THE EFFECTS OF POLLUTION ON THE PHYSICO-CHEMICAL PARAMETERS OF WATER AND DIVERSITY OF AQUATIC MACROINVERTEBRATES: A CASE STUDY OF THE KHAMI DAM.

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ABSTRACT

The impact of industrial effluent discharged into Khami Dam was assessed through physico-chemical parameters and also by bio-monitoring of benthic macro-invertebrates. Samples for physico-chemical parameters were measured at three sites over a period of six months and sampling was done once each month. Composite samples of 1000ml for nitrates and phosphates were collected using a beaker on all sites and placed on schott bottles and placed on ice filled cooler boxes and were then taken to the laboratory and refrigerated at (< 4 ^{o}C) for analysis using a Hach spectrophotometer (DR010 Hach Co, Loveland, Colorado, USA). Temperature was measured using a mercury bulb thermometer at the dam; the bulb was placed in the water and allowed to stand for 5 minutes and the recordings were taken. pH was measured using a Mettler Toledo 320 pH meter at the dam, the probe was placed in the water for 5 minutes and the readings were taken. An oxygen meter was used to measure the amount of dissolved oxygen at the dam, the probe was allowed to stand for 5 minutes and results were taken. A Mettler Toledo MC 226 conductivity meter was used to measure conductivity at the dam, the conductivity probe was allowed to stand for 10 minutes and results were taken. Total Dissolved Solids (TDS) were measured using the filter paper method where a volume 1000ml of composite sample was filtered using a filter paper and allowed to dry for 5 days at room temperature. Turbidity levels were measured using the Hach 2100A turbidity meter at the dam, that is, the probe was allowed to settle for 5 minutes and the readings were recorded. The Shannon-Wienner and Evenness indices were used to assess the health of the dam using aquatic macroinvertebrates as indicators of pollution. The highest diversity was observed at site 1 (reference point) having the highest value (1.957) and the least was at site 2 (middle point of the dam) with a value of (1.705). High levels of chemical pollutants were recorded at sites 2 and 3 (ZINWA red category) whereas site 1 (reference site) consisted of relatively clean water (ZINWA blue category). All the physical and chemical parameters were measured at selected sites on the dam and were analysed using one way anova. There were no significant differences for pH ($p > 0.05$), pH ranged from 8.4 to ± 8.2 units. For conductivity there were significant differences ($p < 0.05$) conductivity ranged from 487 to ± 160μScm^{-1}. As for oxygen there were significant differences ($p < 0.05$) oxygen ranged from 7.8 to ± 5.7 mgL^{-1}, whilst temperature showed no significant differences ($p > 0.05$) temperature ranged from 30.32 to ±27.88 ^{0}C. There were significant differences of TDS amongst the sites ($p < 0.05$) conductivity ranged from 576 to ±105 ppm. Phosphates ranged from 10.65 to ±0.1 mgL^{-1} as a result there were no significant differences amongst the sites (anova $p < 0.05$); however nitrates ranged from 2.07 to ± 0.01mgL^{-1} therefore there were significant differences. Turbidity ranged from 0.5 to ±0 NTU; hence there were significant differences amongst the sites ($p < 0.05$). These were compared with the standards set by ZINWA for waste water. The results of the study showed that there was a high degree of pollution on the Khami Dam and recommendations on reduction of pollution in the dam should be made. Sources of water pollution included effluents from industries, sewage and agricultural practices by the nearby farmers.

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DEDICATION

This work is dedicated to my mother Sibongile Moyo and my late father Steven Dondo.

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ACRONYMS

ZINWA:	Zimbabwe National Water Authority
NTUs:	Nephelometric Turbidity Units
WHO:	World Health Organization
TDS:	Total Dissolved Solids
EMA:	Environmental Management Act
LEAP:	Local Environmental Action Plans
EIA:	Environmental Impact Assessments

CHAPTER 1: INTRODUCTION

1.1 Background

Water is essential to all forms of life and makes up 50-97% of the weight of all plants and animals and about 70% of human body (Allan, 1995). Water is also a vital resource for agriculture, manufacturing, transportation and many other human activities. Despite its importance, water is the most poorly managed resource in the world (Chutter, 1998).

