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Impacts of land use and land cover changes on the water quality of surface water bodies: Muzvezve Sub-catchment, Zimbabwe

BY

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A thesis submitted in partial fulfillment of the requirements of the Degree of Masters of Science in Integrated Water Resources Management at the University of Zimbabwe

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DECLARATION

I, Felistas Mupedziswa, declare that this research report is my own work. It is being submitted for the Degree of Master of Science in Integrated Water Resources Management (IWRM) at the University of Zimbabwe. It has not been submitted before for examination for any degree at any other University.

Date: ……………………………….

Signature: ………………………………………….

DISCLAIMER

The findings, interpretations and conclusions expressed in this study do neither reflect the views of the University of Zimbabwe, Department of Civil Engineering nor those of the individual members of the MSc Examination Committee, nor of their respective employers.

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DEDICATION

To my loving husband, Ngonidzashe V. Mupedziswa; and to my special daughter Elaine.

ABSTRACT

Many catchments in Southern Africa, including the Muzvezve Subcatchment in the central part of Zimbabwe have been negatively affected by the deterioration of water quality. This study aimed at assessing the impacts of land use and land cover changes on the water quality of Muzvezve River and Claw dam in Zimbabwe. Five sampling campaigns across the wet and dry seasons were conducted from Mid-December 2015 to end of February 2016 at six systematically selected sampling points. Eight physico-chemical parameters including turbidity, electrical conductivity (EC) Total Dissolved Solids (TDS), pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), phosphorus and nitrogen, were analysed using Standard Methods. The biological parameters measured were faecal coliforms and total coliforms. Heavy metals analysed included; Copper, Zinc, Cadmium and Lead. The river water quality was compared to EMA ambient water quality guidelines. Land cover was characterized using the Normalized Difference Vegetation Index (NDVI) and was correlated with selected ground measured parameters of turbidity and TDS. A rapid water quality assessment for Claw Dam was done using remotely sensed and ground measured data. Analysis was conducted within a GIS environment and statistical software. Results showed that, for the measured parameters along the Muzvezve River, most were below the EMA standard guidelines, indicating that the river water quality is fairly good. The parameters which were below the threshold levels include EC, TDS, coliforms, BOD, COD, turbidity, phosphates and coliforms. However, based on WHO standards, the Muzvezve River water is not safe for drinking, without some form of appropriate effective treatment. Agriculture and settlement had no significant effect on water quality ($p > 0.05$). Mining had significant effect ($p < 0.05$) as seen by high zinc and lead especially in the dry season. Results of the NDVI correlation with measured water quality parameters of turbidity and TDS showed that NDVI had a strong and significant positive relationship ($p < 0.05$) with turbidity ($r = 0.998$) and TDS (r ranging from 0.961 to 0.980) in the dry season. From these results, it was concluded that land cover could be used to predict turbidity during the dry season and TDS during the wet season. Turbidity showed positive correlation with the Blue, Red and NIR bands of Landsat 8 imagery. Results, however, showed that Secchi depth and Chlorophyll a correlations were weak. It was concluded that more work needs to be done on testing whether remotely sensed data can be used to estimate water quality in environments similar to the study area.

Key words: Land use, water quality, NDVI

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CHAPTER 1: INTRODUCTION

1.1 Background

Water is a prime natural resource, a basic human need and a precious natural asset (Gupta *et al.*, 2009). However, many rivers have been observed to be negatively affected by the deterioration of water quality. In the current decade, fresh water has become a scarce commodity due to the over exploitation and pollution of water sources (Gupta *et al*., 2009). The quality of a river at any point reflects several major influences, including the lithology of the basin, atmospheric inputs, climatic conditions and anthropogenic inputs (Bricker *et al*., 1995). However, landuse is the primary factor causing poor water quality (Hema and Muthalagi, (2009); Kibena *et al*.(2013)). Thus, understanding the impact of land use on water quality is critical.

According to Ayele (2011) land use refers to a series of operations on land, carried out by humans, with the intention to obtain products and/or benefits. This is obtained through the use of land resources including soil resources and vegetation resources which is part of land cover. In this respect, land use often influences land cover. Majumder (2011) simply defines land cover as the physical or natural state of the Earth's surface. Due to increased intensity of land use, water quality in many rivers have been observed to be deteriorating. For example, studies done on rivers like the Thamalakane-Boteti River in Botswana (Masamba and Mazvimavi, 2008), Mazowe River ((Munuo, 2012) and Manyame River (Chivava, 2015) (both the last two in Zimbabwe) have supported this. Masamba and Mazvimavi (2008) found out that unsustainable landuse is causing land degradation, which in turn degrades the water quality (Kibena *et al*., 2013).

Predominant land uses in Zimbabwe associated with deteriorating water quality include intensive small scale alluvial mining, agriculture and dense settlement patterns. Increased settlements lead to increased load on the waste water treatment plants which results in an increase in untreated sewage disposal into water bodies. For example, Kadoma is abig settlement close to the study area and would contribute to water pollution due to sewer overflows. Although most of the land uses are good in terms of gross domestic product contribution and their contribution to human welfare, they have potential to negatively affect water quality. A study by Alparslan *et al*.(2007), concluded that the uncontrolled urbanization in the vicinity of Omerli lake (Turkey) has led to poor water quality for Istanbul City. Yu *et al*.(2015), also concluded that in the dry season the Wei River basin (China), agricultural land use was strongly correlated with most physico-chemical and nutrient variables. This suggested that agriculture has negative effects on river water quality as a result of intensive fertilization and irrigation during the farming season.

In a study by Chouinard and Veiga (2008), it was indicated that the Kadoma-Chakari area, which lies within Muzvezve Subcatchment, produces about 10% of the country's artisanal small scale mining gold, this is a good statistical representation, but poses a threat to the subcatchment's water resources. Mineral extraction not only decreases the quantity and quality of underground ores, but it critically erodes the quantity and quality of other resources associated with this extraction, including water (Velalmeida *et al.*, 2015). For example, results from the chemical analysis of water samples collected from tributaries of the Manyame river located downstream from four abandoned gold mines in the Beatrice gold belt, indicated the high presence of heavy metals (lead (Pb), nickel (Ni) and zinc (Zn)) in surface water (Ravengai *et al.*, 2005). In a similar study, deterioration in the quality of surface waters has been observed at an iron mine in the Mazowe catchment of Zimbabwe. Water in the Yellow Jacket River was contaminated with copper (Cu), cobalt (Co), iron (Fe), nickel (Ni), sulphate ions (SO_4^{2-}), lead (Pb) and zinc (Zn), (Meck *et al*., 2006). Thus, the development of methods to rapidly monitor the state of water quality in catchments is critical.

The development of remote sensing has improved the prospects of detecting water quality issues over large spatial extents, as well as aid investigations of the catchment factors (Kapalanga, 2015) affecting water quality such as agricultural and mining activities. Several studies have developed and used different prediction models for water quality parameters in different water bodies using satellite spectral bands with several ratios or indices such as NDVI (Alparslan *et al*., 2007; Hansen *et al*., 2015; Ouyang *et al.*, 2009; Pirottia *et al.*, 2014; Salama *et al.*, 2009). These studies have largely found that both physical and chemical water quality parameters change as a result of the impact of land uses (Lobo e*t al.*, 2015; Yu *et al.*, 2015; Zipper *et al.*, 2016).

The present study aimed at describing the physico-chemical properties of Muzvezve River in relation to the land use activities in the subcatchment, and how these vary spatially and temporally (dry and wet season). The relationships between Normalised Difference Vegetation Index (NDVI) and a few selected parameters (turbidity and Total Dissolved Solids (TDS)) were also assessed. A rapid assessment of water quality in Claw dam was done using remote sensing in comparison to a few selected ground measured parameters (turbidity, Secchi depth and chlorophyll a).

1.2 Statement of the problem

Although previous studies have shown that different land uses negatively affect water quality, very few studies in Zimbabwe have been conducted to determine the extent of water quality (Chawira *et al.*, 2013; Kibena *et al.*, 2013; Murwira *et al.*, 2014). The relationship between catchment conditions estimated using Landsat OLI remotely sensed data and to how they correlate with point measured water quality parameters like Total Dissolved Solids (TDS) and turbidity has not been adequately studied. In addition, the use of remotely sensed data to assess the effects of land use on water quality, especially in the developing world is still in its infancy (i.e. less than 10 years) with few studies having used this technology (Chawira *et al.*, 2013; Majozi *et al.*, 2014.; Ndungu, 2014). In this regard, there is need to use remotely sensed data to determine the impacts of different land uses such as settlements, waste municipal water disposal, mining and agriculture including changes in land cover on water quality.

1.3. Main objective

In this study, the main objective was to use Geographic Information Systems (GIS) remotely sensed data and ground based water quality parameters to assess the impacts of land use and land cover dynamics on water quality in Muzvezve sub-catchment, Zimbabwe from December 2015 to March 2016.

1.3.2 Specific Objectives

1. To assess water quality in the Muzvezve River using selected physico-chemical parameters from December 2015 to March 2016
2. To test whether and to what extent the catchment condition estimated using Normalised Difference Vegetation Index (NDVI) relates to selected water quality parameters from December 2015 to March 2016
3. To conduct a rapid water quality assessment for Claw dam using insitu and remote sensing techniques for March 2016

1.4 Justification

Zimbabwe's water resources are under increasing threat of pollution from various anthropogenic sources and activities. Understanding the relationship between land use and water quality is critical, as it helps in the formulation of sound management strategies and policies aimed at reducing the negative impacts of land use on water quality. This is in line with Dublin Principle I, which states that there is need to conserve water since it is a vulnerable and finite resource. Efforts to reduce water pollution have been hampered by lack of adequate water quality data. This study therefore described the physico-chemical and biological properties of the surface water in the subcatchment, and how these vary spatially and temporally according to different land use activities as a step towards strategic water policy development.

The development of science based policies is fundamental to fulfilling Zimbabwe’s obligations to the SADC Protocol on Shared Watercourses. Under this Protocol, individual countries made a commitment to the reduction and monitoring of environmental degradation of the Zambezi River. Therefore, the management of headwater pollution of the Zambezi’s tributaries must be critically considered by Zimbabwe, since it is a signatory to the Protocol.

In addition, good water quality will help the country to achieve environmentally sound management of chemicals and all wastes, so as to significantly reduce their release to water and soil. This helps in the achievement of Sustainable Development Goal 6 (SDG 6), which states the need to reduce pollution, by eliminating dumping and minimizing release of chemicals into surface waters. This also contributes to the fulfilment of the Cluster outputs for Environmental Management under the Zimbabwe Agenda for Sustainable Socio-Economic Transformation (ZimAsset).

This thesis consists of six chapters. Chapter1 gives an introduction to water quality problems in Sothern Africa, associated with land use practices. Also the statement of the problem is clearly outlined and the objectives to this study are given. Chapter 2 gives an insight into literature review, basing on similar previous work which has been done and the findings thereof. Definition of terms used within the study is also done. In Chapter 3, the study area is described, and the maps are shown. Chapter 4 describes the materials which were used to achieve the objectives and the different methods are also clearly explained. Chapter 5 presents the results, and the discussions to all the results are presented basing mostly on literature. Chapter 6 then gives the conclusions and the suggested recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter explains the background related to previous studies on land use activities and how these affect water quality. Artisanal mining, municipal activities, agriculture and settlements effects on water quality will be reviewed from literature. Physico-chemical parameters for water quality will be defined and explained in detail. The water quality standards used in Zimbabwe for ambient surface water quality will also be indicated, and in this study the Environmental Management Agency (EMA) and Environmental Protection Agency (EPA) guidelines were used. In conclusion, the role of GIS in the determination of water quality will also be reviewed from literature.

2.2 Land Use and Land Cover (LULC)

According to Ayele (2011), land cover refers to the vegetation (natural and planted), water, bare rock, sand and similar surface and man-made constructions occurring on the earth’s surface. However, land use refers to a series of operations on land, carried out by humans, with the intention to obtain products and/or benefits. This is obtained through the use of land resources including soil resources and vegetation resources which is part of land cover. In this respect, land use often influences land cover.

The above description is similar to that made by Majumder (2011), who defines land use as the manner in which human beings employ the land and its resources, and land cover as the physical or natural state of the earth’s surface. The author further goes on to explain that, information on current LULC is essential for the development and implementation of programs for further land use, and can be used to manage the ever increasing demands for basic human needs and welfare.

Changes in land cover by land uses do not essentially translate to degradation of the land. However, due to the alteration of land use patterns, land cover changes have been negatively impacted thereby affecting biodiversity, water and other processes that subsequently affect climate and the environment (Majumder, 2011). This assertion has also been supported by a study conducted by Masamba and Mazvimavi (2008) in Botswana to determine the effects of human activities within and around an urban village on the water quality of the Thamalakane-Boteti River which drains from the Okavango Delta. Masamba and Mazvimavi (2008) found out that unsustainable landuse is causing land degradation, which in turn degrades the water quality (Kibena *et al*., 2013).

2.3 Impacts of different land uses in Muzvezve Subcatchment

Land use refers to a series of operations on land, carried out by humans, with the intention to obtain products and/or benefits (Ayele, 2011). Numerous studies have attempted to identify the linkage between land use surrounding rivers and water quality. Most of related studies focused on three scales which were basin, sub-basin and riparian scales. The linkage between land use and water quality in different scales were inconsistent (Allan, 2004; Bu and Meng, 2014; Hurley and Mazumder, 2013; Johnson and Gage, 1997).

2.3.1 Artisanal small-scale gold mining (ASGM)

Small-scale mining is commonly associated with informal, unregulated, under-capitalized and under-equipped mining operations, where technical and management skills are lacking. These techniques make ASGM an activity with high negative environmental impacts, mainly mercury pollution and land degradation (Saldarriaga-Isaza *et al.*, 2013).

Zimbabwe experienced an upsurge in artisanal gold mining in the 1990s, largely as a result of the deteriorating agricultural sector and the layoff of public sector workers, following the implementation of a series of Structural Adjustment Programs (Spiegel, 2009). The Global Mercury Project (GMP) identified Kadoma-Chakari region as having the highest population of artisanal and small-scale miners in Zimbabwe (approximately 20,000). The Project documented the widespread use of mercury during gold processing (Billaud *et al*., 2004).

Surface mining disturbs geologic strata and soils, exposing disturbed materials to atmospheric oxygen and rainfall. As a consequence, it often enables accelerated chemical weathering that releases soluble constituents that enter surface waters (Hurley and Mazumder, 2013). Some observable evidence of river pollution includes siltation and colouration, from panning, which is often carried out along and within river profiles.

For example, deterioration in the quality of surface waters has been observed at an iron mine in the Mazowe catchment of Zimbabwe. Water in the Yellow Jacket River was contaminated with iron (Fe), nickel (Ni), copper (Cu), cobalt (Co), lead (Pb), zinc (Zn), and sulphate ions (SO_4^{2-}) (Meck *et al.*, 2006). It has also been noted that Zimbabwe gold mining discharges many metals and metalloids, and is predominantly associated with high level arsenic, zinc, copper and nickel discharges (Ravengai *et al*., 2005).

In addition to the water quality problem, the land cover in Muzvezve Subcatchment has also changed due to mining and other activities. After the ore from mining is crushed and panned, waste rock is dumped into heaps as tailings. As a result, mining in Muzvezve area has also left behind dredged out and contaminated streams, disturbed vegetation and littered landscapes and open trenches which fill up with water. Poisonous compounds and heavy metals previously locked in the undisturbed strata and minerals are often leaked to the environment, inhibiting plant growth (Velalmeida *et al.*, 2015).

Mining affects the ecosystem and the aesthetics of the landscape. For example, in a study carried out in Lower Lusatia (Brandenburg, Germany), it was observed that the extensive mining of coal has permanently changed the ecosystem, land use potential and the attractiveness of the landscape. Furthermore, mining leaves behind damage stretching over large areas. A complex relationship exists between disturbance and heterogeneity in a landscape. The extent of this relationship depends on the degree of disturbance and underlying environmental factors (Antwi *et al.*, 2008). This has also been the case in Muzvezve subcatchment.

2.3.2 Municipal activities in Muzvezve Subcatchment

The aquatic environment is the ultimate sink of wastewater generated by man's industrial, commercial and domestic activities. Nearly 800 million litres per day of untreated wastewater finds its way into rivers and lakes the world over (Metcalf. and Eddy., 2004). Population growth has led to the overloading of sewage treatment plants which have not been expanded to cater for this increase (Mathuthu, 2005). Consequently the effluent quality being discharged has also deteriorated. As noted by Gondo (2013), with the ever increasing rates of unemployment, most residents in major towns have resorted to backyard industries for which the monitoring of wastewater is difficult to implement. This results in significant impacts on the surface water pollution in these settlements.

2.3.3 Agricultural activities in Muzvezve Subcatchment

Studies done by some researchers have shown that farmers' use of fertilisers and other agricultural chemicals affect the water quality of major rivers. This is supported by studies done for Upper Manyame River (Gumbo and Savenije, 2001; Kibena et al., 2013; Magadza, 1997).

Kibena *et al.* (2013) mentions that the general recommendation by EMA in Zimbabwe is that all cultivation activities should be done at least 30 m from a stream. The author then suggests reasons as to why few communities adhere to this regulation. She suggested that this is mainly because of the increased pressure for land in recent years. She also noted that there is lack of strict monitoring of the activities that are happening within the propinquity of the catchment area, and this has led to increased rate of siltation and water quality impairment of the rivers.

In addition, a study done by Yu *et al*. (2015), concluded that in the dry season the Wei River basin (China), agricultural land use was strongly correlated with most physico-chemical and nutrient variables, which suggested that agriculture has negative effects on river water quality because of intensive fertilization and irrigation during the farming season.

2.3.4 Settlements in Muzvezve Subcatchment

A study done by Alparslan *et al.*(2007) concluded that the uncontrolled urbanization in the vicinity of Omerli lake (Turkey) is deteriorating the water quality of this vital potable source of Istanbul City and measures should be taken to improve the water quality. Surface water is more vulnerable to pollution than groundwater. A study for groundwater pollution potential showed that the presence and increase of unplanned settlements with high- population density has led to the increase in the use of pit-latrines. Dzwairo *et al.*(2006), concluded that pit latrines microbiologically impact on groundwater quality which is within 25 m lateral distance, and that shallow water tables increased pollution potential from pit latrines. A similar study in Epworth high density area (Zimbabwe, Harare) done by Zingoni *et al.*(2005), also showed significantly elevated levels of nitrates (20-30 mg/l) and coliform bacteria (>10,000 cfu) in most parts of the settlement. If this can be said for groundwater resources, then for surface waters, the vulnerability of water quality from settlements can be fatal.

2.4 Water Quality

Water quality is a term used to describe the chemical, physical and biological characteristics of water in relation to all other hydrological properties, usually in respect to its suitability for a particular purpose. Any characteristic of the water that affects its potability and the survival, reproduction, growth and production of aquaculture species or that, affects management decisions or causes environmental impacts, can be also termed a water quality variable or parameter (Oyhakilome *et al*., 2012).

2.5 Physico-chemical Parameters

Physico-chemical parameters which include, turbidity, electrical conductivity (EC), Total Dissolved Solids (TDS), pH, Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), are going to be discussed in detail. Nutrients such as phosphorus and nitrogen will also be reviewed from literature, as well as and heavy metals

2.5.1 Turbidity

According to Clesceri *et al.*(1999) turbidity is a measure of the clarity of water or is an optical property of water based on the amount of light reflected by suspended particles. It is measured in

Nephlometric Turbidity Units (NTU). Turbidity is caused by the occurrence of suspended matter such as clay, silt, colloidal organic particles, plankton and other microscopic organisms (Clesceri *et al.*, 1999). Turbidity is exacerbated by deforestation activities which make soil prone to erosive agents with the resultant surface runoff being loaded with suspended sediments, which are then deposited into water bodies.

High turbidity results in reduced light transmission into the water, thus depriving aquatic organisms of light. Invertebrates may suffer from clogging of their breathing systems, suspended sediments can damage the gills of some fish, causing them to suffocate, thus limiting their ability to find food (EPA, 2001).

2.5.2 Electrical Conductivity (EC)

Electrical conductivity (EC) is the measure of water's capability to pass electrical flow. The standard units for freshwater measurements are Micro Siemens per centimetre (μS/cm). EC's ability is directly related to the concentration of ions found within the water (Kemker, 2014). According to Clesceri *et al* (1999) the conductivity of water depends on the quantity of dissolved salts present and for dilute solutions it is approximately proportional to the total dissolved solid content. The greater the number of ions that are present, the higher the conductivity of water thus sea water has high EC.

2.5.3 Total Dissolved Solids (TDS)

The term total dissolved solids (TDS) refers to all the constituents dissolved in water (Norliyana, 2009). TDS refers to any minerals, salts, metals, cations or anions dissolved in water. Hence the term TDS is often used interchangeably with salinity (Norliyana, 2009).

Dissolved solids are important to aquatic life by keeping cell density balanced. In distilled or deionized water, water will flow into an organism's cells, causing them to swell. In water with a very high TDS concentration, cells will shrink. These changes can affect an organism's ability to move in a water column, causing it to float or sink beyond its normal range (EPA, 2012). However, depending on the ionic properties, excessive TDS can produce toxic effects on fish and fish eggs. For example, salmonids exposed to higher than average levels of $CaSO_4$ at various life stages experience reduced survival and reproduction rates (Kemker, 2014).

