in Chiyadzwa Marange. The discharge of mine effluent with significant Ferrosilicon into Save and Odzi has resulted in increased concentration levels of heavy metals mainly Iron , Nickel, Aluminium and Manganese. These heavy metals are the major constituents of FeSi which is added to increase the SG of water at the DMS for diamond separation.

The other problems associated with the discharge of mining effluent into fresh waters were quite significant. These included, COD, BOD, conductivity and turbidity. The runoff effluent made the water dirty and unclear and this subsequently affected the COD and BOD of the water in both Rivers mainly on all points which were within and below the mine discharge areas.

Conductivity and pH were also found to be high mainly due to the, increased concentration of ions and salts in the waters in both Rivers. Notably the high effluent discharge by mines into Save and Odzi Rivers are due to poor water management and slimes dam infrastructure by all the five operating diamond mines. However it is critical to note that if the five operating diamond mines are committed, the above mentioned pollutants are not difficult to harness and meet the WHO and EMA (S.I 6 of 2007) requirements.

5.2 Conclusion

In carrying out this research the following conclusions were made:

The study undertaken has shown a protracted increase in water quality problems in both Save and Odzi Rivers due to the mining operations in Chiyadzwa Marange. Heavy siltation was noticed on both Save and Odzi Rivers as well as the tributaries which feed them These Rivers include Singwizi and Makodzi. Diamond mines have established slimes dams which are poorly constructed on water channels mainly Singwizi and Makodzi. Marange Resources and Anjin have established water catchment ponds which are less than 20 metres from the river banks. These ponds with insignificant water holding capacity are always filled up channelling water in Odzi River. Water from processing plants should be contained on lined slimes dam with significant capacity which matches the production capacity of the processing plants. The slimes dams should also be constructed on appropriate land away from the river channels to enable the mines to contain accidental slimes dam failures.

Another major effluent problem that was clearly identified was that of chemical pollutants (Iron, Nickel, Aluminium, and Manganese) . These pollutants are major constituents of Ferrosilicon which is added at the DMS for diamond separation. Ferrosilicon is not supposed to be discharged into the environment. When operating efficiently Ferrosilicon should be recycled back into the diamond processing system. Remnants of FeSi in the water should be collected by a magnasep and pumped back to the DMS. Loss of Ferrosilicon can account for a drop in the SG of water resulting in process inefficiencies. More so Ferrosilicon is expensive and can also cause irreparable damage to the environment as envisaged. The concentration of these heavy metal which are carcinogenic mainly Nickel, Aluminium and Manganese can cause cancer especially when all were found to be in Red and Yellow categories according to WHO and EMA standards. The mentioned heavy metals also render the water unsuitable for domestic and agricultural purposes.

Notably, the water quality problems in the area have far reaching socio economic problems for the communities around the famous Rivers under review. Diseases and death of animals can cause poverty, loss of life on both people and animals as well as extinction of certain species of animals and plants. The operating mines should contain all the effluent recycle the water for reuse and carryout appropriate social responsibilities and Environmental Management Programmes(EMPs) which will ensure all negative impacts of mining activities are contained to levels permissible by EMA .

Aquatic life is threatened due to increase concentration of BOD, COD, turbidity, iron, Aluminium and Manganese. Due to the high salts and ion concentration in water, the water becomes acidic resulting in the death of fish, frogs, plankton and algae. The loss of these species alters the Save and Odzi ecosystems.

The dirty water due to effluent discharge is also another problem establish during this research. Water turbidity was very poor rendering the water unusable for domestic (washing, bathing and agricultural activities) and other recreational activities like swimming.

5.3 Recommendations

5.3.1Recommendations from the study

The researcher recommends the following to the various stakeholders:

- Construction of standard/ appropriate slimes dams by all the 5 operating mines in Chiyadzwa which are lined to store effluent water from the processing plants. These should be fitted with pizzometers and inspected regularly in accordance with mining and Environmental regulations.
- Environmental Impact Assessment for the slimes dams infrastructure should be carried out by all mines operating and intending to operate in Chiyadzwa, so that the dams are located on appropriate land sites not in valleys or river channels.
- Diamond mines should employ sound water management programmes which encompass cleaner production methods such as water recycling after it has settled in slimes settling ponds.
- Operating diamond mines should construct water treatment plants to remove all pollutants in water before it is discharged into the environment.
- De-mystify diamond mining operations in Chiyadzwa by allowing EMA , Ministry of Mines officials and other legal monitoring agents to operate freely without victimisation and hindrance.
- Diamond mines should undertake progressive rehabilitation of rivers to avert siltation of rivers.
- Water quality tests should be carried out by diamond mining companies so that they monitor their contamination levels. EMA quarterly reports should be send to EMA for review to ensure sound water management programmes are in place.
- Diamond mining companies should harmonise their mining operations, with government policies, environment, social aspects and technology as propounded by Smyth and Dumanski (1996) to ensure socio economic development.

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