The availability and quality of water has always played an important role in determining the quality of life. Water quality is closely linked to water use and to the state of economic development (Chapman, Jackson and Krebs, 1996). Ground and surface waters can be contaminated by several sources. In urban areas, the careless disposal of industrial effluents and other wastes may contribute greatly to the poor quality of water (Mathuthu, Mwanga. and Simoro, 1997). Most of the water bodies in the areas of the developing world are the end points of effluents discharged from industries (Mathuthu *et al.*, 1997).

Pollution of the aquatic environment as defined by GESAMP (1988), occurs when humans introduce wastes, either by indirect or direct discharge, into the water. Pollution is introduced through atmospheric pollution, substances or energy that result in deleterious effects such as hazards to human health, harm to living resources, disturbance to aquatic activities such as impairment of water quality with respect to its use in agriculture, industry or fishing and reduction of amenity value (GESAMP, 1988). Water pollution is also defined as the undesirable and unwanted presence of a chemical on a given natural water body (Trumble and Vickerman, 2003). This is a major problem which is affecting all continents, nations and hence as a result it is frequently crossing natural and political boundaries (Trumble and Vickerman, 2003).

Water pollution is a major problem in the global context (Moyo and Worster, 1997). The problem of water pollution is being experienced by both developing and developed countries (Moyo and Worster, 1997). Sewage disposal is of major concern in most urban areas of Zimbabwe. Wastewater from industries and sewage spillages from burst pipes around the country are released into streams and rivers which finally discharge into dams around the cities of Zimbabwe (Moyo and Worster, 1997). With the prevailing hard economic situation in the country, most of the trade waste effluents are released into the environment untreated or partially treated (Moyo and Worster, 1997).

Industrialists have adopted the use of sub-standard treatment methods that partially treat and in some instances, forego the effluent treatment process (Moyo and Worster, 1997). In Bulawayo, Zimbabwe, raw sewage is at times discharged into Khami Dam (Moyo and Worster, 1997). The same problem was experienced in the Lake Chivero catchment where raw sewage was finding its way into Manyame, Marimba and Mukuvisi rivers, the tributaries of the lake leading to its eutrophication (Moyo and Worster, 1997). The result is an increase in organic pollutant loads hence increased algal growth that greatly affects aquatic macroinvertebrate diversity (Chutter, 1972).

Macroinvertebrates are often given a ranking according to how well or badly they tolerate living in water of bad quality and as a result the better the water quality the greater the number of animals that will be present. The tolerance levels are mainly based on organic pollution, such as sewage, high loads of leaf matter, dog faeces, or agricultural run-off, which cause lowered oxygen levels. The tolerance levels of the macroinvertebrate groups may vary with other forms of pollution such as toxic metals, pesticides and sediment inputs. Within the group, tolerances of individual species may vary (Arimoro, Iwegbue. and Enemudo, 2008).

1.2 Justification

Khami Dam is located near the residential area and has not been spared from pollution. Effluent from the old sewage treatment plant located on the Phekiwe stream, whose treatment is not as effective probably due to lack of funding or failure to cope with the loads received, are discharged into water ways that eventually lead into Khami Dam. The sewage system is also old and this has been evidenced by the frequent pipe bursts in the Pumula South area. These eventually reach the Khami dam via its tributaries (Gumbo, 1997).

The dam could also be suffering pollution from farms which lie in its catchment. These include the farmers in resettlement plots in the Umguza catchment. The runoffs from their fields contribute to the addition of organic matter into the dam. The level of nutrients such as phosphorous and nitrates in freshwater ecosystems is a worldwide problem (WHO, 2000). In most cases, the major cause of these contaminations is the increased use of manure and manufactured fertilizers in agriculture. In the United States, for example, agriculture is the single greatest source of pollution degrading the quality of surface waters like rivers and lakes with croplands alone accounting for 40% of the Nitrogen pollution and 30% of the Phosphorous pollution (WHO, 2000). WHO (2000) noted that natural waters have low nitrate and phosphorous levels but these increase with runoff from farmlands as well as from industrial wastewater. Eutrophication of lakes and rivers is a critical problem in Asia and some parts of African countries of which the main cause is nitrogen and phosphorous contained in fertilizers.