High EC and TDS values are good indicators of possible water pollution sites in water quality determination. According to WHO (2008), freshwater has TDS values lower than 1000 mg/l, while salty water has TDS values ranging from 1,000 to 10, 000 mg/l. The EC in freshwater ranges from 500 to 1,500 µS/cm.

2.5.4 pH and Alkalinity

pH is the potential of Hydrogen. It is a measure of the degree of acidity and alkalinity of a solution or water; this is influenced by the concentration of the hydrogen ion [H^+]. On the pH scale of 0-14, a pH of 7 indicates neutral condition and values above and below this denote alkalinity and acidity respectively (Kaur and Sing, 2011).

Several processes in natural waters are considerably influenced by changes in pH. For example, the surface charges of colloids in natural waters and hence their ability to coalesce or sorb ions, will be determined by the hydronium ion concentration (OH^-); as will the solubility and speciation of dissolved ions. Most fresh water bodies have pH typically ranging between 6.5 and 7.5 (Oyhakilome *et al*., 2012). At pH values between 6.7 and 8.6, aquatic environments are well balanced (WHO, 2008). However, at pH values less than 5 or more than 9, most aquatic species are affected. For example, corrosion effects may become significant below a pH of 6.5, and the frequency of incrustation and scaling problems may be increased at pH values above 8.5 (Oyhakilome *et al*., 2012).

Alkalinity is the name given to the quantitative capacity of an aqueous solution to neutralize an acid (Kaur and Sing, 2011). Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. The alkalinity of natural water is influenced by the soil and substratum through which it passes as it moves through the hydrological cycle. The major sources for natural alkalinity are rocks which contain carbonate, bicarbonate and hydroxide compounds. Phosphates, borates and silicates may also contribute to alkalinity (Kemker, 2014). Limestone is rich in carbonates, so that waters flowing through limestone regions or bedrock containing carbonates generally have high alkalinity, hence good buffering capacities.

Meck *et al.*(2006) noted that low pH values increase the solubilities of heavy metal compounds, which in turn increases contamination of the environment. Additionally, acid mine drainage affects pH, resulting in reduced acid neutralizing capacity and lower pH. Meck *et al.*(2006) further went on to point out that, at pH values less than 7.0, corrosion of water pipes may occur, releasing metals into drinking water. Corrosion can be toxic and may pose health problems if concentrations of such metals exceed recommended limits.

2.5.5 Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

Biological oxygen demand is the amount of oxygen to be used in the breakdown of waste. It is an indirect measure of waste. BOD determination is an empirical test in which standardized laboratory procedures are used to determine the relative oxygen requirements of wastewater, effluent, and polluted waters. The test has its widest application in measuring waste loadings to treatment plants and in evaluating the BOD-removal efficiency of such treatment systems (Clesceri *et al*., 1999).

COD is a measure of the oxygen equivalent content of a given waste by using a chemical to oxidize the organic content of the waste. The higher the equivalent oxygen content of the water or waste, the higher the COD, and resultantly the greater it's polluting potential. The COD test has higher oxygen values than those of BOD_5 test, because more oxygen equivalents can be oxidised by the chemical than can be oxidized by the microorganisms (Sincero and Sincero, 2002).

2.6 Nutrients

The main nutrients that will be discussed are phosphates and nitrogen. Unlike temperature and dissolved oxygen, the presence of normal levels of nutrients usually does not have a direct effect on aquatic insects or fish. However, excess levels of nutrients in water can create conditions that make it difficult for aquatic insects or fish to survive. The process through which there is dissolved nutrients enrichment of a water body that encourages the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen is termed eutrophication (EPA, 2001). As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water body of available oxygen, compromising the survival of other organisms, for instance fish (Kaur and Sing, 2011).

2.6.1 Phosphates

Phosphorus occurs widely in nature, and is mainly in the form of phosphates. Phosphates exist in three forms: orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate. Each type of compound contains phosphorous in a different chemical form and arrangement. Orthophosphate forms are produced by natural processes, but major man-influenced sources include partially treated and untreated sewage and runoff from agricultural sites (Mathuthu, 2005). Organic phosphate is the phosphate that is bound or tied up in plant tissue; after decomposition, this phosphate can be converted to orthophosphate (Islama *et al.*, 2015). Polyphosphate forms are used in detergents. In water, polyphosphates are transformed into orthophosphate and may then be available for plant uptake. Orthophosphate is readily available to the biological community and typically found in very low concentrations in unpolluted waters (Mathuthu, 2005).

The significance of phosphorus in water is principally with regard to the phenomenon of the eutrophication of lakes along with nitrogen as nitrate. As phosphates increase and the growth of aquatic plants is encouraged, algal blooms can occur. With the increase in algae growth and decomposition, the dissolved oxygen levels will decrease (Oyhakilome *et al.*, 2012).

2.6.2 Nitrogen

Nitrogen is naturally found abundantly in the atmosphere, and is also introduced through anthropogenic activities. For example, chemical fertilizers and animal manure are commonly applied to crops to add nutrients. Runoff can carry these impurities into nearby water bodies. Ineffective wastewater-treatment plants also contribute towards high levels of nitrogen in surface or groundwater (M.P.C.A., 2008).

Excessive growth of aquatic plants and algae from excessive nitrogen enrichment can block water intakes, use up dissolved oxygen as they decompose, and obstruct the penetration of light to deeper waters. Severe nuisance algal blooms yield unpleasant odour and reduce the aesthetic appeal of lakes. This may result in declines in fishing and swimming activities. Too much nitrogen in the form of nitrate can result in restriction of oxygen transportation in the bloodstream. Infants under 4 months of age, lack the enzyme required to correct this condition ("blue baby syndrome") (M.P.C.A., 2008).

2.7 Heavy metals

Historically, mining belts (i.e. zones where mining has been taking place for long periods of time) tend to be associated with major environmental problems. Some metals occur in high concentrations along mining belts and tend to release substantial loadings of metals from both mined areas of the belt and also unmined areas. From the unmined areas, metals are released by natural rock–water interaction processes (Kimball *et al*., 2002).

The mining of gold in Zimbabwe takes place in Archaean greenstone belts, which are scattered throughout the country. Gold reefs are sulphide-bearing, and therefore the extraction of gold is related to the exposure of the sulphides to surface conditions, where acid mine drainage occurs. The oxidation of sulphide minerals such as pyrite (FeS_2), pyrhotite (FeS), marcasite (FeS_2), galena (PbS), sphalerite (ZnS), arsenopyrite ($FeAsS$), and chalcopyrite ($CuFeS_2$) leads to heavy metals concentration. For example, in one of the iron mines in Mazowe Subcatchment, when FeS_2 is exposed to Oxygen and water it oxidizes to sulphuric acid and ferrous hydroxide as indicated in Equation 2.1:

$$2FeS_2 + 6H_2O + 7O_2 \rightarrow 4H_2SO_4 + 2Fe(OH)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2.1}$$

The strong acidic property of the water comes from sulphuric acid, whereas ferrous hydroxide is responsible for the jelly-like yellowish orange colouration to the Yellow Jacket river water. Sulphide minerals are then broken down by sulphuric acid to release metals such as Pb, As, Cd, Cu, Zn, Ni (Ravengai *et al*., 2005).

Additionally, a study done for Owena dam (Nigeria) by Oyhakilome *et al*.(2012) showed that higher metal concentrations were observed in the dry season than in the wet season. This trend could be attributed to local concentration of metals via water evaporation from water body during the dry season and also differences in individual metal solubility, pH and leaching by acidic rain during the wet season.

2.8 Water quality standards

Water quality is most frequently used with reference to a set of standards against which compliance can be assessed. Ambient Water Quality (AWQ) monitoring seeks to make a measurement of the pristine conditions of water bodies. The term ambient refers to the immediate, undisturbed surroundings of the environment (EMA, n.d). Table 2.1 and 2.2 shows Environmental Protection Agency and Zimbabwean Environmental Management Agency guidelines respectively which were used in this study. The values attributed to water quality parameters can be used to describe the pollution status of the source (Oyhakilome *et al*., 2012).

Table 2.1: Ambient WQ standards for selected parameters (EPA, 2001)

Examples of Parameters	Units	Non/slightly polluted	Lightly polluted	Moderately polluted	Severely polluted
Total Dissolved Solids	mg/l	0-0.25	-	-	>150
Biological Oxygen Demand	mg/l	<3	3-4.9	5-15	>15
pH	no units	6.5-9	6.5-6.3	6.3-6.0	6.0-5.3

2.8.1 Current Legislation on wastewater in Zimbabwe

Zimbabwe’s existing legislation as enshrined in the Environmental Management Act (Chapter 20:27) states that pollution is an offence that is punishable by the law. The penalty for the offence may be in the form of a fine, imprisonment or both. It also states that any individual or organisation desiring to dispose of wastewater into a public water body (surface or underground water) should apply for a license/permit from the Water Pollution Control Unit of EMA, which approves or rejects such disposal. EMA generally requires individuals or organisations to take certain measures or steps in order to prevent pollution. It regulates effluent quality standards using a scale that comprises four categories (Table 2.2), namely: Blue (environmentally friendly), Green (low hazard), Yellow (medium hazard) and Red (high hazard).

Table 2.2: Environmental Management Agency (EMA) Effluent Guidelines (EMA, 2007)

Parameter	**Units**	**Blue**		**Green**	**Yellow**	**Red**
		Sensitive	Normal			
Turbidity	NTU	<5	<5			
Conductivity	µS/cm	<200	≥200<1000	≥1000<2000	≥2000<3000	≥3000<3500
Total Dissolved Solids	mg/l	<100	≥100<500	≥500<1500	≥1500<2000	≥2000<3000
pH	no units	6.0-7.5	6-9	5-6 or 9-10	4-5or 10-12	0-4or 12-14
BOD	mg/l	<15	≥15<30	≥30<50	≥50<100	≥100<120
COD	mg/l	<30	≥30<60	≥60<90	≥90<150	≥150<200
Phosphates	mg/l	<0.5	<0.5	<1.5	≥1.5<3	≥3<5
Faecal coliforms	no./100ml	<1000	<1000	<1000	≥1000<1500	≥1500<2000
Total heavy metals	mg/l	<1.0	≥1.0<2.0	≥2.0<4	≥4<10	≥10<20
Copper	mg/l	<1.0	<1.0	≥1.0<2.0	≥2.0<3.0	≥3<5
Lead	mg/l	<0.05	<0.05	≥0.05<0.1	≥0.1<0.2	≥0.2<0.5
Zinc	mg/l	<0.3	≥0.3<0.5	≥0.5<4	≥4<5	≥5<15

2.9 Determination of water quality

Traditional in situ water quality measurements had spatial and temporal limitations, which made it difficult to describe the spatial distribution of parameters like chlorophyll a concentration in a certain water body. The technological advancements which now make use of GIS in estimating water quality, offer three substantial advantages over ground sampling. Firstly, the near-continuous spatial coverage of satellite imagery allows for synoptic estimates over large areas. Secondly, it allows the assessment of water quality in remote and inaccessible areas. Thirdly, the long record of archived imagery allows approximation of historical water quality. However, there are also vital drawbacks of satellite estimates which include: their potential to distinguish among the various constituents of the water is limited. Also, the depth of sampling is restricted to the surface only. While each of these approaches can be used alone, the combination of ground and satellite estimations is often the most effective approach (Hellwegera *et al*., 2004).

2.9.1 Use of remote sensing in the determination of dam water quality

The basis of remote sensing is that the backscattering characteristics of surface water are significantly affected by substances present within it. Optical wavelengths are used to measure different water quality parameters. Remote sensing techniques depend on the ability to measure the changes in the spectral signature backscattered from water and relate these measured changes by empirical or analytical models to a water quality parameter. Major factors affecting water quality in water bodies are suspended sediments (turbidity), algae (chlorophylls, carotenoids), chemicals (nutrients, pesticides and metals), dissolved organic matter, thermal releases, aquatic vascular plants, pathogens, and oils. However, chemicals do not directly affect the spectral properties of surface water therefore they are usually inferred from other measurements (Ritchie *et al*., 2003).

Some of the studies done (Alparslan *et al*., 2007; Hansen *et al*., 2015; Ouyang *et al*., 2009; Pirottia *et al*., 2014; Salama *et al.*, 2009) have developed and used different prediction models for water quality parameters in different water bodies using satellite spectral bands with several ratios or indices such as NDVI. The water quality parameters included chlorophyll-a, suspended matter and turbidity (Hansen *et al.*, 2015) as they most likely change the water color. A few studies by (Alparslan *et al.*, 2007; Ouyang *et al*., 2009), have attempted to monitor and model nutrient (such as total nitrogen, phosphorus and nitrates). This is because these models do not yield results as statistically strong or consistent as constituents that have optical properties such as chlorophyll-a, turbidity and colored organic matter, although remote sensing has the ability to make these predictions (Kapalanga, 2015). The best correlations were found mainly in the visible (Red, Green, Blue) and near infrared spectral range (Alparslan *et al*., 2007).

For example, it is important to estimate chlorophyll a concentration in monitoring water quality, because it is a key indicator of phytoplankton biomass. Phytoplankton biomass is an important bio-physical characteristic that is commonly used to assess the eutrophic status of water bodies. Chlorophyll a photoactive pigments, cause distinct color changes of water by absorbing and scattering the light incident on water. Remotely sensed spectral reflectance data can estimate chlorophyll a by relating optical changes observed in the reflected light at specific wavelengths to the concentration of chlorophyll a (Moses *et al*., 2009).

Predicting water quality characteristics from remote sensing requires ground truthing and validation (Blake *et al*., 2013.). In Zimbabwe, several studies have been done to this effect. For example, technical reports have been produced on the assessment of surface water resources to evaluate whether satellite-derived estimates of water quality and quantity are consistent with ground based observations (Murwira *et al*., 2014). It is also recommended that field measurements and satellite overpass should coincide or be within a time window of ±7 days (Sriwongsitanon *et al*., 2011). Cloud cover is important in the use of satellite imagery because it affects the reflectivity of objects on the surface, thus being detrimental to image usefulness and visibility.

2.10 Relationship between Normalized Difference Vegetation Indices (NDVI) and water quality

Spectral vegetation indices are an algebraic combination of reflectance values from different wavelength bands to produce a single value. Ratio images are enhancements resulting from the division of digital number values in one spectral band by the corresponding values in another band. Vegetation indices amongst other approaches have been reliable in monitoring vegetation change, which can then be related to water quality (Campbell, 1987).

The Normalized Difference Vegetation Index (NDVI) is a measure of the amount and vigor of vegetation at the surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. In general, higher values of NDVI indicate greater vigor and amounts of vegetation. The importance of NDVI comes from the fact that it gives information about primary production (vegetation) over time (Pirottia *et al*., 2014).

$$NDVI = (\text{Near Infrared band} - \text{Red band}) / (\text{Near Infrared band} + \text{Red band}) \ldots\ldots \text{Equation 2.2}$$

NDVI values range from -1.0 to 1.0. NDVI values between -1.0 and 0 represents non- vegetative features such as bare surface, built- up area and water body. On the contrary, values greater than 0 show vegetation covers (Chivava, 2015; Murwira *et al*., 2014; Pirottia *et al*., 2014).

NDVI is typically used because vegetation differential absorbs visible incident solar radiant and reflects much in the Near Infrared (NIR), data on vegetation biophysical characteristics can be derived from visible and NIR and Mid- Infrared portions of the electromagnetic spectrum (EMS). The NDVI approach is based on the fact that healthy vegetation has low reflectance in the visible portion of the EMS due to chlorophyll and other pigment absorption and has high reflectance in the NIR because of the internal reflectance by the mesophyll spongy tissue of green leaf (Campbell, 1987).

In summary, the land use/land cover pattern of a region is a result of natural and socio– economic factors and their utilization by man both spatially and temporally. Little changes in LULC can considerably alter the water quality in that area. However, the use of GIS techniques can help in the monitoring of water quality.

CHAPTER 3: STUDY AREA

3.1 Description of the study area

3.1.1 Location

Muzvezve subcatchment is part of the Sanyati catchment which is one of the seven hydrological catchments in Zimbabwe. Muzvezve Subcatchment is found in Mashonaland West province of Zimbabwe. It lies between longitudes of 29.574 and latitudes of 30.751 ^{0}E and 18.369 and 18.552 ^{0}S. The main areas covered in this sub-catchment are Kadoma and part of Mhondoro. The catchment area is 3,271 square kilometres. Figure 3.1 shows the study area map of Muzvezve Subcatchment.

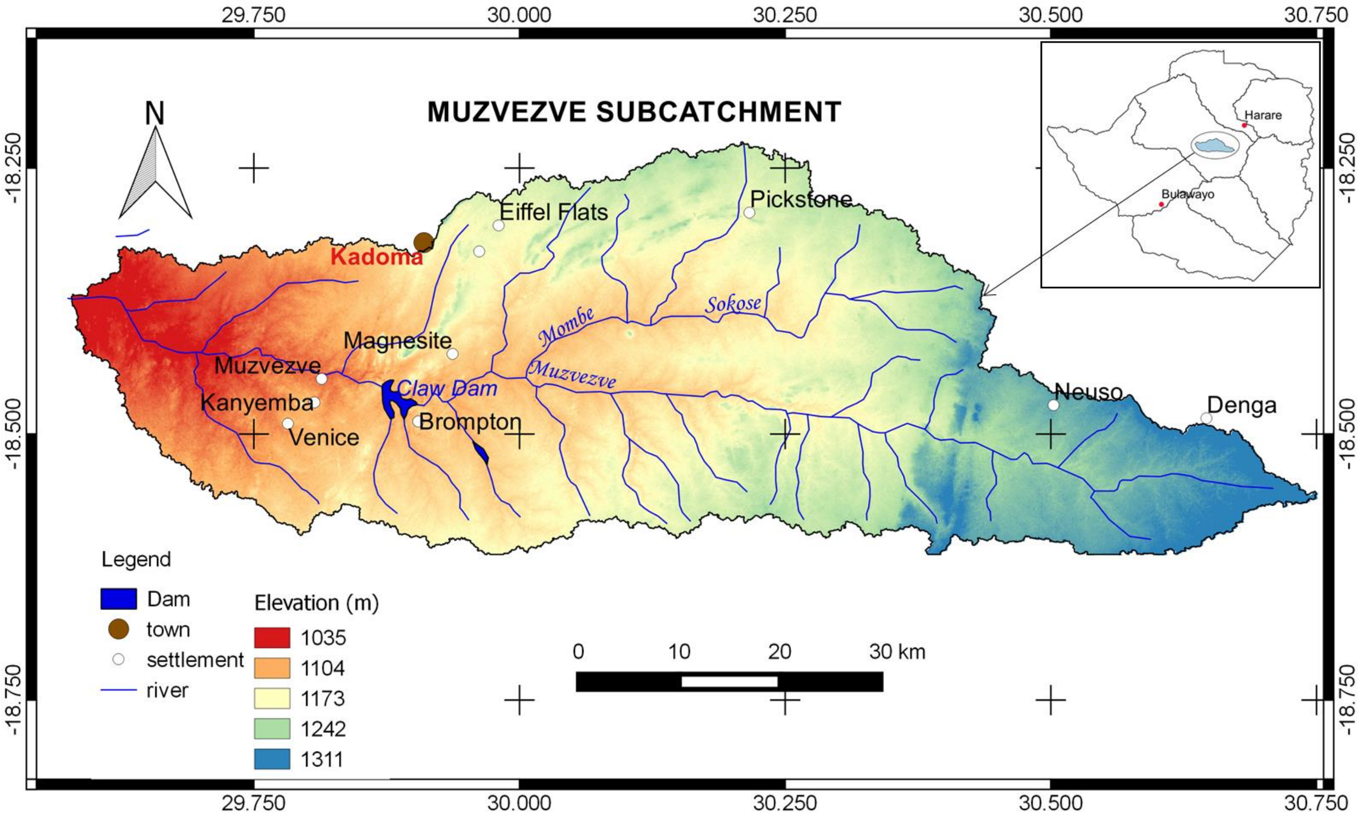

Figure 3.1: Study area map of Muzvezve Subcatchment, Zimbabwe

3.1.2 Geology and topography

Muzvezve Subcatchment is underlain by the Greenstone Belt comprising metasediments, felsic, andesitic, dacitic and basaltic metavolcanics covering the eastern parts of Muzvezve, Lower Munyati and Zivagwe subcatchments. The greenstone belt stretches from Chegutu through Kadoma, Kwekwe and Gweru towns. The Great Dyke, which is a huge extensive ultramafic to mafic body approximately 8 kilometres wide cuts across all the subcatchments, extending from the

Musengezi Complex in the Northern part to Wedza Complex in the Southern part of the Sanyati catchment. Figure 3.2 and 3.3 show the geological and soil maps of Muzvezve Subcatchment.