Fishing is an activity that occurs in the dam and therefore adds to the pollution. Fishing is a concern as it may result in a fully degraded ecosystem as a result of overfishing. This results in a dead zone with excessive nutrients in the water column, resulting in oxygen depletion and elimination of organisms beneficial to the ecosystem (WHO, 2000).

Water quality is of vital importance not only to human life but also to animal, aquatic and plant life. Water used for drinking and cooking should be free from pathogenic microorganisms that cause illnesses such as typhoid fever, dysentery, cholera and gastroenteritis. The presence of harmful bacteria in effluents from industries and other illegal deposits has adverse effects on human beings and are responsible for disease outbreaks through the consumption of fish caught in these polluted dams (Cruickshank, Duguid, Marmion and Swain, 1975). The bacterium *Vibrio cholerae* is responsible for causing cholera. Water of very high or low acidity may hinder the growth of plant life thus hampering the ecological balance of a particular area (Cruickshank *et al*., 1975). All life is dependent on water, for example human beings, aquatic life, domestic and wild animals (Cruickshank *et al*., 1975). Strictly speaking chemically pure water does not exist for any period of time in nature (Cruickshank *et al*., 1975). When falling as rain, it picks up small amounts of gases, ions and dust from the atmosphere. Then as it flows on surface layers it dissolves and carries with it some of the effluent particles which are dumped recklessly and everything it touches, including that which is dumped into it by man. These added substances maybe classified as biological, chemical (both inorganic and organic), physical and radiological impurities (Cruickshank *et al*., 1975). These include industrial commercial solvents, metals and acid salts, sediments, pesticides, herbicides, plant nutrients, road salts, decaying animal and vegetable matter and living organisms. These give water bad taste, odour and cloudy appearance (turbidity), cause hardness, corrosiveness, staining or froth and they may damage growing plants and transmit disease. Too much of Nitrates and Phosphorous in water systems tend to promote massive growths of algal blooms (eutrophication).

A number of studies on water quality in Zimbabwe have been concerned with assessing the physico-chemical parameters of water (Mathuthu *et al*., 1997; Moyo and Worster, 1997, Magadza, 2003; Ndebele, 2009). No studies have been made at the Khami dam around the main water pan which seek to investigate the effects of water pollution on the physico-chemical parameters of water and diversity of aquatic macroinvertebrates. This study seeks to build a database on the investigation of the effects of pollution in relation to water pollution at Khami Dam.

1.3: Objectives

1.3.1 Main objective:

- to determine the effects of pollution on the physico-chemical parameters of water and diversity of aquatic macroinvertebrates.

1.3.2 Specific objectives:

- to determine the effect of water pollution on species richness and evenness of macroinvertebrates in all the sites,
- to determine the effects of water pollution on the abundance and assemblages of aquatic macroinvertebrates with increase in distance from site one to three,
- to identify chief polluting agents in Khami dam,
- to compare the physico-chemical parameters from site 1 to site 3, and
- to compare aquatic macroinvertebrate's composition and variation among the three sites.

CHAPTER 2: LITERATURE REVIEW

2.1 Water Quality

Water quality can be described in terms of physical, chemical and biological characteristics. Despite having studied the effects of human activities on aquatic systems for decades, the scientists' findings have only been recently translated into methods suitable for monitoring the quality of water bodies (Chapman *et al*., 1996). Changes in the chemical and physical nature of freshwater can produce diverse biological effects and such changes can indicate that the ecosystems along with their associated organisms are under stress or that they are no longer balanced (Chapman *et al*., 1996).

2.2 Types of Pollution

The ecological study of freshwater ecosystems must consider their landscape surroundings, taking into account the spatial arrangement of the ecosystem. Water quality is directly influenced by predominating uses of the land resources within the watershed (Barbosa and Tundisi, 1995). These uses are necessary tools in assessing the existing relationship between aquatic and terrestrial ecosystems. As a result the quantity and quality of effluent inputs are determining factors for the ongoing processes within the water ecosystem. There are two types of pollution sources, point and non-point sources of pollution (Callisto and Moretti, 2005).

2.2.1 Point-source pollution

Point-source pollution is mainly pollution that occurs due to industrial activities. Point source pollutants therefore include effluent from industrial facilities including mining, manufacturing gas and oil extraction and service industries, municipal governments and other government facilities such as military bases and some agricultural facilities which include animal feedlots (Furgal , Smith and Tylor, 1997). In the United States, point sources may not discharge into surface waters without a permit from the National Pollutant Discharge Elimination system as governed by the US Environmental protection Agency in partnership with State Environmental Agencies (Furgal *et al*., 1997).

2.2.2 Non-Point sources

Non-point sources pollution, unlike pollution from the industrial and sewage treatment, comes from many diffuse sources. It is caused by snowmelt moving over and through the ground or precipitation of rain. As the water moves, it picks up and carries natural and man-made pollutants. As a result these are deposited into lakes, wetlands, rivers and even underground sources of water. The non-point sources consist of agricultural storm water discharges and storm water runoffs from industrial sources and municipal storm drains, sediments from improper management of construction sites, crop and forest lands and eroding stream banks and acid drainage from abandoned mines and bacteria and nutrients from livestock and fault septic tanks.

Other common pollutants include organic matter from industrial water and domestic sewage. The effect of organic matter is to deplete oxygen from the water column as it decomposes stressing and suffocating water life. Excess nutrients from agricultural lands overstimulate algal bloom growth. Algae then decompose, robbing water of its oxygen and harming aquatic life. Other sources of pollution include microbial contaminants such as *Cryptosporidium,* cholera and other bacteria or amoeba, for example. The spread of infectious diseases is aggravated by such pollutants which are transmitted through contaminated water causing millions of diarrheal diseases and intestinal parasites and also providing one of the causes of childhood mortality in the developing world (Furgal *et al*., 1997).

Dissolved salts, on the other hand, reduce water quality for drinking and recreation and degrades aquatic habitats smothering them with silt, disrupting spawning and interfering with feeding (Furgal *et al*., 1997). These salts are leached from alkaline soils by over irrigation, soil erosion and construction activities in watersheds (Furgal *et al*., 1997).

In the South American region, in Brazil for example, activities such as the deforestation of the Atlantic forest and the development of economic problems that have an important environmental impact are of major concern. These economical activities include mining, steel processing, gold mining, intense human occupation and reforestation projects with *Eucalyptus* species (Callisto and Morretti, 2005).

In Asia regions, urban water has emerged as one of the most critical forms of environmental degradation (Rock, 2002). Water pollution is therefore now on the political agenda of most Asian countries which include China and Vietnam (Rock, 2002). In terms of solutions they are presented in technical guises such as waste water treatment plants (Rock, 2002). The water pollution, which however now characterizes most of urban Asian, is far from a temporary phase as is shown by the level of development and the conflict ensuring from environment issues (Rock, 2002).

In the region the rivers continue to act as open and increasingly toxic sewers with a few remedies in sight (Rock, 2002). The lack of consensus between the state, civil society and business over the sources of pollution, what needs to be done and by whom, aggravates the situation (Rock, 2002). A classic example is that of the urban poor, who are often the target for pollution blame, environmental issues are also about rights, tenure, responsibilities, citizenship and livelihood (Rock, 2002). The growth of populations has implications in the ecology of the region where population growth has occurred as a result water; air and solid waste pollution have reached extreme levels in most cases (Rock, 2002). In Thailand, 1/3 of its citizen lives and works in urban areas and this scenario has created the Bangkok Metropolitan Region. This kind of growth has been accompanied by a loss of ground cover, deforestation of uplands around cities, contamination of aquifers and seepage of sea water supply sources. An estimated 1.5 billion cubic meters of untreated domestic and industrial pollutants are discharged directly into Bangkok's waterways on a daily basis (Rock, 2002). This is a consequence of the inadequate infrastructure and service provided to informal and poor settlements which are a common feature (Rock, 2002).