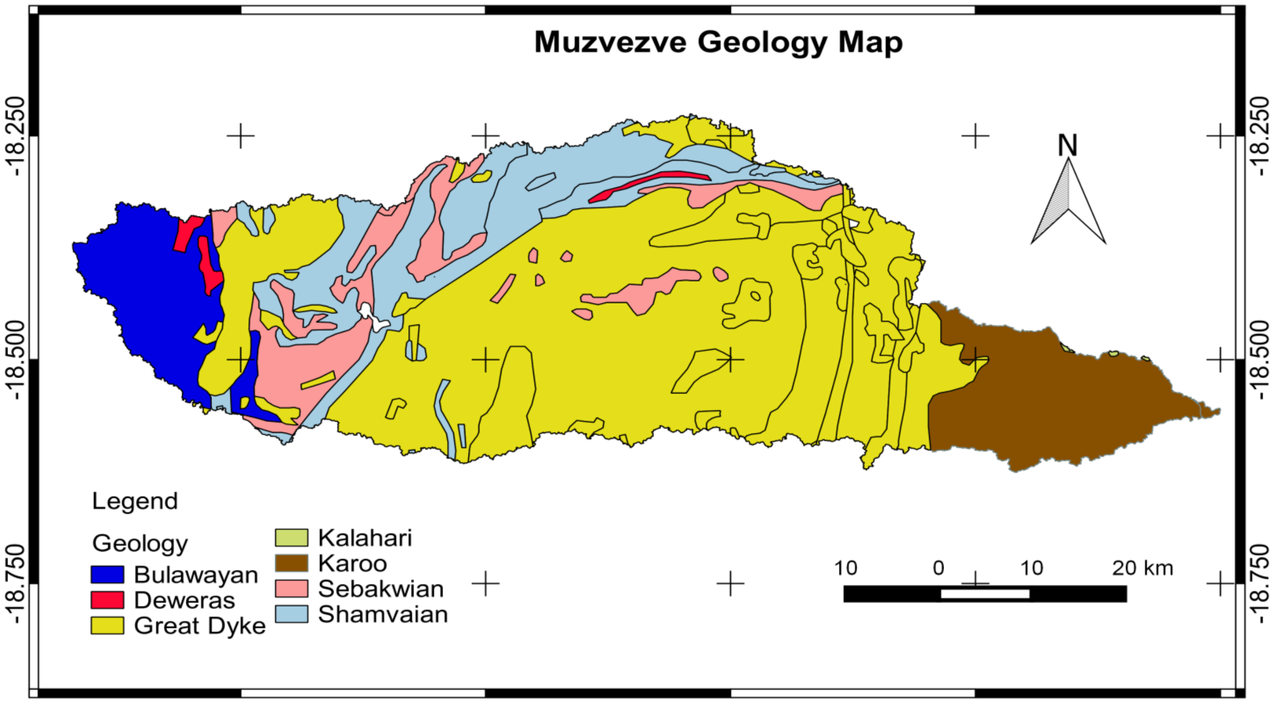

Figure 3.2: Geological map of Muzvezve Subcatchment (Source: Zimbabwe Surveyor General Dept., n.d)

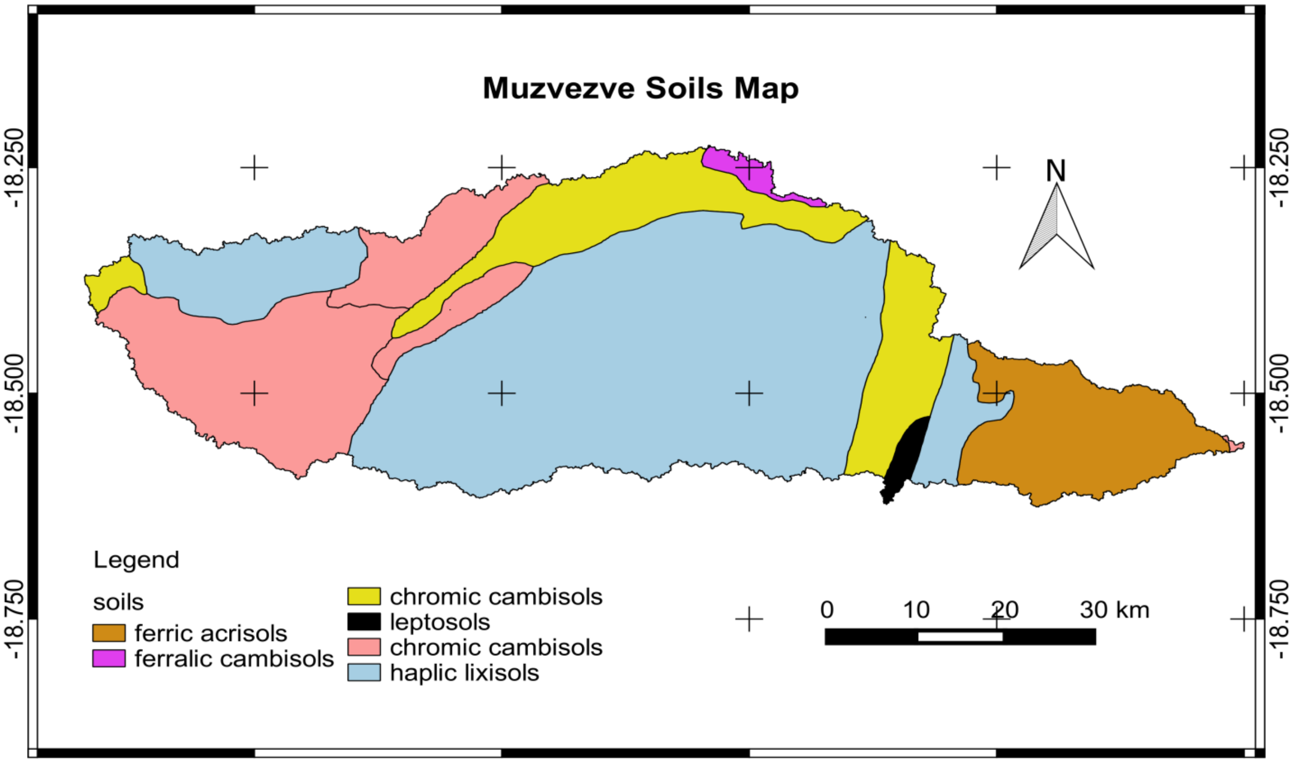

Figure 3.3: Soil map of Muzvezve Subcatchment (Source: Zimbabwe Surveyor General Dept., n.d)

3.1.3 Climate

Muzvezve Subcatchment lies in Natural Region III of Zimbabwe. Rainfall in this region on average ranges from 650-800 mm per annum, with infrequent heavy falls and high temperatures. The altitude is above 900 m. This semi-intensive farming region is marginal for maize, burley and cotton production.

3.1.4 Hydrology

The subcatchment lies in Hydrological Zone C, consisting of only subzone CUS. The major drainage system in the area is the Muzvezve River, which is a major tributary of the Munyati River. Claw dam, which supplies the bulk of Kadoma City’s water requirements, is situated on the Muzvezve River.

3.1.5 Groundwater resources

Groundwater occurrence is determined by the underlying geology. Fractures, fault zones, contact zones and weathered horizons of the prevailing geological formations control groundwater occurrence. There are 3 main geological formations namely Lomagundi, Deweras and Piriwiri groups. Under the Piriwiri group are Piriwiri phyllites, whose stratigraphy consists of quartz, chlorite, feldspar and iron oxides (Master, 1991). The Piriwiri phyllites weather into clayey material, hence reducing the permeability potential of the rocks. The resulting aquifer type after the weathering of Piriwiri phyllites are sedimentary consolidated aquifers. These rocks are characterized by low groundwater potential with average depth to water table between 5 and 15 metres. The average yield ranges from 10,000 to 50,000 L/day (SRSOP, 2009).

3.1.6 Socio-Economic activities in Muzvezve Subcatchment

Sanyati catchment is one of the seven hydrological catchments, in which Muzvezve subcatchment lies. Sanyati catchment has the highest concentration of urban centres in the country. There are three cities namely Kwekwe, Gweru and Kadoma and four towns Chegutu, Redcliff, Kariba and Gokwe. There are also semi-urban centres like Chivhu, Mvuma, Beatrice and Mubaira. Kadoma is the major city in Muzvezve Subcatchment. Economic life in the urban centres is based on formal employment, large and small scale businesses such as informal trading, cross border trading and vending. A1, A2 and commercial farmers engage in semi-commercial farming of mainly food crops, cash crops and animal rearing. Gold mining at Venice and Brompton mines and artisanal small scale mining activities are very prevalent. Large scale industries include a paper milling company, a gold refinery and a cotton processing company (although some are currently non-functional).

CHAPTER 4: MATERIALS AND METHODS

4.1 Assessment of water quality in the Muzvezve River using selected physico-chemical parameters

To assess water quality in the Muzvezve River using selected physico-chemical parameters from December 2015 to March 2016, the selection of sampling sites, the determination of parameters, sampling frequency, sample collection and analysis were carried out. Six sites were selected for data collection. These consisted of six on-river sample points. An additional sampling point was selected from a wastewater tributary. For a more detailed analysis of the dynamics in water quality, historical data would have been useful. However, there was a limitation to this, due to the differences in the spatial coverage of the ambient water quality sampling points as compared to those which were to be used in this particular study.

4.1.1 Selection of study site for sampling

Obtaining representative samples is important for a relevant description of the environment. Collecting comparable data over the duration of the sampling campaigns and among sampling sites is necessary for a valid analysis and interpretation of the data (Clesceri *et al*., 1999). The land uses that have been taking place in Muzvezve catchment over the past 20 years have prompted the need for a water quality assessment in this area, hence this study area was chosen. Figure 4.1 shows the map of the area and the sample collection points.

4.1.2 Selection of sampling sites/areas

The sampling points within the Subcatchment were selected after considering the anthropogenic activities, particularly agriculture, settlements and mining, and how they might influence water quality. Close proximity of the sampling sites to the activities makes them susceptible to pollutants through leachates, direct discharge and seepage from chemicals and effluents. An additional sampling point was selected from a waste water tributary (SP7), this point was used to capture the effect of partially treated effluent from Kadoma and its contribution on the Muzvezve water quality. The coordinates of these points were taken using a Geographic Positioning System, (Garmin model). The sampling point’s locations are shown on Figure 4.1 and described in Table 4.1.

4.1.3 Selection of parameters for analysis

The selection of water quality parameters was based on the anthropogenic activities within the subcatchment like agriculture, settlements and mining on the local water quality and Muzvezve River. Each of the land uses affect different parameters, which may have potential impacts to both aquatic organisms and people, who depend on the water. The selected parameters are listed below:

1. Parameters tested in-situ- pH, turbidity;
2. Parameters tested in the laboratory- Electrical Conductivity (EC), Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD$_5$), faecal coliforms, total coliforms, nitrates, phosphates and heavy metals (i.e. zinc, copper, lead, and cadmium).

Table 4.1: Description of sampling points

ID	**Description**	**Location**	**Geographical coordinates**	**Distance from sampling point 1(i.e. source) (km)**
SP1	Source of study area sampling points	Upstream of Claw dam	18^{o}28′0 55″S 29^{o}56′2 05″E	0
SP2	Before Claw dam	Upstream of Claw dam	18^{o}28′0 00″S 29^{o}56′1 35″E	5
SP3	After Claw dam wall	Upstream of Claw dam	18^{o}26′7 94″S 29^{o}52′1 45″E	15
SP4	Settlement (Muzvezve)	Downstream of Claw dam	18^{o}26′7 05″S 29^{o}48′8 68″E	20
SP5	Agriculture (maize and groundnuts fields)	Downstream of Claw dam	18^{o}25′9 24″S 29^{o}46′9 19″E	23
SP6	Mining (artisanal gold mining)	Downstream of Claw dam	18^{o}25′7 10″S 29^{o}46′0 23″E	26
SP7	WWTP at discharge point	Tributary of Muzvezve River	18^{o}22′1 9″S 29^{o}54′30 77″E	20

4.1.4 Methods of sampling and sampling frequency

Sampling locations were determined in such a way that samples collected were representative in space within the specified boundaries of the study area. Sampling frequency was selected so that the samples could be representative in time. This was done fortnightly except for instances when the effects on water quality of particular events like heavy storms effects had to be captured. Grab sampling was used. This method involved collecting samples at approximately 30 cm below the water surface. Sampling was carried out in the morning while temperatures were reasonably low, i.e. below 22 ^{o}C. All the samples were collected, preserved, and analysed according to the Standard Methods (Clesceri *et al*., 1999). Sample bottles were cleaned by collecting the water to be sampled twice and flushing it out before the actual sample was collected and stored. Sampling bottles were well labelled accordingly, soon after each sample collection at the different sites to avoid mix up and confusion of the samples. The sampling dates are shown on Table 4.2.

Table 4.2: Description of sampling frequency

Sampling campaign number	Sampling campaign dates	Sampling day number
1	13/12/15	1
2	10/01/16	29
3	17/01/16	36
4	07/02/16	57
5	21/02/16	71

4.1.5 Sample preservation, transportation and storage

.Acidification of water samples preserves trace elements by reducing precipitation, microbial activity and sorption losses to container walls (EPR, 2009). For the COD sample, upon collection in a 500 ml sample, 1 ml of sulphuric acid was added immediately as a preserving reagent. For the heavy metal samples, 1 ml of nitric acid was also added directly after collection. Table 4.3 summarises the sample preservation methods that were used in this study and the maximum holding times for the different parameters.

Table 4.3: Sample preservation methods

Parameter	**Container**	**Volume collected (ml)**	**Volume required (ml)**	**Preservation method**	**Max Holding time**
Micro-biological: faecal coliforms Total coliforms	Sterile glass bottles	500 ml	100 ml each	Store at temps <4 ⁰C	1 day
Other parameters	Plastic containers	500 ml	100 ml each	Store at temps <4 ⁰C	1 day
COD	Plastic containers	500 ml	20 ml each	Store at temps <4 ⁰C Add 2 ml sulphuric acid/1 litre sample	7 days
Heavy metals	Glass/plastic	500 ml	100 ml /sample	Store at temps <4 ⁰C Add 2 ml of nitric acid/1 litre sample	180 days

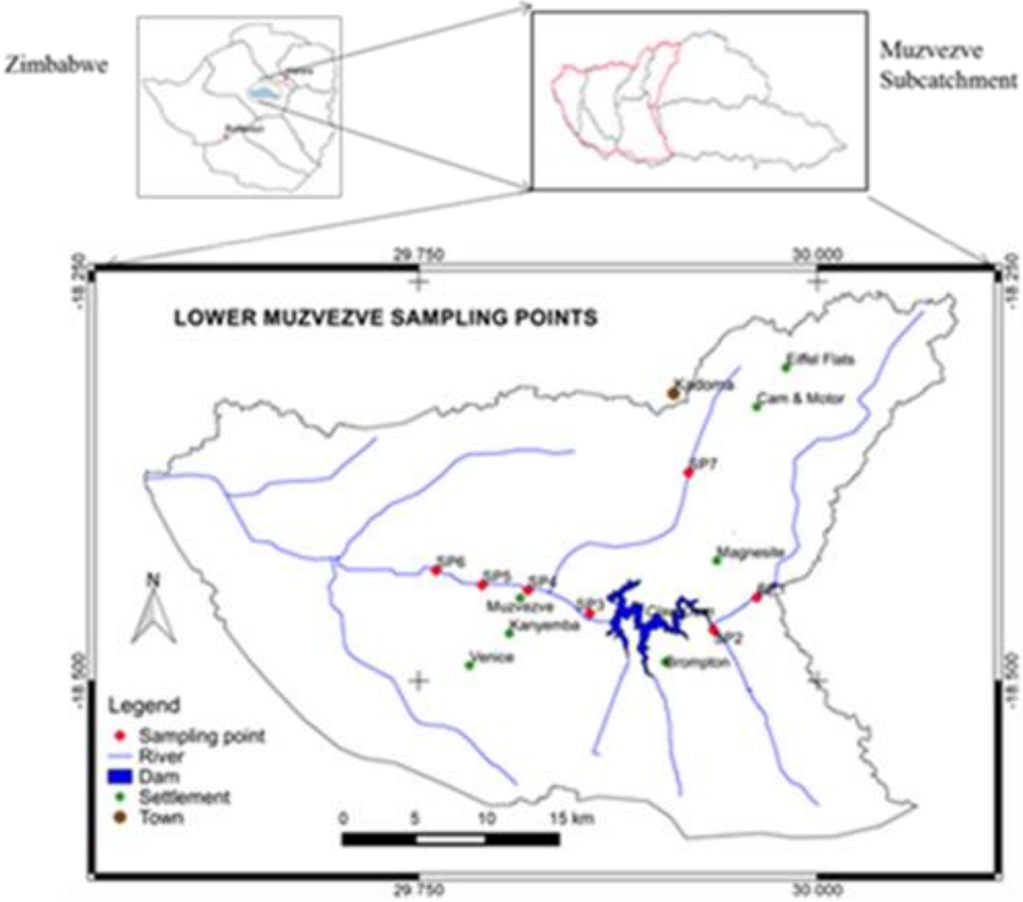

Figure 4.1: Map showing sampling points within the Lower Muzvezve Subcatchment

A record of the dates and sampling time was documented. Samples were then transported to the laboratory in a cooler box with ice. In the laboratory samples were stored in the refrigerator at < 4 °C until analysis.

4.1.6 Water quality testing

Table 4.4 shows the equipment used for water quality testing. All parameters were tested according to Standard Methods (Clesceri *et al.*, 1999).

Table 4.4: Sampling equipment

Parameters	**Units**	**Equipment**	**Equipment Model**	**Standard Method No.**
In-situ				
pH	no units	Digital pH meter	ESC tester pH1	APHA 2310B
Turbidity	NTU	Turbidity meter	HANNA H (98703)	APHA 2130B
Laboratory analysis				
Electrical conductivity	µS/cm	Electrical conductivity probe	Microprocessor (Lasany 1-50)	APHA 2510
Total Dissolved solids	mg/l	TDS probe	Microprocessor (Lasany 1-50)	APHA 4500-OG
BOD$_5$	mg/l	BOD$_5$ Winkler method	N/A	APHA 5210 B
COD	mg/l	Titration	N/A	APHA 5220A
Phosphates	mg/l	Palin test (Low Range)-Spectrophotometer	N/A	APHA 4500-PE
Total coliforms	CFU/100ml	Membrane filtration method	N/A	APHA 9221 APHA 9222
Faecal coliforms				
Heavy metals	mg/l	Atomic absorption spectrometer	Thermo-scientific ICE 3000	APHA 2111B

4.2 Determination of the relationship between selected water quality parameters and catchment condition using Normalised Difference Vegetation Index (NDVI)

In order to determine the relationship between selected water quality parameters with catchment condition, Normalised Difference Vegetation Index (NDVI) was used. However, first the watershed boundaries had to be delineated using a 90 m Advanced Space borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) in an ArcView 10.2.2 GIS environment (ESRI, 2014). The Hydrology tool was used for hydro-processing operations which included the fill, flow direction, flow accumulation, and snapping of pour points operations. Each sampling point was used as a pour point for the seven watershed delineations.

Three images were downloaded as shown in Table 4.5, from the United State Geological Survey (USGS) website (USGS, 2016). The downloaded images were first uncompressed using ALZIP free software. A new folder was created for each image containing TIFF format files and a text file, and exported to Quantum GIS. Table 4.5 show the dates of the images which were downloaded as well as the cloud cover, path and row.

Table 4.5: Downloaded images for NDVI analysis

Date of Satellite Imagery acquired	**Resolution**	**Cloud cover (%)**	**Path/Row**
29/12/15	30 m	0	170/63
06/01/16	30 m	0	170/63
07/02/16	30 m	7	170/63

In QGIS the files were processed with a plugin (Build Virtual Raster Catalogue) which was used to set the resolution to high and to separate the bands for easier manipulation. This produced a georeferenced GeoTiff image.

Top of Atmosphere (ToA) correction was performed to convert digital numbers to reflectance using the Geosud ToA reflectance plugin in QGIS. This produced ToA parameters for the equation:

$$TOA = (\pi * L_\lambda * d^2) / (ESUN\lambda * \cos\theta_s) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 4.1}$$

Where

L_λ is the spectral radiance at the sensor, d is the Earth-sun distance in astronomical units, $ESUN_\lambda$ is the mean solar exoatmospheric irradiance for each band and $\cos\theta_s$ is the solar zenith angle in degrees, which is equal to $\theta_s = 90^0 - \theta_e$ where θ_e is the sun elevation.

The corrected image was then imported into ILWIS for the Normalised Difference Vegetation Index (NDVI) calculation. The NDVI operation used was under the ILWIS operation tree using the equation:

$NDVI = (NIR - R) / (NIR + R)$………………………………………………………*Equation 4.2*

Where

NIR – Band 5 for Landsat 8 images

R – Band 4 for Landsat 8 images

NDVI values below 0 indicate water while NDVI values above zero indicate different land surfaces from bare ground (0-0.1) to dense green vegetation (0.5-1) (Pirottia *et al*., 2014).

The NDVI maps for December 2015, January and February 2016 were then crossed with the Watershed map in ILWIS 3.31 GIS environment (ITC, 2007). Using the Aggregation operation, the mean NDVI values for each watershed were obtained. These were correlated with the point measured parameters of turbidity and TDS.

4.3 Water quality assessment for Claw dam

In order to evaluate the water quality changes of Claw dam using remote sensing, the aim was to determine the applicability of remote sensing to this dam for water quality assessment and its applicability for future water quality predictions.

Chlorophyll a concentrations, Secchi disk depth and turbidity are directly linked to the trophic state of water bodies and are amenable to measurement by satellite remote sensing hence they are widely used to ,monitor water quality (Levy, 2007; Pirottia *et al*., 2014; Thomas and Ralph, 2004; Usali and Ismail, 2010). Field data on Chlorophyll a concentrations, Secchi disk depth, Turbidity were collected from 10 randomly chosen sampling locations and were correlated with reflectance values at those points within 7 days of a satellite overpass. Ten points were chosen because this is the minimum number of points required to perform regression analysis (Faraway, 2002).

At each sampling location, a water sample of 500 ml was also collected from the uppermost water layer (approx. top 30 cm). In situ measurements were done for turbidity using a turbidity meter. Secchi depth was measured using a 40 cm diameter, black and white quadrated disk, which is shown in Appendix 1. The disk was lowered slowly into the water. The depth at which the disk was no longer visible was taken as the measure of the transparency of the water within the dam. The other samples for Chlorophyll a were stored in a cooler box and returned to the laboratory, for the analysis of the remaining parameter. Table 4.6 shows the parameters which were collected and analysed from Claw dam. Figure 4.2 shows the location of the sampling points which were used during sampling within Claw dam.

Table 4.6: Rapid water quality parameters collected and analysed from Claw dam

Parameter	**Analysis method**	**Equipment and Model**
Chlorophyll a	Extraction method using Acetone	N/A
Turbidity	Spectrophotometric	DR/2010 HACH Spectrophotometer
Total Suspended Solids	Spectrophotometric	DR/2010 HACH Spectrophotometer
Total Dissolved Solids	N/A	Microprocessor (Lasany 1-50)
Secchi Depth	N/A	Black and white quadrated secchi disk
pH	pH meter	ESC tester pH1

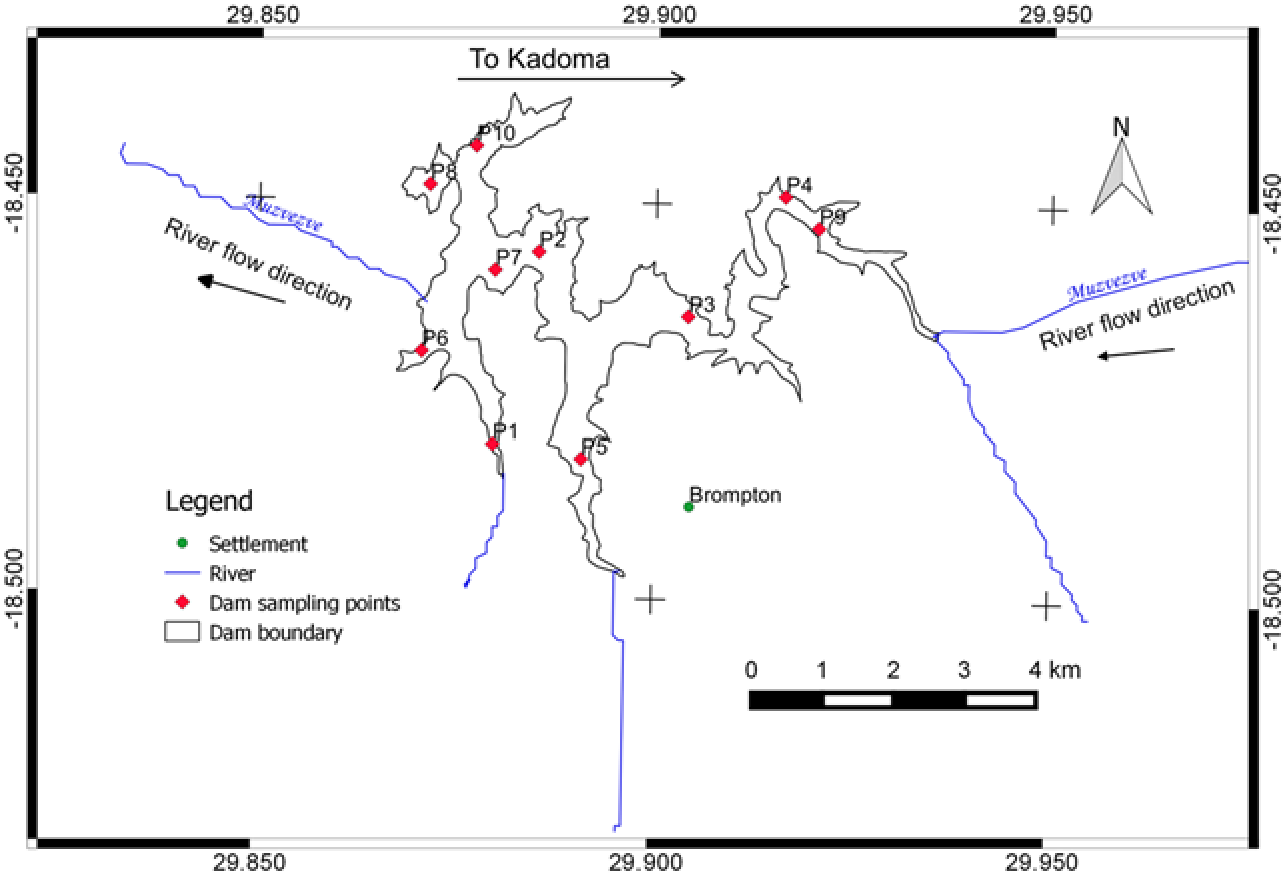

Figure 4.2: Map showing sampling points within Claw dam

4.3.1 Satellite image processing

Landsat 8 OLI imagery (path 170 and row 73) for the 26th of March 2016 was downloaded from the freely available Landsat archives at *http:glovis.usgs.gov.* The images, which had less than 5% cloud cover were selected and then registered to the Universal Transverse Mercator zone 36 south projection using the WGS84 as the global datum. The nearest neighbour resampling method was used for image registration.

Satellite image processing was conducted using the same method as that described in Section 4.2. The corrected image was then imported into ILWIS 3.0. In ILWIS bands 2, 3, 4, and 5 (i.e. Blue, Green, Red, NIR bands respectively) of the Landsat 8 image were imported via Geogateway, and a maplist was created using the 4 bands. ILWIS 3.7.2 was then used to perform the overlay function to extract a reflectance value at each sampling point for the respective bands. Next, the reflectance values for each band were then correlated using correlation in SPSS, against the mean value of each of the measured parameters for the 2 sampling campaigns done.

Ground measured parameters of Chlorophyll a, Secchi depth and turbidity were interpolated using ILWIS software. This was done so as to determine the concentration and distribution of the different parameters within the dam, which is vital in monitoring the water quality. In ILWIS, interpolation using the moving averages method was applied, and maps which show the spatial distribution of the parameters were produced.

4.3.2 Selection of bands

The selection of bands to use in the correlation analysis was based on the following reviews. In a study by Usali and Ismail (2010), the best correlation of turbidity and reflectance was found using the Red band, which was consistent with the results of Lathrop and Lillesand (1986). In another study, multiple linear regression analysis using Landsat Red (630–690 nm) and Near-Infrared (750–900 nm) bands was used to predict turbidity in a glacial lake in Alaska where highly scattering rock flower (sediment originated from glacial rock weathering) dominates the particulate fraction (Dogliottia et al., 2012), and the results showed a positive correlation.

Remote sensing has also been used to measure chlorophyll concentration and patterns. Measurements from aircraft, Landsat, SPOT and SeaWiFS have used a variety of algorithms and wavelengths to map chlorophyll of the oceans, estuaries and fresh water. In principle, chlorophyll absorption occurs in short wavelengths. Hyper spectral sensors have been considered as the future sensors to measure chlorophyll concentration in water. The reflectance height at 690 nm above the base line from 670 to 850 nm was a sensitive indicator for chlorophyll concentration (Gitelson *et al*., 1995).

4.4 Quality assurance and quality control

Quality assurance encompasses analytical quality control but also includes many other aspects such as showing competency of the individuals, equipment calibration procedures, sample handling procedures and so on (Clesceri *et al*., 1999). In this study, prior to taking equipment to the field, the equipment were well calibrated to ensure that they were functioning as expected. Laboratory tests were conducted in duplicates and then averaged inorder to reduce errors. Inorder to ensure quality control for heavy metals and COD, samples were collected and preserved by adding 1ml of nitric and sulphuric acid respectively. Bottles for microbiology were sterilised before use. Measuring probes were rinsed with distilled water after use at every sampling site. Cooler boxes with ice and refrigeration at < 4 ^{o}C were used in the preservation of samples before analysis.

4.5 Data analysis, interpretation and presentation

After data collection, data was subjected to normality tests. These were done so that they would guide in the selection of the appropriate test for the data. Normality tests were performed using the Shapiro-Wilk and Kolmogorov-Sminorv (KS) tests. For normally distributed data, the paired samples t-test parametric tests were used to test for differences amongst the different campaigns which were conducted in the dry season and wet season. For data which did not follow normal distribution, the Wilcoxon Signed Rank test was applied, which is a non-parametric test. If the p value was > 0.05, it showed that there was no significant difference between the campaigns.

Pearson correlation analysis using SPSS was performed for determination of the strength of relationship between NDVI and WQ. The relationship R^2 ranges from -1 to +1. A strong negative relationship was indicated by -1, 0 showed no correlation and +1 indicated a strong positive correlation. The independent variable was the NDVI and the WQ is the dependent variable.

Correlation analysis was performed in SPSS for ground measured parameter and different spectral bands. Scatter plots were used and a linear regression line was fit along with the R^2 and equations were displayed to describe the relationship. High R^2 (greater than 0.4, indicates the good fitting of the model, the independent (i.e. band reflectance) variables are good predictor for dependent variables (i.e. water quality parameters) (El Saadi *et al*., 2014).

Data was also subjected to other calculations like the calculation on means, standard deviations, maximum and minimum. Bar graphs with error bars were used to present the data.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Rainfall in Muzvezve catchment

The minimum rainfall amount during the sampling period was recorded Mid-December with average of 3 mm/day. The highest rainfall was recorded Mid-January with averages of 35 and 40 mm/day. This rainfall pattern is different from the usual, were October marked the rainy season onset; this could be due to the climatic shifts being experienced globally. This has resulted in the delay of the rainy season (Gozzard *et al.*, 2011). Figure 5.1 shows the results for average rainfall recorded at the two raingauges.

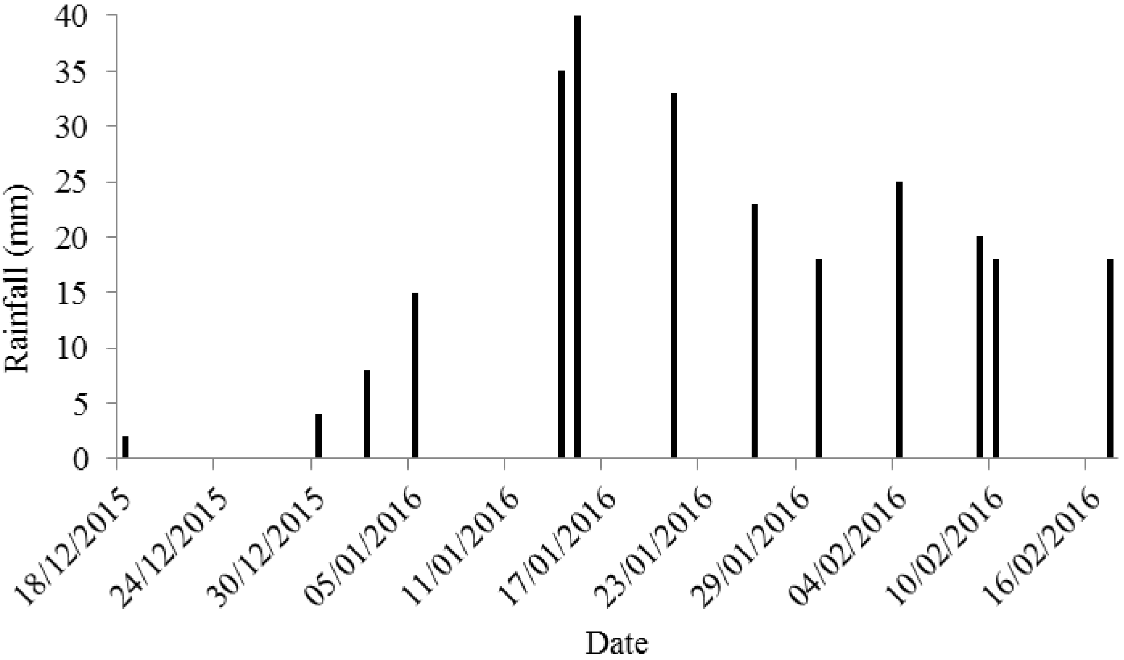

Figure 5.1: Mean daily rainfall for Lower Muzvezve Subcatchment from December 2015 to February 2016

5.2 Spatial variations of parameters for each campaign

5.2.1 pH

The measured pH ranged from 6.5 to12. It can be observed that the end of January campaign (Campaign 3) recorded the most alkaline pH ranging from 11-12.1. The Kolmogorov-Sminorv (KS) test for normality showed that data was not normally distributed, and a Wilcoxon sign rank test was performed (Appendix 2).

The results illustrated that pH flactuates significantly as the rainfall season progresses This may have been attributed to limestone bedrock which is rich in carbonates, thus with increased rainfall the bedrock is weathered away leading to increased alkalinity. Higher alkalinity levels in surface waters buffers acid rain, preventing pH changes that are harmful to aquatic life. For instances when pH values are between 6.7 and 8.6, aquatic ecosystems thrive well (WHO, 2008). However, at pH values less than 5 or more than 9, most aquatic species are affected. Figure 5.2 shows the pH variations for all sites for the five campaigns.

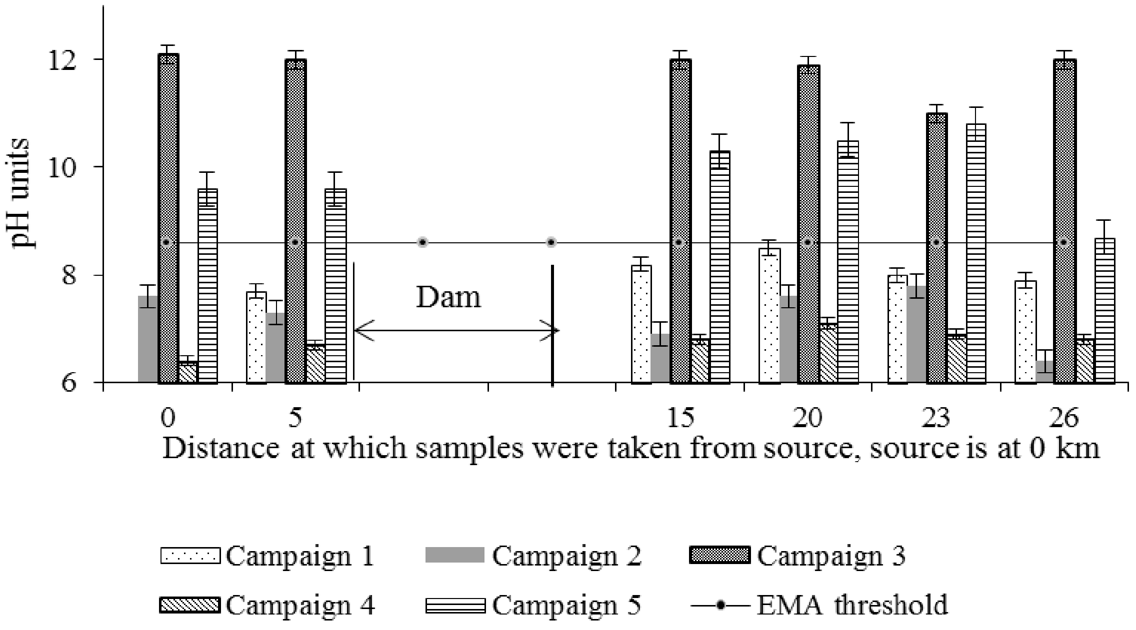

Figure 5.2: Variations of p H with distance from source (source is at 0 km)

5.2.2 Electrical conductivity (EC) and Total dissolved solids (TDS)

The Shapiro-Wilk and KS tests for normality showed that the data was normally distributed with all p values > 0.05 (Appendix 2). There were also no significant (p >0.05) differences amongst all the campaigns in EC and TDS, using the paired samples t-test. SP6 had the highest EC values which correlate with high TDS of averages 422 μS/cm and 327 mg/l respectively, these values show high pollution potential.

During the mid-December campaign (Campaign 1), EC values were high. EC results ranged from 82.3 to 664 μS/ cm. However, this EC value decreased with time due to the dilution effect of rainfall received. EC values measured for the dry season (Campaign 1) were higher than for the wet season (Campaign 2 to 5). This was attributable to excessive evaporation of water from the open water sources during the dry season, which might have consequently increased the concentration of dissolved salts as reflected in the high TDS values (Ouyang *et al*., 2009). Figure 5.3 illustrates these variations using Campaign 1, 3 and 5. There were low EC and TDS values recorded at SP3 because of the attenuation capacity of the dam. EC values ranged from 82.3 to 664 µS/ cm, so most of the values were within the recommended range, whose threshold is 1000 µS/cm (EMA, 2007). For example, a study done by Munuo (2012) for Mazowe River found EC ranges from 119.3-1069.2 µS/cm as compared to this study which had ranges of 82.3-664 µS/cm. This may perhaps mean that Mazowe River has poorer water quality than Muzvezve River. According to Chinhanga (2005), as the flow increases, EC decreases, this was the case for upstream sites like SP1, SP2 and SP3 sites which had lower EC end-January (Campaign 3) due to Claw dam downstream releases which at sampling time for end-January had not yet reached other downstream sampling sites like SP5 and SP6 sites.

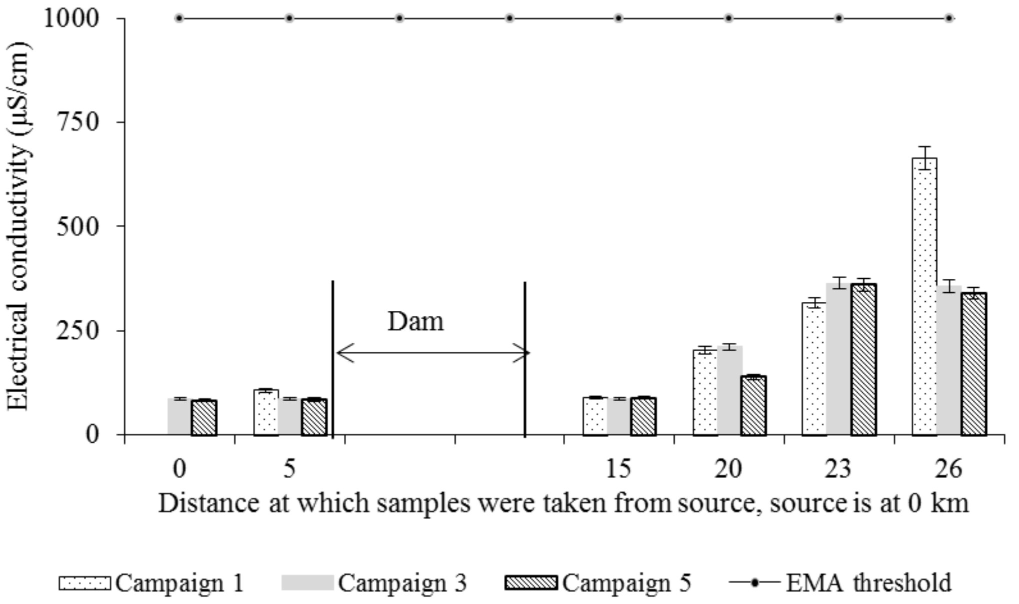

Figure 5.3: Variations of electrical conductivity with distance from source (source is at 0 km)

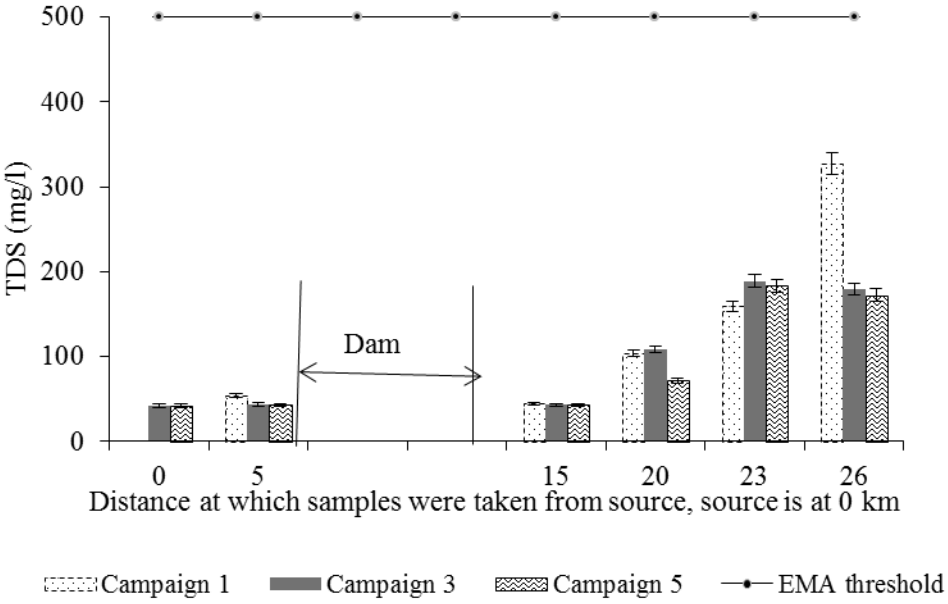

Figure 5.4: Variations of total dissolved solids with distance from source (source is at 0 km)

5.2.3 Turbidity

Turbidity ranged from 3 to 352 NTU. The Shapiro-Wilk test for normality showed that data did not follow normal distribution. The Wilcoxon sign rank test showed that there were significant ($p < 0.05$) differences between the dry and wet season campaigns (Appendix 2).