2.2.3 Effects of pollution

Pollution has been shown to have diverse and profound effects on different living organisms, numerous studies have attempted to assess the effects of organic pollution on macroinvertebrates (Callisto and Moretti, 2005). Such body enrichment usually changes community structure when the most sensitive species disappear and increase the relative abundance of the more tolerant group (Callisto and Moretti, 2005).

2.3 Water pollution in developed and developing countries

Water pollution is not just a small problem in the global context; the problem of water pollution is being experienced by both developing and developed countries (Moyo and Worster, 1997). In developed countries, treatment and discharge systems of sewage can sharply differ between countries and between rural and urban users, with respect to socio-economic income (Doorn, Towprayoon, Maria, Vieira, Irving, Palmer, Pipatti and Wang, 2006). The disposal of wastewater should be considered as a matter of urgency across the world. For example, the Thames River in England was once regarded as the ‘sewer’ of Europe because treated sewage effluent was being discharged directly into it causing disastrous effects on the natural water ecosystem (Wells, 1975). In Canada, St Mary’s River was listed as one of 43 areas of concern in the Great lakes due to high levels of pollutants discharged from industries and wastewater treatment plants. These elevated levels of pollutants caused disturbances to the natural ecosystem leading to loss of a lot of macroinvertebrates, fish species richness and diversity and eutrophication (Ripley, 2009).

In Uganda, a study on the impact of industrial effluents on water quality was done by Walakira (2011). The streams were assessed so that preventive measures of effluent disposal could be taken. These streams pass through Kinawataka wetland that is being degraded thus increasing the degree of pollution into Lake Victoria (Walakira, 2011). Water samples were taken from areas with active industrial activities and from an area where there is no industrial activity. The water samples they assessed were tested for parameters which include pH, heavy metals, turbidity and conductivity. They discovered that there was a high degree of pollution in the stream and recommendations on reduction of pollution in the streams were made (Walakira, 2011). Sources of water pollution include effluents from a fish filleting industry, foam mattress manufacturing/metal fabricating industry, soft drinks manufacturing industry, pharmaceutical industry and food processing industry (Walakira, 2011).

A study on the industrial effluents and their impact on water quality on receiving rivers in Nigeria clearly showed that Industrial wastewaters, when they enter a water body, represent a heavy source of environmental pollution (Kanu, Achi, Ezeronye, and Anyanwu, 2011). It actually affected both the microbial and aquatic flora as well as the water quality. Industrial wastes which contained high concentration levels of microbial nutrients obviously promoted an after-growth of significantly high coliform types and other microbial forms (Kanu *et al.*, 2011). The release of industrial pollutants into the receiving water bodies in Nigeria invariably resulted in the presence of high concentrations of pollutants in the water and sediment (Kanu *et al.*, 2011). The pollutants had shown to be present in high concentration levels, which were toxic to different types of organisms. The effluents also had considerable negative effects on the water quality of the receiving water bodies and as such, they were considered not good for human consumption (Kanu *et al.*, 2011).

Dumping of sewage and industrial chemicals is one of the major concerns in most developing countries such as Zimbabwe in their urban areas (Moyo and Worster, 1997). Contaminated wastewater from industries and sewage spillages from burst pipes around the country are discharged into rivers and streams which finally release into dams around the cities of Zimbabwe. With the ongoing hard economic situation in the country, most of the trade waste effluents are released into the natural water bodies partially treated or untreated. A few industrialists have adopted the use of low grade treatment methods that partially treat and in some instances, forego the effluent treatment process (Moyo and Worster, 1997). At Thorngrove sewage works, Zimbabwe, raw sewage is at times discharged into Mazai stream to avoid plant clogging when electricity cuts are experienced (Moyo and Worster, 199). Lake Chivero catchment is facing the same problem, that is, raw sewage is finding its way into Mukuvisi, Manyame and Marimba rivers, the lake's tributaries, leading to its eutrophication (Moyo and Worster, 1997).