During the raining season, rivers receive large volumes of storm water with retained suspended materials; this resulted in the source site (SP1) recording the highest turbidity during the beginning of the rainy season. The lowest turbidity was recorded at SP3 with an average of 3 NTU, because most of the suspended solids would have been attenuated and settled within the dam surface. SP5 also has the least turbidity due to reduced runoff from agriculture practices and the thick riparian vegetation in the river channel.

Turbidity was high at SP6 due to mining in Campaign 1 (dry season) before rains because of alluvial mining which disturbs the geological composition of the bedrock resulting in high water turbidity. Limits for colour in potable water have traditionally been based on aesthetic considerations rather than on the basis of a health hazard (Oyhakilome *et al.*, 2012). The recommended threshold for turbidity for surface water is 5 NTU (EMA, 2007). High turbidity can have an effect on the health of river organisms such as the clogging of fish gills. Figure 5.5 illustrates the variation of turbidity with distance from the source.

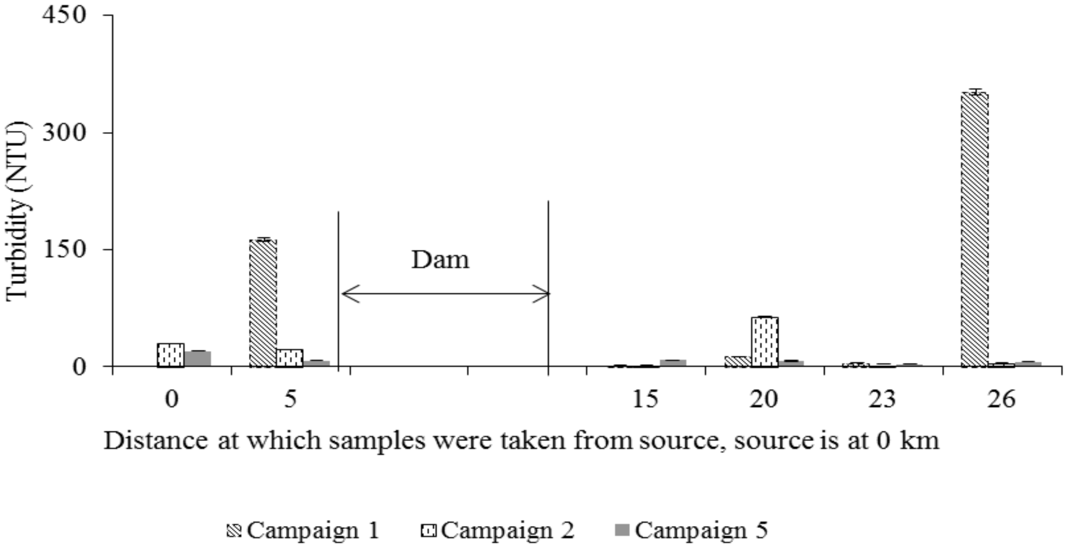

Figure 5.5: Variations of turbidity with distance from source, (source is at 0 km)

5.2.4 BOD and COD

Biological oxygen demand (BOD) results ranged from 1 -58.6 mg/l. The highest BOD range of 5 - 30 mg/l was recorded at SP4, this can be attributed to settlements which are prevalent in the area. Relatively higher values of COD compared to BOD were measured in the water samples.

Chemical oxygen demand (COD) results ranged from 0 - 88 mg/l. The mean COD for the study was 24.5 mg/l which was below the 60 mg/l threshold for EMA. The highest COD value of 88.mg/l was also recorded at SP4. The highest COD was recorded during Campaign 2 at SP4, which was characterised by high settlements. This was because of high water pollution as a result of runoff from settlements. During Campaign 3, as rainfall increased there was a drop in COD levels due to dilution effect, same as for Campaign 5; these results are illustrated in Figure 5.8. These parameters also decreased with increases in flows, lower BOD and COD values during Campaign 3.

High BOD level causes dissolved oxygen depletion, which could be detrimental to aquatic life. However according EMA standards, the recommended threshold for river freshwater COD is < 60mg/l and for BOD it is < 30 mg/l, Muzvezve River is generally below the thresholds. Figure 5.7 illustrates the BOD variations with distance from the source.

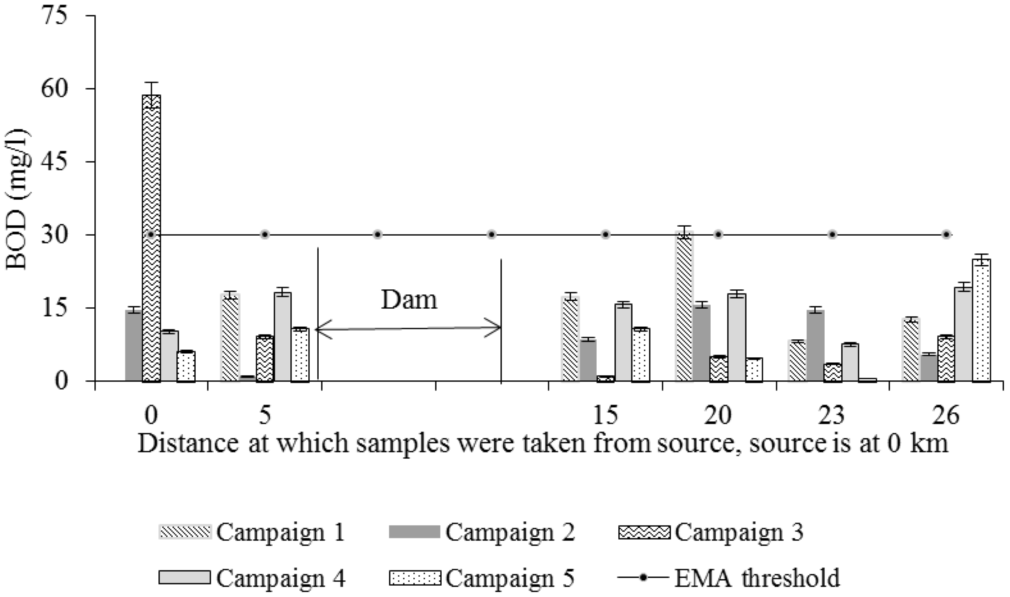

Figure 5.6: Variations of Biological oxygen demand with distance from source (source is at 0 km)

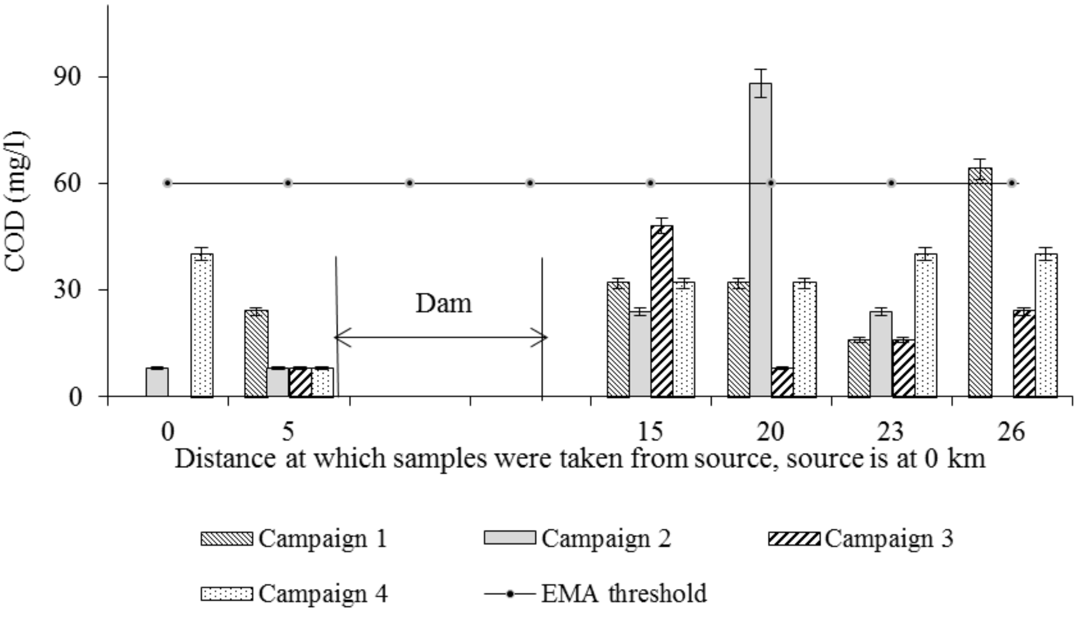

Figure 5.7: Variations of Chemical oxygen demand with distance from source (source is at 0 km)

5.2.5 Phosphorus and Nitrogen

Phosphorus which was analyssed in this study was in the form of phosphates. Phosphate concentrations ranged from 0 - 0.49 mg/l. The KS test showed that data was normally distributed except for Campaign 2. The Wilcoxon signed rank test showed that there were no signifant differences ($p > 0.05$) for all campaigns (Appendix 2). The EMA threshold of 0.5 mg/l was used for this study (EMA, 2007).

Typical phosphate concentrations in surface waters range from 0.001 mg/l in clean water to 0.30 mg/l or more in nutrient enriched waters. For all campaigns, SP4 and SP5 points recorded the highest values ranging from 0.42 to 0.49 mg/l. As the agriculture season progressed, phosphate levels increased gradually due to communal farming practices present, which make use of fertilizer and chemical application. However, phosphates were highest upstream at SP1 and SP2 site in the wet season (Campaign 4) due to residual fertilizers from the previous cropping seasons. As for SP4, detergents from laundry soaps used by the locals also contributed to high phosphates levels.

Nitrogen in the form of nitrates were analysed during the first three campaigns. All results obtained were below the recommended thresholds and were not of significant levels; therefore the tests were discontinued in subsequent campaigns.

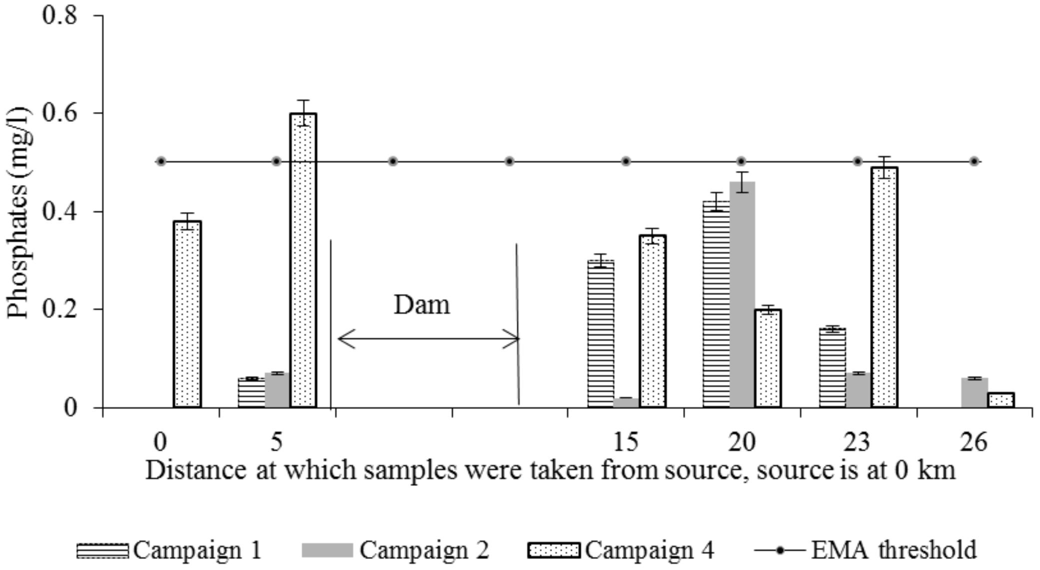

Figure 5.8: Variations of phosphates with distance from source (source is at 0 km)

5.3 Biological parameters

5.3.1 Coliforms

Total coliforms ranged from 0 - 1000 cfu/100 ml during the five campaigns. The Wilcoxon sign rank test showed that there were no significant differences ($p > 0.05$) amongst the campaigns. Coliforms were highest at SP1 and SP2 but the coliforms decreased at SP3 which is a sampling point just after the dam. This shows that the dam has high attenuation capacity to hold and allow the coliform contaminated water to settle within the dam. SP5 site which is within close proximity to surrounding settlements had high coliform count during Campaign 3; this could be attributed to faecal coliforms from livestock and other faecal material deposited by runoff into the river. However, some communities downstream of this sampling point obtain their drinking water directly from the same water source, Muzvezve River; this may lead to future health problems, because the recommended threshold for drinking water is 0 cfu/100 ml (WHO, 2008). However, for surface water the threshold is 1000 cfu/100 ml, and all sampling points had values equal or below the threshold, this is illustrated in Figure 5.9.

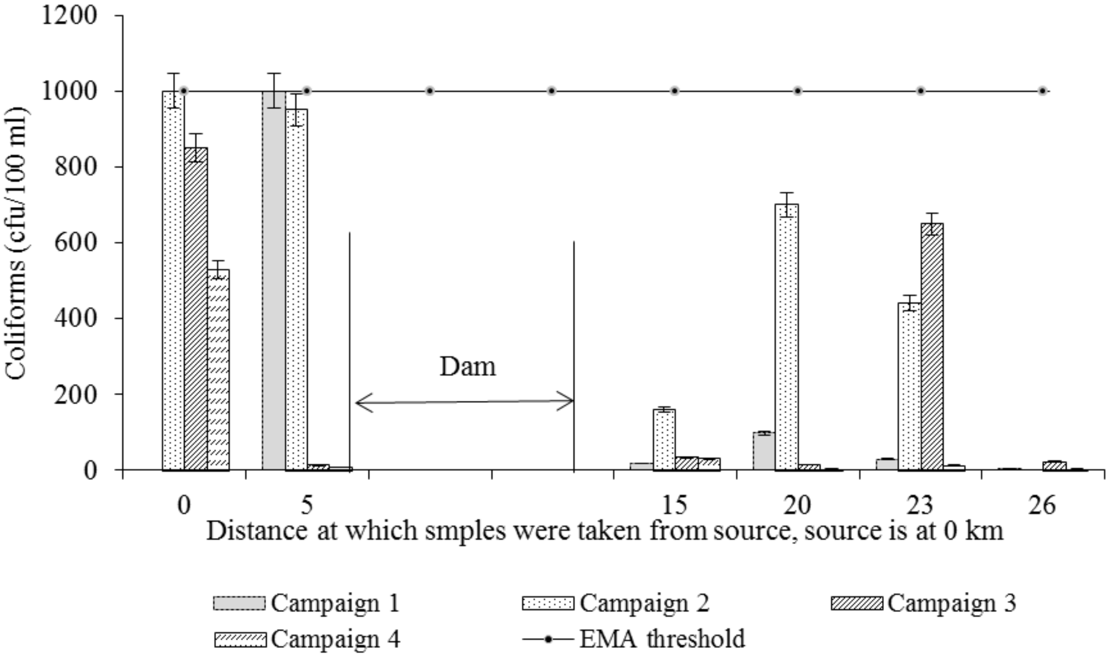

Figure 5.9: Variations of total coliforms with distance from source (source is at 0 km)

5.4 Temporal variations of parameters at each sampling point

The importance of temporal scale for the relationship between land use and water quality is very important. Dominant factors on the temporal scale include precipitation, temperature and landuse practice, these vary among seasons and with time. They play a pivotal role on water chemistry. turbidity, TDS, COD and phosphates are some of the parameters that will be discussed in this section.

5.4.1 Turbidity

Figure 5.10 illustrates that, in the dry season when sampling began the highest turbidity values were recorded at SP6 and SP2, this was due to alluvial mining activities and concentration of runoff with high suspended material respectively. As the rainfall season progressed, particularly on day 36 the turbidity increased due to high rainfall amounts received but these decreased with time.

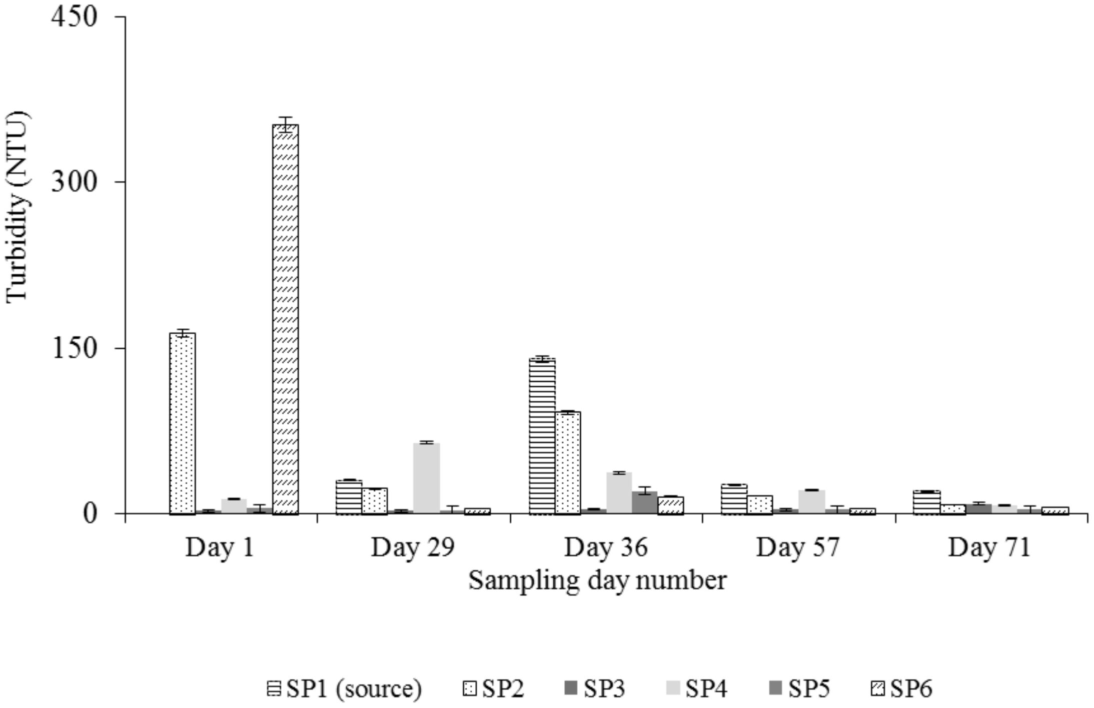

Figure 5.10: Variation of turbidity with time from 1st sampling day to 71st sampling day

5.4.2 Total Dissolved Solids

Figure 5.11 illustrates an example of TDS variations for all sampling sites. TDS values were highest at SP5 and SP6 because of the predominance of agriculture around SP5. SP3 had the lowest TDS; this can be attributed to the attenuation capacity of the dam.

5.4.3 Chemical Oxygen Demand

The pattern shown for COD was almost the same for all points, showing an increase in COD as the rainy season progressed. This means pollution levels were increasing as runoff with pollutants from the surrounding land uses were being deposited into the river. This variation is shown in Figure 5.12.

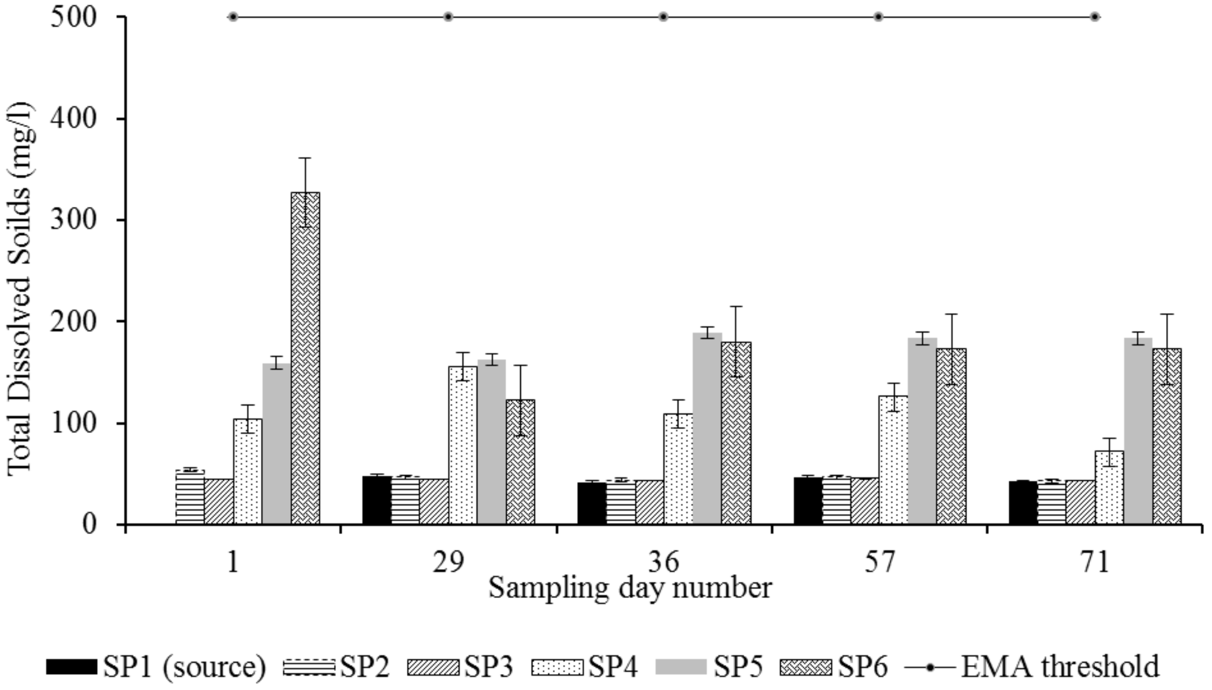

Figure 5.11: Variation of TDS with time from 1st sampling day to 71st sampling day

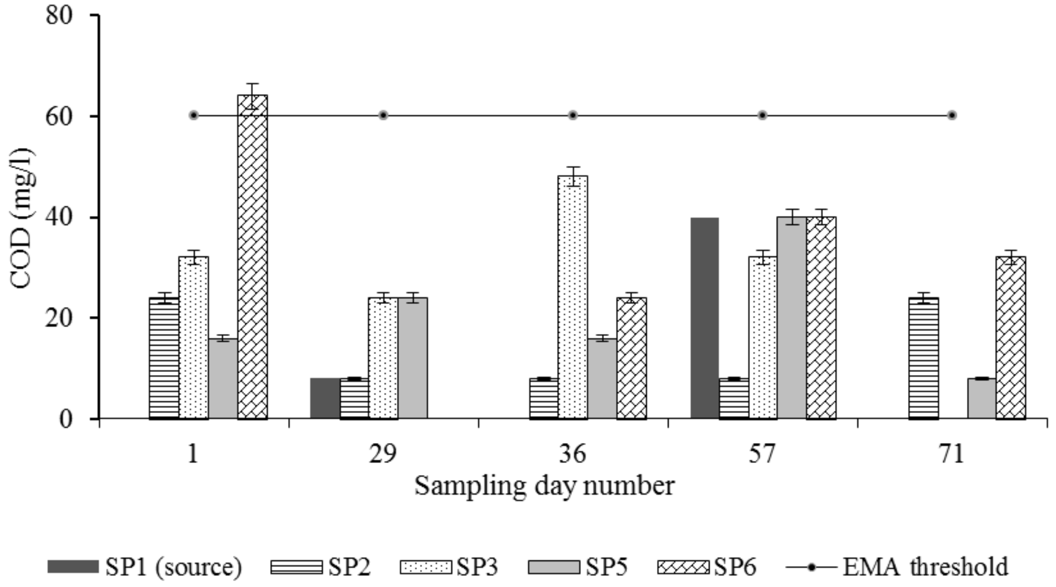

Figure 5.12: Variation of COD with time from 1st sampling day to 71st sampling day

5.4.4 Phosphates

Figure 5.13 shows fluctuations, with initially low concentrations, then a decrease in phosphate concentration at Day 29, then a gradual increase on Day 36 followed by a steady increase. This is attributed to low agricultural activities as the rainy season begun, and then an increase in fertilizer application as the season progressed leading to a gradual increase in phosphate concentration. However, this is not the same for SP4 because of the influence of phosphates from detergents used during laundry activities along the river.

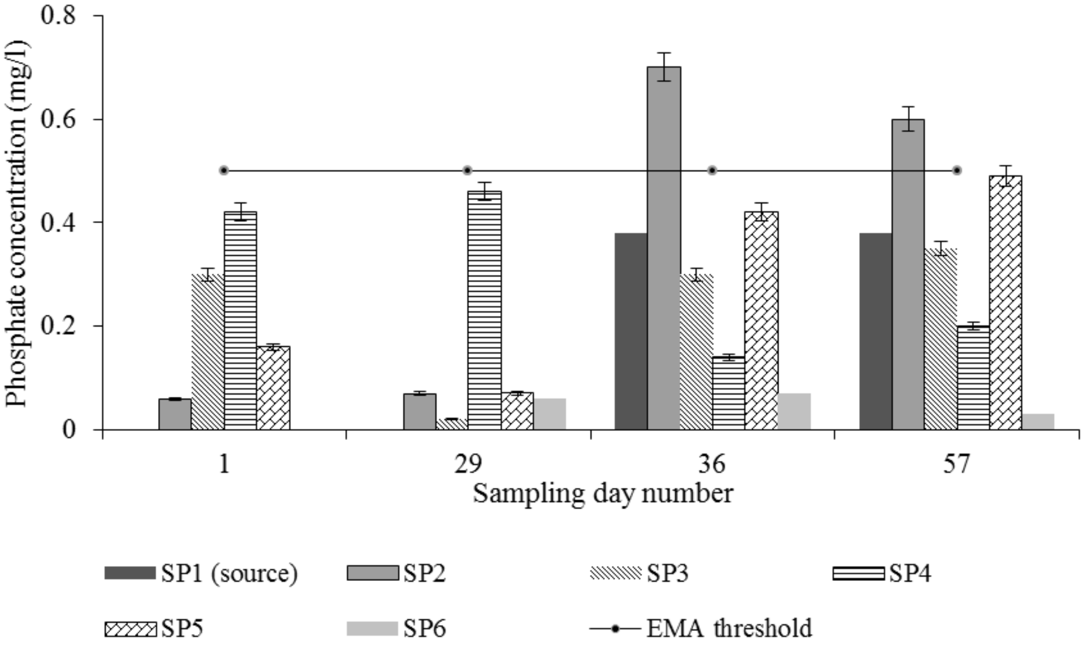

Figure 5.13: Variation of phosphates with time from 1st sampling day to 57th sampling day

5.5 Heavy metals analysis

5.5.1 Lead, Copper, Zinc, Cadmium

Sources for trace metals (e.g. zinc, lead, copper, cadmium) in reservoirs are the atmosphere, riverine inputs and various human waste discharges. Metals are introduced both in solution and in particulate form. The particles will partially settle to the bottom, but the dissolved trace metals are subject to adsorption, and uptake by biota in the epilimnion (i.e. by incorporation in algal tissues).

Metals concentrations were higher in dry season (Campaign 1) than during the wet season (Campaign 2 onwards) due to the lower water flow during the dry season which could help to accumulate the heavy metals in the sediment (Islama *et al*., 2015).Of all the measured metals, Zinc and Lead were the ones with the highest concentrations.

Zinc, due to its geochemical mobility in surface waters, is the most commonly encountered pollutant metal in the surface waters of metal mining regions. Zinc is typically present in its most ecotoxic form, Zn^{2+}, in riverine environments and consequently, stringent environment quality standards (EQS) of 0.008 - 0.125 mg/l (depending on water hardness) have been set to reflect the toxicity of zinc to aquatic biota, which causes numerous ecotoxicological impacts on receiving watercourses (Gozzard *et al.*, 2011).This is shown in Figure 5.14 which illustrates the concentrations of Zinc and Lead during the five sampling campaigns.

Lead concentrations from Day 29 onwards sampled under rainy weather conditions, decreased compared to observations on Day 1 which was the dry season. This can be due to horizontal water mixing during the rains or stirring up of bottom sediments, creating favourable conditions for dissolved metals to bind to these additional particles as the particulate phase is often the preferred one, especially for lead (Nguyena *et al.*, 2005b).

Copper (Cu) exhibits a strong potential to form a range of stable soluble inorganic complexes (Nguyena et al., 2005a), causing decrease of Cu levels as the season progresses with no copper detected on Day 57 (Campaign 4).

Metals such as Cu, Zn and Pb have high affinity to humic substances present in organic matter. Presence and quantity of organic matter differentially influence the binding of metals within the sediments and reduce adsorption of Cd and Cu and increased adsorption of Zn (Nazeera *et al.*, 2014). This can be seen by high levels of zinc as opposed to other metals. Figure 5.14 illustrates the concentrations of Zinc and Lead during the five sampling campaigns.

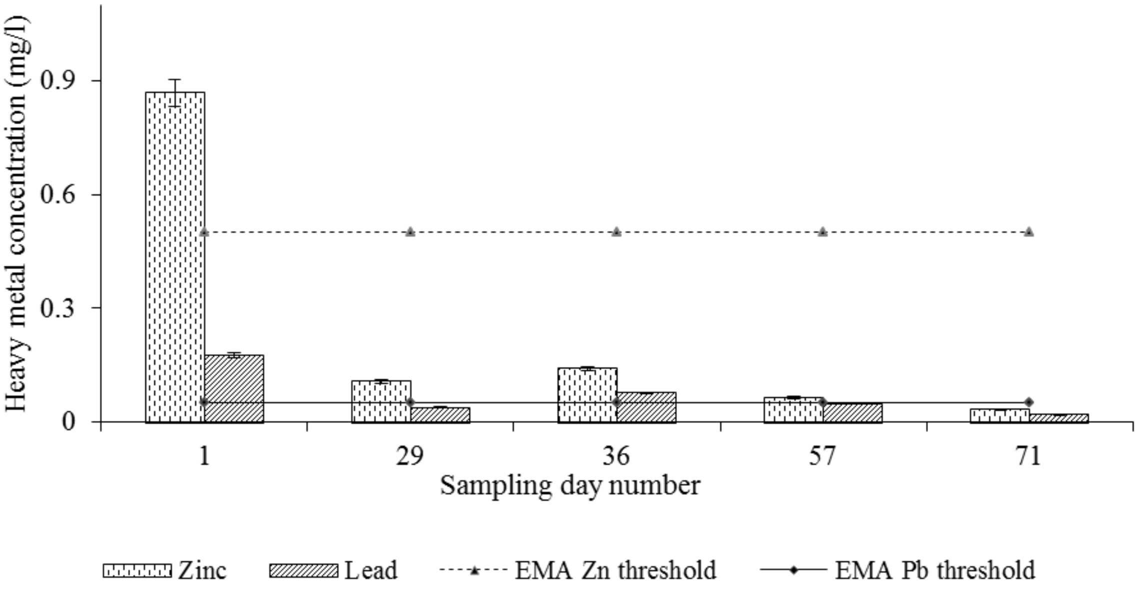

Figure 5.14: Variation of zinc and lead concentrations with time at SP6 from 1st sampling day to 71st sampling day

The results from data analysis show that, the water is of good quality for purposes other than drinking which may include recreation, livestock, irrigation and other domestic uses. It is however unfit for drinking purposes without some form of treatment. However, there could be gross differences in the test results of some samples at different laboratories in the country, which could limit the use of these data for sensitive policy issues.

5.6 Determination of the relationship between selected water quality parameters and catchment condition using Normalised Difference Vegetation Index (NDVI)

Watershed delineation was done in Arc GIS using a 90 m Advanced Space borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM). This resulted in the production of Figure 5.15. The map shows the watershed covered by each sampling point i.e. the drainage area which pours into a particular sampling point.

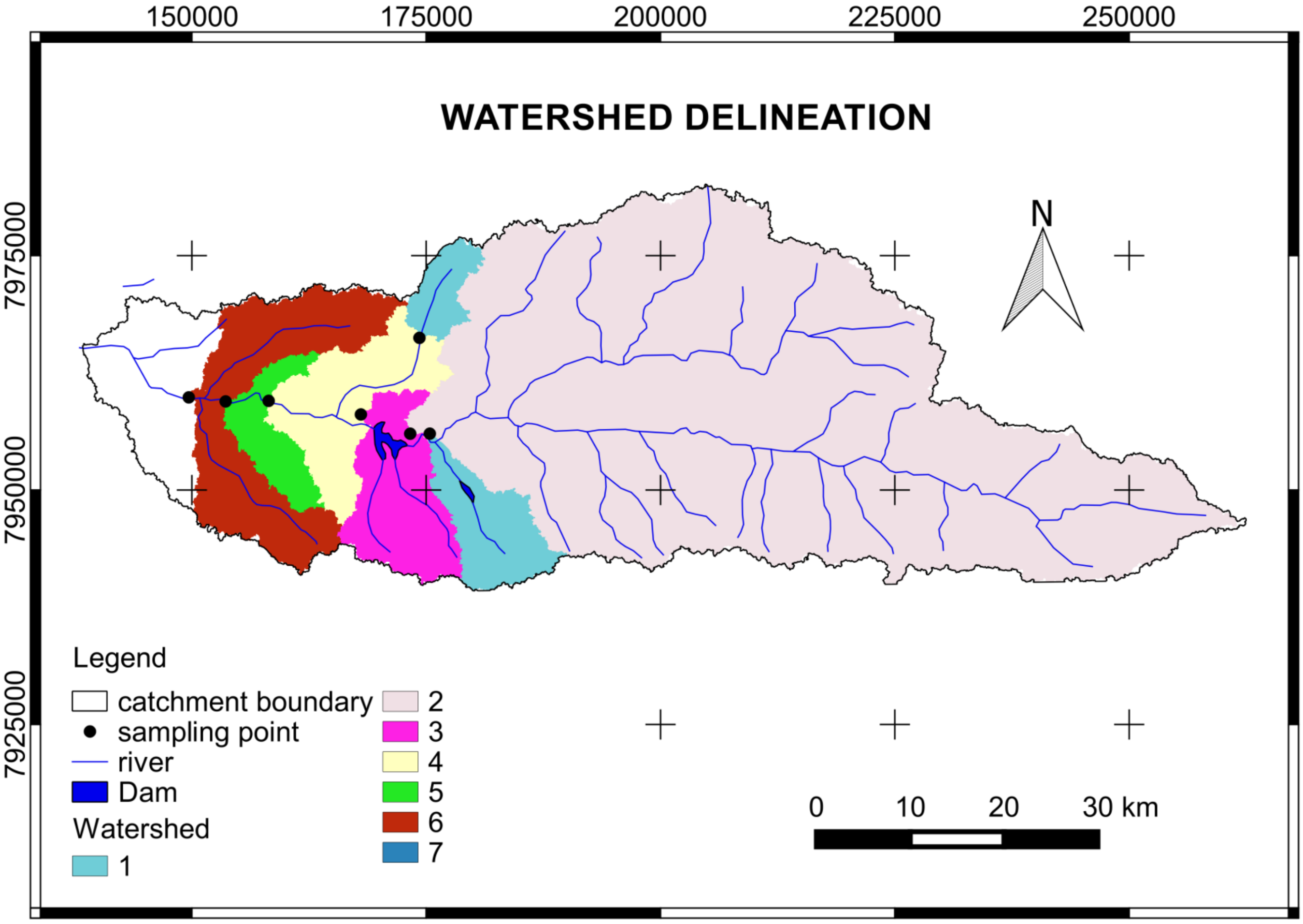

Figure 5.15: Watershed delineation map for Muzvezve Subcatchment

NDVI maps for the study area for the months of December, January and February were produced as shown on Figure 5.16. The Figure shows that December had lower NDVI values than January; this is because photosynthetic activities were lower since the rainfall season had not yet begun. The mean for January NDVI was higher than those for December. The mean NDVI for February was the highest with an average NDVI value of 0.20.

After crossing the NDVI maps with the Subcatchment's watersheds (Figure 5.15) the results were analysed using Statistical Package for Social Scientists (SPSS). The box plot was used to test data for normality, and the results are shown in Figure 5.17.

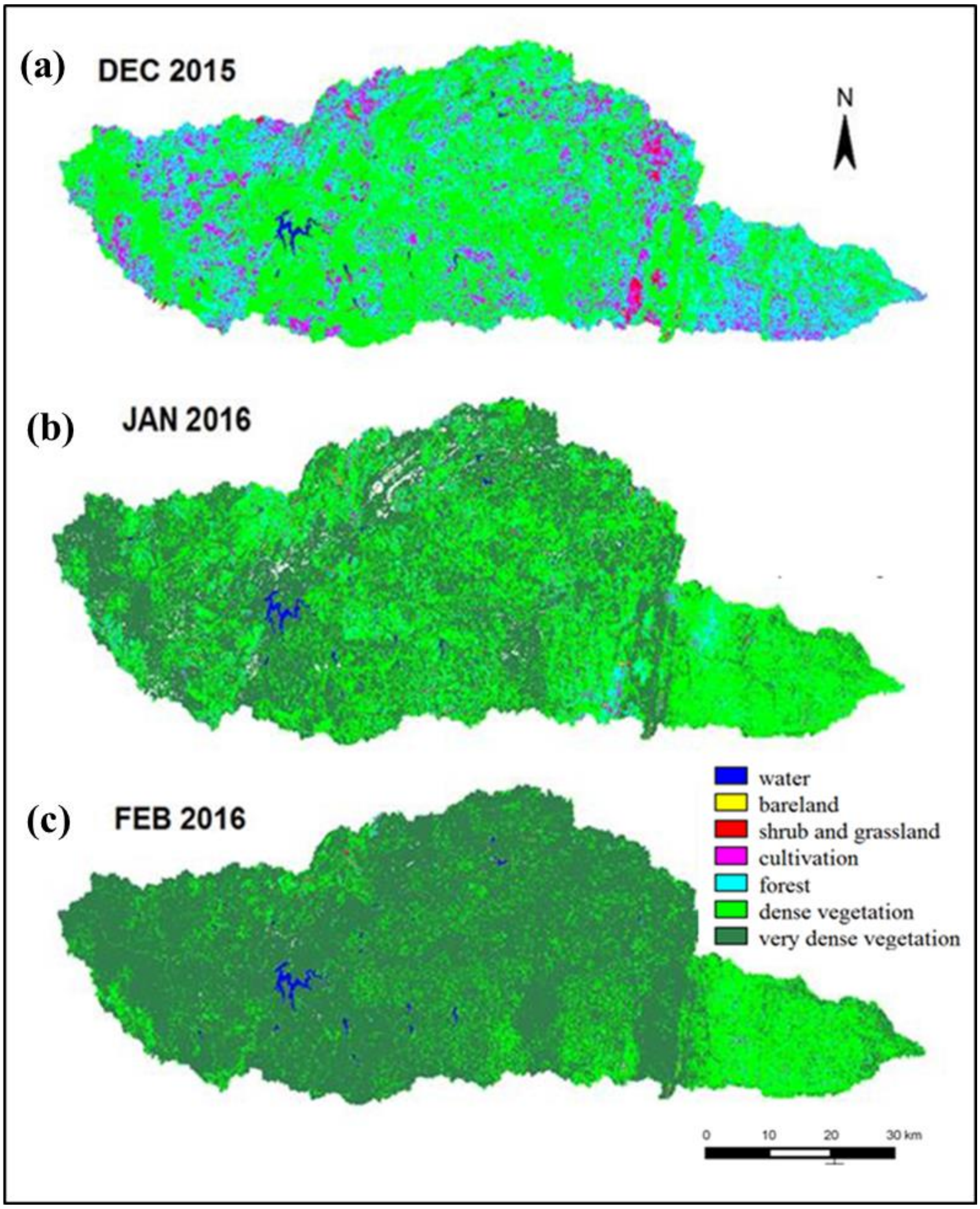

Figure 5.16: NDVI derived maps for December 2015, January 2016 and February 2016

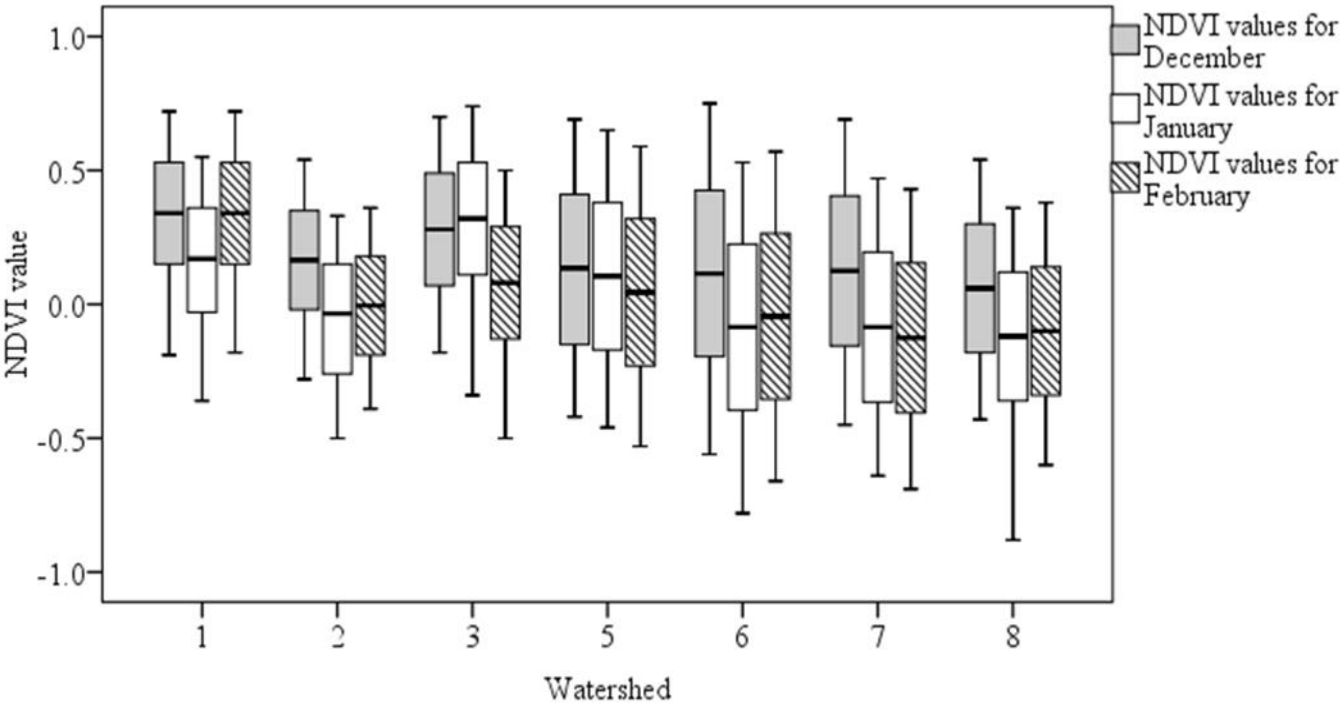

Figure 5.17: Box plot showing normal data distribution for Subcatchment NDVI analysis

Figure 5.17 results showed that there was normal distribution of the data; this prompted the use of the one–way ANOVA to determine significant difference amongst the means. The resultant $p < 0.05$ showed that there was significant difference in all cases hence the use of the Post hoc multiple comparison, Scheffe test. This showed that there were significant differences amongst the following Watersheds for the different months.

Table 5.1: Scheffe test multiple comparisons results for NDVI values in the 7 watersheds

Month	**Watershed**
December 2015	1 vs 2, 5, 6, 7, 8 3 vs 6, 8
January 2016	1 vs 6, 7 3 vs 6, 7, 8
February 2016	1 vs 5, 6, 7, 8 3 vs 7

The differences in the mean NDVI values can be owed to the different land uses in the different watersheds. Kadoma city lies in Watershed 1, therefore the NDVI values there are significantly different from all other watersheds due to the many buildings and paved surfaces there which reflect differently with mean NDVI of approximately 0.25-0.3 from the other watersheds, which are dominated by forests, bareland and communal land. The other watersheds are dominated by forests, grasslands and agriculture land use.

5.6.1 Correlation results

Correlation results for the different parameters and the mean NDVI values for each watershed are given in Table 5.2. A strong positive relationship is shown by values closer to +1 and negative relationships are shown by values closer to -1.

Table 5.2: Summary of correlation matrices for NDVI versus turbidity and TDS results

Parameter		**Campaign 1**	**Campaign 2**	**Campaign 3**	**Campaign 4**	**Campaign 5**
Turbidity	Pearson correlation	0.998	0.931	0.983	0.377	-0.581
	Sig. (2-tailed)	***0.037***	0.069	0.117	0.531	0.304
	N	3	4	3	5	5
TDS	Pearson correlation	0.426	0.938	0.979	0.961	0.980
	Sig. (2-tailed)	0.574	0.062	***0.021***	***0.039***	***0.03***
	N	4	4	4	4	5

Studies by Griffith *et al.*, (2002) have shown a strong correlation between NDVI and WQ. This is also evidenced by the results in Table 5.2. Campaign 1 which was conducted in the dry season (Mid-December) had a significant positive correlation of 0.998 with mean NDVI. This could be attributed to alluvial mining activities which were taking place along the river beds thereby affecting the turbidity of the water. Campaign 2 and 3, which were done in the wet season still showed positive correlation, although not significant ($p > 0.05$). This period was characterized by heavy rainfall events, which resulted in the river carrying away suspended material within the flow, thereby affecting turbidity, resulting in a strong positive correlation of 0.983, although not significant. As the rainfall season progressed, NDVI increased, a study by Rundquist and Harrington (2000) concluded that NDVI has a strong positive relationship with precipitation.

Increased NDVI resulted in less erosion as vegetation cover increased resulting in the r value decreasing from 0.983 to -0.58. However, a study done Chien *et al*. (2015) showed that turbidity has a negative correlation with NDVI. In their study, after incorporating NDVI in their model the explaining ability and improvement rate of their model increased by 11.2 and 8.72% respectively. As the rainfall season progressed the correlation was -0.581.

TDS results showed that there was a positive correlation between NDVI and TDS, although not significant for Campaign 1 and 2. This was contrary to the findings of a study done for both the drier (Sanyati and Mzingwane) and wetter (Mazowe and Manyame) catchments, which showed that TSS decreased significantly as the mean vegetation density increased (Murwira *et al*., 2014). Since TSS and TDS have a strong positive relationship, similar results were expected. The positive correlation can be attributed to the increased NDVI from agricultural fields which in turn contribute to increase in TDS from runoff with chemicals and fertilizers from those fields particularly for February campaigns. Figure 5.16 shows the changes in NDVI from Landsat images and February had the highest NDVI.

In summary, there is a strong significant positive relationship between NDVI and turbidity in the dry season (Campaign 1), this is mostly due to mining activities prevalent at that time. TDS shows strong significant positive relationship with NDVI in the wet season which can be attributed to more agricultural practices and therefore washing away of dissolved solids into Muzvezve River.

5.7 Water quality assessment for Claw dam

Inorder to evaluate the water quality changes of Claw dam using remote sensing, ground measured points within Claw dam were taken into ILWIS software (ITC, 2007) and produced the maps shown in Figures 5.18, 5.19 and 5.20. Nutrients are important in influencing accrual of algal biomass in streams where extended periods of low flow occur in certain seasons. Higher nutrient concentrations tend to occur in streams with longer periods of stable flow (i.e., >20 day accrual), and biomass in these systems is also higher for a given nutrient concentration than in streams with shorter periods of stable flow (and thus shorter accrual periods) (Biggs, 2000). In Claw dam, the flow was stable during the study period due to the rainfall pattern which was unpredictable and infrequent.

Chlorophyll a was high at points P4, P9 and P3; this is the upper part of the dam, as shown in Figure 5.19. There was high productivity there due to organic compounds being carried into the dam from Muzvezve River; this caused an increase in the mean monthly nutrient concentrations of the stable flow into the dam. Once deposited, sedimented materials either buffer or modify nutrient concentrations in overlying water. These regulatory processes are influenced by flow regime, reservoir morphology, tributary loading, trophic state, and the presence of gradients (Thornton *et al*., 1985).

Differences in basin morphology influence nutrient gradients, with the broad, deep basin having a longer residence time (Thornton *et al*., 1985). Therefore, the quantity of material retained in this basin would, be greater than that retained in the narrow, shallow basin. Claw dam basin is narrow and shallow as shown in Figure 4.2, meaning that the amount of material it is likely to retain is lower.

Distance downstream from the river mouth is a surrogate measure of time. Therefore, in the narrow, shallow basin concentrations along the length would decline less sharply and to a lesser extent than in a broad, deep lake. Turbidity interferes with photosynthesis, since algal development may be attenuated by the presence of suspended inorganic particles (McCartney *et al*., 2001). This can also explain the low Chlorophyll a concentration in the End-March campaign which had very high turbidity (as shown in Figure 5.21).

The deep lower part of the dam recorded the deepest secchi depth, whilst the upper part of the dam recorded the lowest Secchi depths. This is shown in Figure 5.19.

The lower part is deeper and also shows lower Chlorophyll a. Chlorophyll a has a negative correlation with Secchi depth (Mohamed, 2015), this is also shown in Figure 5.18.. At P5 which is close to Brompton gold mine the chlorophyll a concentrations are low, this may be due to the effect of chemicals used during mining which kill algael growth and reduce primary productivity.

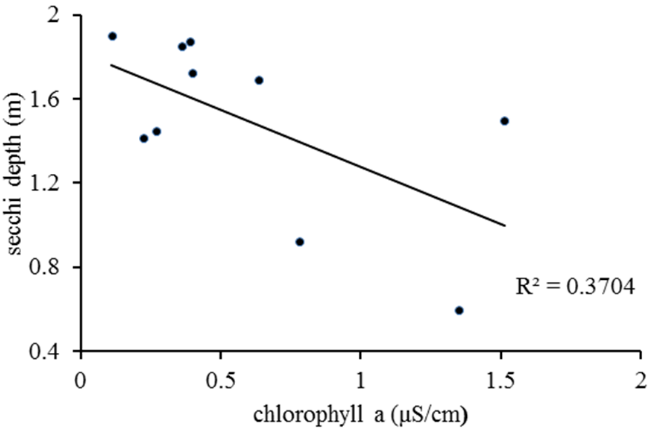

Figure 5.18: Correlation between Secchi depth and Chlorophyll a

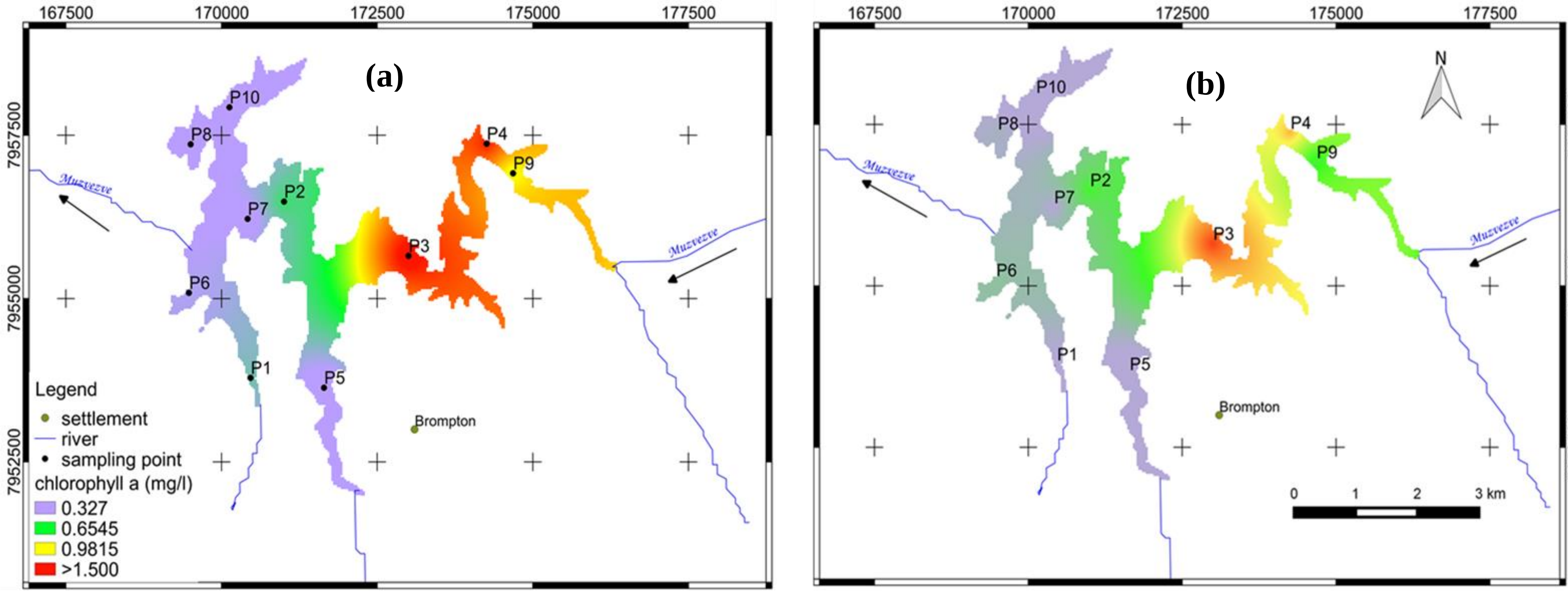

Figure 5.19: Maps showing chlorophyll a concentrations variations within Claw dam for the two sampling campaigns respectively (a) Early March 2016 (b) End of March 2016 campaigns

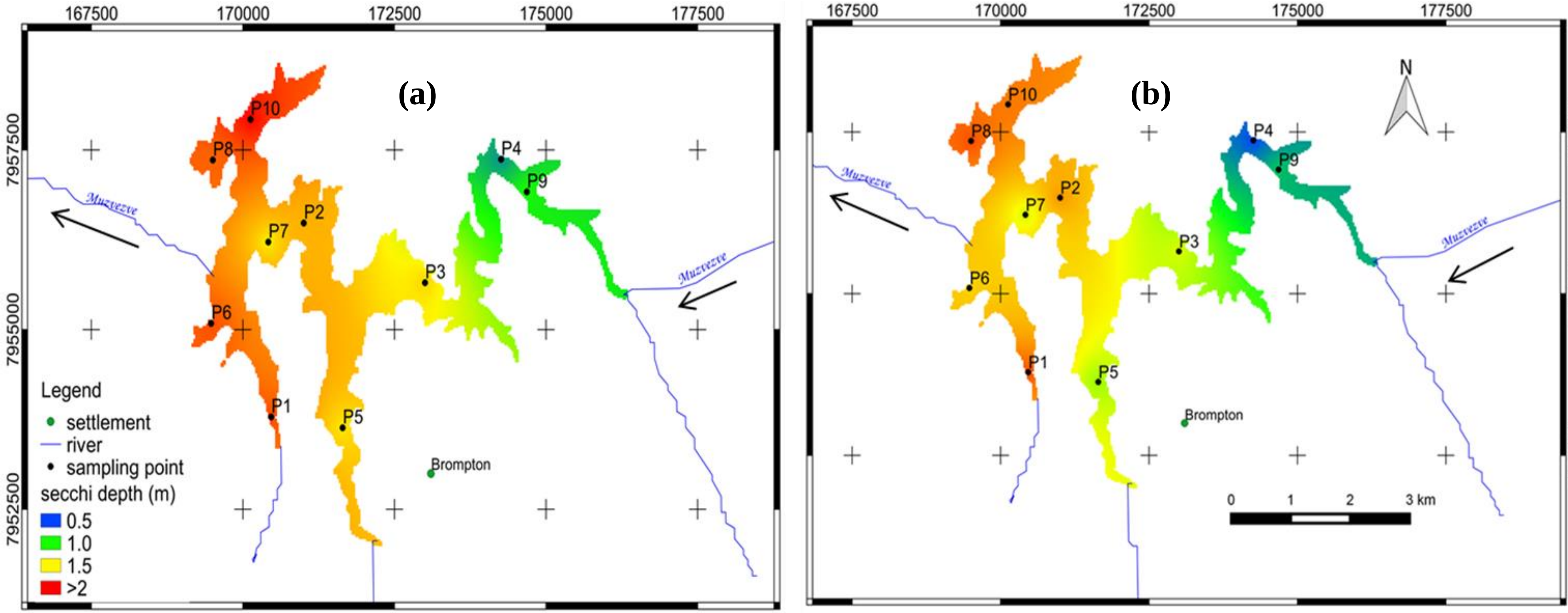

Figure 5.20: Maps showing Secchi depth variations within Claw dam for the two sampling campaigns respectively (a) Early March 2016 (b) End of March campaigns

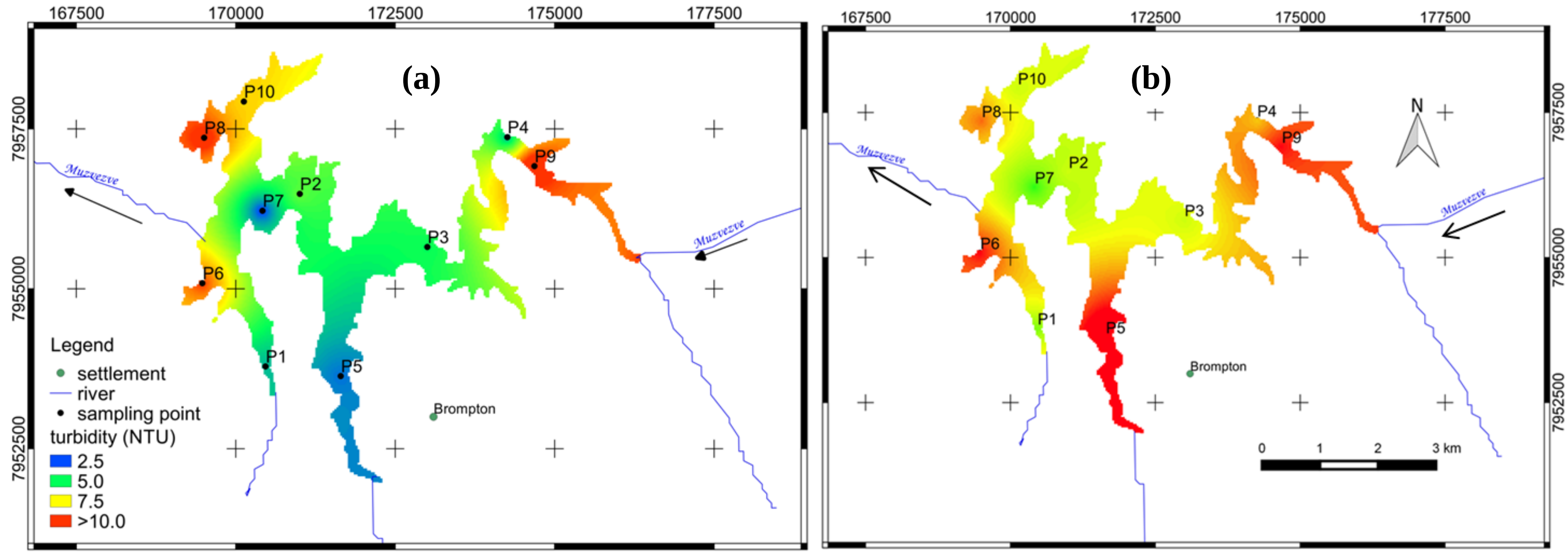

Figure 5.21: Maps showing turbidity variations within Claw dam for the two sampling campaigns respectively (a) Early March 2016 (b) End of March 2016 campaigns

Turbidity in End-March (Figure 5.21(b)) is higher than in Early-March (Figure 5.21(a)), this is because of the progression of the rainy season which washes away suspended and soil particles into the dam thereby increasing turbidity. Turbidity was however highest at P4 and P9 than at the lower part of the dam, because of the settling down of material to the reservoir bottom as the water flows through the reservoir.

5.7.1 Satellite imagery results

For the development of equations to use in satellite imagery regression with ground measured results, there was the selection of the most appropriate bands to use in regression for each parameter. The bands which were used are shown in Table 5.3.

Table 5.3: Bands used for parameter determination in statistical analysis

Parameter	**Bands**	**Wavelength (μm)**
Turbidity	Band 2 (Blue) Band 4 (Red) Band 5 (NIR)	0.452-0.512 0.636-0.673 0.851-0.879
Chlorophyll a	Band 4 (Red) Band 5(NIR)	0.636-0.673 0.851-0.879
Secchi depth	Band 2 (Blue) Band 4 (Red)	0.452-0.512 0.636-0.673

5.7.2 Relationship between ground-measured parameters and satellite data

In this section, Pearson correlation was used to determine the correlation coefficients which show the strength of the correlation between the measured parameters and the different wavelengths. Pearson correlation was made use of because the data was found to be normally distributed when normality tests were done. Regression analysis was not made use of because the datasets used had less than 10 points which is the minimum data requirement for regression analysis (Faraway, 2002).

5.7.3 Relationship between turbidity and reflectance

Pearson correlation analysis showed positive relationships for all bands, and the r values were 0.52 for the Blue band, 0.47 for the Red band 4 and 0.7 for the NIR band. NIR showed the highest correlation coefficient of 0.7, than all the other bands. The correlation coefficient of 0.7 indicates a strong positive relationship, meaning as the NIR wavelength increases, so does the turbidity. This means turbidity values can be predicted from the NIR values in Band 5.

In the visible spectrum, the Blue and the Red bands have higher reflectance than NIR, thus the r value in the Blue band is higher (r=0.52). Increasing amounts of dissolved inorganic materials in water bodies tend to shift the peak of visible reflectance toward the Red region from the Blue/Green region (clearer water) of the spectrum. This can explain the high r value exhibited by NIR (Hellwegera *et al.*, 2004; Ritchie *et al.*, 2003; Yang, 2016). Figure 5.22 shows the scatter plots of the relationship of the reflectance in the Red to NIR bands versus field measured turbidity in Claw dam.

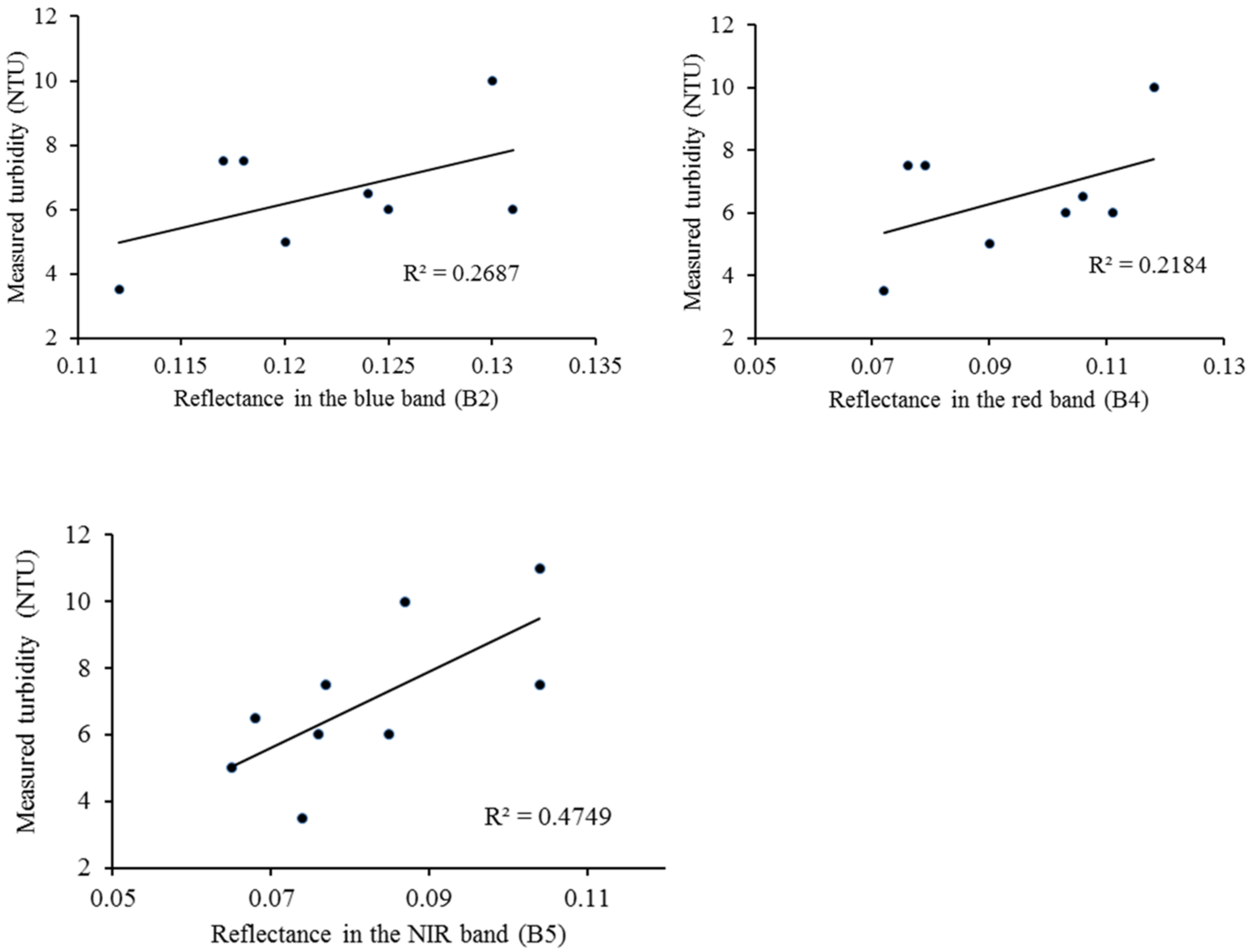

Figure 5.22: Scatter plots of the relationship of the reflectance in the Red to NIR bands versus field measured turbidity in Claw dam

5.7.4 Relationship between Secchi depth and reflectance

There was a positive relationship between reflectance and the Blue band, with r value of 0.41, and for the Red band there was no relationship. The correlation coefficient of 0.41 showed that there was a weak positive correlation. This means the Blue band cannot be used to predict secchi depth in Claw dam. The weak correlation, this is probably caused by atmospheric scattering which occurs in the Blue and Green bands. Secchi depth showed no relationship with the Red band because of the low reflectance of the wavelength, this situation would have been however different if the river had significant amounts of sediments as sediments have higher reflectance in all visible bands. The results are consistent with those from a study done by Hellwegera *et al*. (2004), which showed that reflectance in the Red band generally decreases with Secchi depth. Figure 5.23 shows the scatter plots of the relationship of the reflectance in the Blue to Red bands versus field measured Secchi depth in Claw dam.

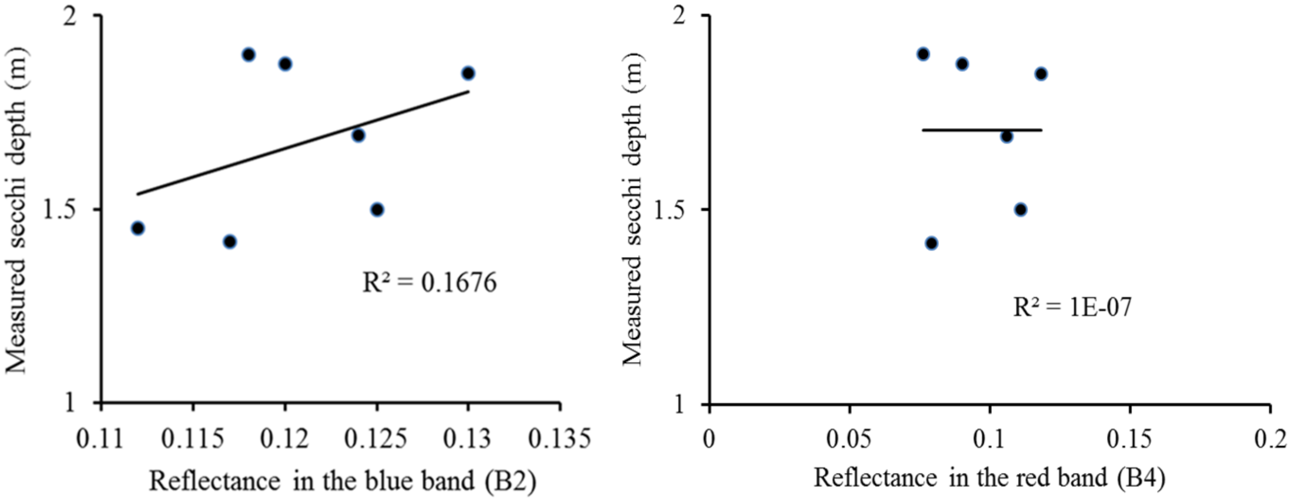

Figure 5.23: Scatter plots of the relationship of the reflectance in the Blue to Red bands versus field measured Secchi depth in Claw dam

5.7.5 Relationship between Chlorophyll a and reflectance

Pearson correlation analysis showed positive relationships for the Red band and a negative relationship for the NIR band, and the r values were 0.68 and -0.7 respectively. NIR band showed a negative strong relationship, probably due to the wavelength's low water depth penetration ability, therefore low reflectance. Similar results were obtained in previous studies which concluded that NIR band is highly sensitive to Chlorophyll a (Lim and Choi, 2015; Yang, 2016). However, it is also important to note that the best spectral indices for retrieving chlorophyll a are dependent on the spectral characteristics of the waters investigated, and possibly even the time it was investigated (Tilstone *et al*., 2012). This is because inland waters are optically complex and their reflectance is determined by the combined effects of absorption and scattering by phytoplankton particles, inorganic and organic particles, and colored dissolved organic matter (Yang, 2016).

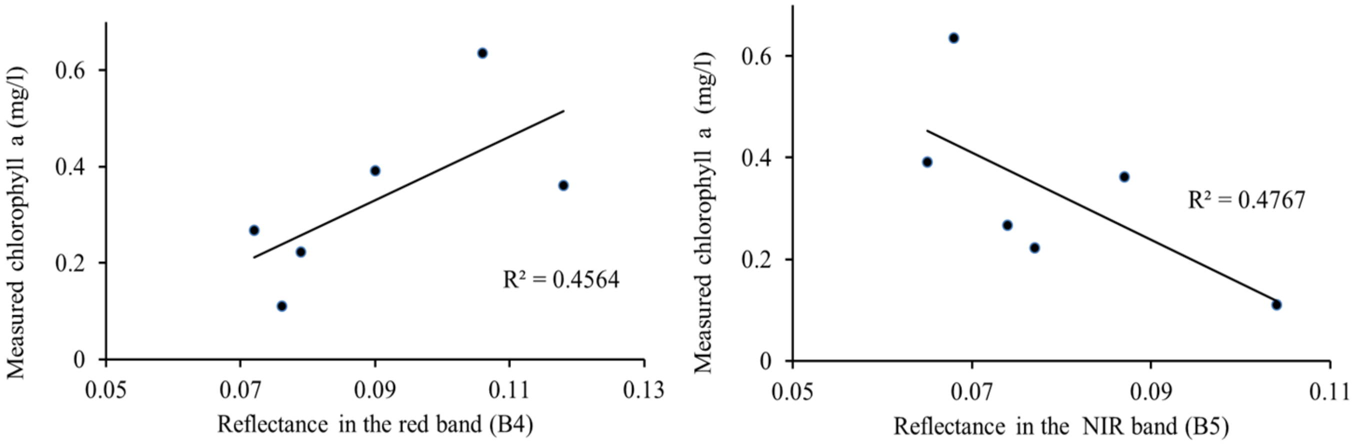

Figure 5.24: Scatter plots of the relationship of the reflectance in the Red to NIR bands versus field measured chlorophyll a in Claw dam

In summary, the measured turbidity values had positive correlation with all the wavelengths which were used. Secchi depth had weak correlation with the respective bands. Chlorophyll a had a negative and positive relationship for NIR and Red bands respectively.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Based on the findings of this study, the following conclusions can be drawn:

1. Most of the measured water quality parameters of Muzvezve River are below the EMA effluent regulations recommended standards In fact, the parameters which were below the threshold levels include EC, TDS, coliforms, BOD, COD, turbidity, phosphates and coliforms. However, based on WHO standards, the Muzvezve River water was found to be not safe for drinking without some form of appropriate effective treatment. In this regard, one can conclude that Muzvezve river water quality is fairly good..
2. Agriculture and settlement had no significant effect on water quality. Mining has significant effect as seen by high Zinc and Lead concentrations especially in the dry season, where the zinc (1.3 mg/l) and lead (0.07 mg/l) concentrations were both above the recommended EMA thresholds of 0.5 and 0.05 mg/l respectively. This proves that land use does affect the water quality of Muzvezve River.
3. There was a significant ($p < 0.05$) positive relationship between dry season turbidity and NDVI values. Conversely, there was a significant ($p < 0.05$) positive relationships between TDS and NDVI values during the wet season. From these results, it can be concluded that land cover could be used to predict turbidity during the dry season and TDS during the wet season. This shows that land cover does affect the water quality of Muzvezve River.
4. For Claw dam the measured turbidity values had positive correlation for all the wavelengths which were used. Secchi depth had a weak relationship with the respective bands. Chlorophyll a had a negative and positive relationship for the Near Infrared and Red bands respectively. From the results, it can be concluded that more work needs to be done on testing whether remotely sensed data can be used to estimate water quality in environments similar to the study area.

6.2 RECOMMENDATIONS

1. The organisations responsible for pollution control in Muzvezve Subcatchment (e.g. Environmental Management Agency and Zimbabwe National Water A) should consider developing a mechanism that helps assess management efforts in addressing pollution especially from mining and increasing settlements.

2. Water quality monitoring using secchi disk could be done by taking samples before and after the satellite image acquisition. This may be beneficial in establishing a more representative outline of Secchi depth levels and help in eliminating errors that may occur due to the variations in sun angle. With a more comprehensive dataset, a model could potentially be developed with a higher degree of correlation.

3. The responsible agencies for water quality management should consider use of GIS and remote sensing for near- real time and rapid water quality assessments. This could be more beneficial if they would use data sets with >20 sampling points within the dam and the points should be collected in the deepest parts of the dam to avoid spectral and floating vegetation interference. This could then be used to produce regression models for future prediction of water quality within dams.

6.2.1 Recommendations for further research

1. There is need to measure other nutrients like phosphate within the dams for rapid water quality assessment, as this helps in explaining the nutrient gradient which is useful in discussing water quality parameters like Chlorophyll a

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APPENDIX 1: GALLERY OF PHOTOS FOR FIELD WORK AND LABORATORY ANALYSIS

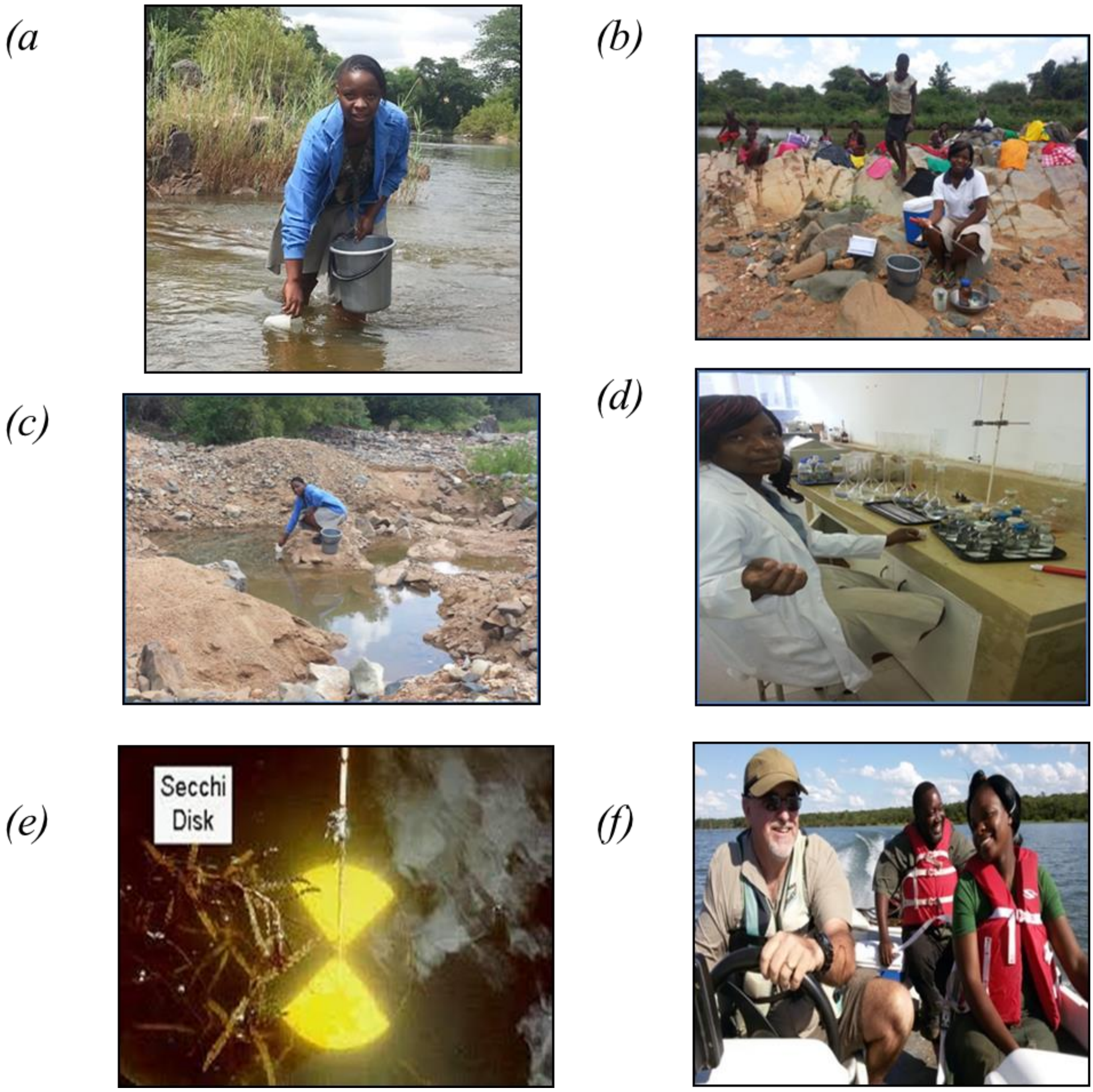

Figure A1-1 showing: (a) Grab sampling method (b) Settlements site (SP4) and locals doing their laundry along the Muzvezve River (c) Mining site (SP6) along the River with high degradation due to alluvial mining (d) Laboratory analysis at UZ Civil Engineering Water Laboratory- BOD Winkler method titration (e) Secchi disk used to collect Secchi depths (f) Collection of samples within Claw Dam

APPENDIX 2: STATISTICAL A NALYSES RESULTS FOR ALL PARAMETERS USING SPSS

NB: Results highlighted in bold italic show a significant difference between campaigns

(A) pH ANALYSIS

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Mid-Dec	.178	5	.200*	.981	5	.940
Mid-Jan	.171	5	.200*	.959	5	.803
End-Jan	.408	5	.007	.618	5	.001
Mid-Feb	.254	5	.200*	.914	5	.492
End-Feb	.248	5	.200*	.920	5	.530

Wilcoxon Signed Ranks Test

	Mid-Jan	End-Jan	Mid-Feb	End-Feb
Mid-Dec	***0.043***	***0.043***	***0.041***	***0.043***
Mid-Jan	-	***0.028***	*0.075*	***0.027***
End-Jan	***0.028***	-	***0.027***	***0.028***
Mid-Feb	*0.075*	***0.027***	-	***0.028***
End-Feb	***0.027***	***0.028***	***0.028***	-

(B) ELECTRICAL CONDUCTIVITY

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Mid-Dec	.231	5	.200*	.848	5	.188
Mid-Jan	.251	5	.200*	.823	5	.124
End-Jan	.239	5	.200*	.829	5	.137
Mid-Feb	.247	5	.200*	.848	5	.189
End-Feb	.280	5	.200*	.795	5	.074

APPENDIX 2 CONT'D

Paired Samples Test

	Mid-Jan	End-Jan	Mid-Feb	End-Feb
Mid-Dec	*0.491*	*0.440*	*0.523*	*0.322*
Mid-Jan	-	*0.742*	*0.478*	*0.861*
End-Jan	*0.742*	-	*0.377*	*0.224*
Mid-Feb	*0.478*	*0.377*	-	*0.245*
End-Feb	*0.861*	*0.742*	*0.245*	-

(C) TOTAL DISSOLVED SOLIDS

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Mid-Dec	.226	5	.200*	.854	5	.209
Mid-Jan	.250	5	.200*	.831	5	.141
End-Jan	.237	5	.200*	.844	5	.177
Mid- Feb	.248	5	.200*	.845	5	.178
End-Feb	.273	5	.200*	.796	5	.075

Paired Samples Test

	Mid-Jan	End-Jan	Mid-Feb	End-Feb
Mid-Dec	*0.520*	*0.472*	*0.529*	*0.327*
Mid-Jan	-	*0.765*	*0.559*	*0.843*
End-Jan	*0.765*	-	*0.541*	*0.218*
Mid-Feb	*0.559*	*0.541*	-	*0.279*
End-Feb	*0.843*	*0.218*	*0.279*	-

APPENDIX 2 CONT''D

(D) TURBIDITY

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
mid-Dec	.331	5	.078	.784	5	.059
Mid-Jan	.309	5	.133	.750	5	.030
End-Jan	.262	5	.200*	.847	5	.185
Mid-Feb	.351	5	.044	.777	5	.052
End-Feb	.231	5	.200*	.903	5	.427

Wilcoxon Signed Ranks Test

	Mid-Jan	End-Jan	Mid-Feb	End-Feb
Mid-Dec	*0.225*	*0.686*	*0.500*	*0.225*
Mid-Jan	-	*0.173*	*0.249*	*0.345*
End-Jan	*0.173*	-	***0.028***	***0.046***
Mid-Feb	*0.345*	***0.046***	-	*0.249*
End-Feb	*0.345*	***0.046***	*0.249*	-

(E) PHOSPHATES

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Mid-Dec	.171	5	.200*	.956	5	.778
Mid-Jan	.441	5	.002	.654	5	.003
End-Jan	.172	5	.200*	.948	5	.721
Mid-Feb	.154	5	.200*	.979	5	.931

Wilcoxon Signed Ranks Test

	Mid-Jan	End-Jan	Mid-Feb
Mid-Dec	*0.686*	*0.465*	*0.225*
Mid-Jan	-	*0.225*	*0.225*
End-Jan	*0.225*	-	*0.686*
Mid-Feb	*0.225*	*0.686*	-

APPENDIX 2 CONT'D

(F) COD

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Mid-Dec	.335	5	.069	.860	5	.228
Mid-Jan	.355	5	.038	.808	5	.094
End-Jan	.224	5	.200*	.842	5	.171
Mid-Feb	.348	5	.047	.779	5	.054
End-Feb	.287	5	.200*	.914	5	.490

Wilcoxon Signed Ranks Test

	Mid-Jan	End-Jan	Mid-Feb	End-Feb
Mid-Dec	*0.588*	*0.197*	*0.785*	*0.063*
Mid-Jan	-	*1.000*	*0.500*	*0.500*
End-Jan	*1.000*	-	*0.194*	*0.785*
Mid-Feb	*0.500*	*0.194*	-	*0.114*
End-Feb	*0.063*	*0.785*	*0.114*	-

(G) BOD

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Mid-Dec	.280	5	.200*	.923	5	.549
Mid-Jan	.219	5	.200*	.933	5	.616
End-Jan	.239	5	.200*	.905	5	.437
Mid-Feb	.297	5	.173	.787	5	.063
End-Feb	.282	5	.200*	.915	5	.498

APPENDIX 2 CONT'D

Paired Samples T-Test

	Mid-Jan	End-Jan	Mid-Feb	End-Feb
Mid-Dec	*0.115*	***0.046***	*0.649*	*0.310*
Mid-Jan	-	*0.630*	*0.283*	*0.939*
End-Jan	*0.630*	-	*0.968*	*0.649*
Mid-Feb	*0.283*	*0.968*	-	*0.093*
End-Feb	*0.939*	*0.649*	*0.093*	-

(H) TOTAL COLIFORMS

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Mid-Dec	.420	5	.004	.622	5	.001
Mid-Jan	.173	5	.200*	.968	5	.865
End-Jan	.456	5	.001	.578	5	.000
Mid-Feb	.277	5	.200*	.831	5	.141
End-Feb	.199	5	.200*	.922	5	.545

Wilcoxon Signed Ranks Test

	Mid-Jan	End-Jan	Mid-Feb	End-Feb
Mid-Dec	*0.225*	*0.893*	*0.225*	*0.893*
Mid-Jan	-	*0.249*	***0.046***	*0.046*
End-Jan	*0.249*	-	***0.027***	*0.917*
Mid-Feb	***0.046***	***0.027***	-	*0.345*
End-Feb	***0.046***	*0.917*	*0.345*	-