A study carried out by the Management of Industrial and Municipal Effluents and Urban Run-off component of the Lake Victoria Environmental Management Project (LVEMP, 2002), indicated that most factories in Uganda do not have effluent treatment plants, even where they are existing, most industrial wastewater treatment plants are poorly designed and constructed (LVEMP, 2002). Of those that have wastewater treatment plants, few, if any, of those examined were achieving effluent discharge standards. Also a similar study carried out by Muwanga and Barifaijo (2006) established industrial effluents as one of the main pollution sources of Kinawata wetland, which receives water from Nakawa-Ntinda streams.

The city of Bulawayo in Zimbabwe has three major man-made dams which are used by people for different purposes and these dams are under strict control in the authority of Bulawayo City Council. The three dams serve as a source of livelihood for the poor households who live nearby in terms of source of income and food security purposes. Hillside, Khami and Umguza dams have reported cases of people poaching the fish in there (Chenje, 2000). High effluent flows have been reported into the Umguza catchment downstream dams. These include Khami, Upper Umguza and Lower Umguza Dams which are located downstream of the effluent discharge zones of Bulawayo City. Hillside Dam is located in a recreational conservancy located upstream of the effluent discharge zones and is therefore considered relatively pristine (Teta, 2014). These dams for many years have been a source of livelihood as the large amounts of locally marketable fish are found in there, but on the other hand the dams are heavily polluted especially with effluents from the industries (Chenje, 2000). The worst case scenario is being experienced at

Khami as a result it is polluted with effluent also from sewage and the effluent discharge is not being treated at all which makes it a harmful to human health. However, some people still go out and fish from these polluted rivers and sell the fish to the surrounding community and some even eat the fish from these dams (Chenje, 2000).

Khami dam is a man-made reservoir located about 20 km west of Bulawayo, which is the second largest city in Zimbabwe and is considered the industrial capital of the country. The city of Bulawayo, despite having six other water supply dams has faced critical water shortages in the past. These shortages have been on the background of droughts, distribution losses and pollution of water within the supply catchments. The non-consumptive water uses included recreation and fishing through an Angling Club that was licensed to stock the reservoir with fish as well as control fishing activities within (Gumbo, 1997). Due to the passage of time there has been growth in population which led to the development of the high-density suburbs of Mganwini, Nkulumane, Tshabalala Extension and Phumula East in the early 1980s and Phumula South in the late 1990s. The suburbs were first occupied in 1983 and development is still going on.

Southern Areas Sewage Treatment Works, with a capacity to treat 6 Ml of sewage per day, was commissioned to treat sewage generated from the new suburbs. In June of 1984 Khami waterworks was closed due to the low level of the reservoir and the imminent commissioning of Southern African Bureau of Standards, which would discharge its effluent into Khami reservoir, at a point 4 km upstream. The effluent from the MAS plant was expected to be of excellent quality, which would enable indirect reuse without any technical problems (Gumbo, 1997).

Low water levels in the major supply reservoirs led to the re-commissioning of Khami waterworks on 1st December 1987 to augment the City's water supply. By mid-November 1988 the quality of raw water at Khami began to deteriorate leading to the decommissioning of the plant on 21st November 1988 (Gumbo, 1997). Up to date the works are still out of commission. The reservoir shows all signs of nutrient enrichment with the surface water looking green and sometimes looking like a thick pea soup.

In most African countries, leather-making is an important source of income; however it can also be a major source of water pollution (UN WWAP, 2003). Imponente Tanning Ltd, a tannery in Harare, Zimbabwe, had high chemical oxygen demand levels in its wastewater, caused by the use of sulfides and other chemicals used to remove the hair from hides by dissolving the hair (UN WWAP, 2003).

2.3.1 Types of pollutants

The city of Bulawayo, due to the low precipitation received in the region, generally witnesses very low water levels in the dams and rivers to dilute any pollutants. This will mean any pollutants reaching the aquatic bodies tend to accumulate over time, reaching extremely high levels in contrast to other similarly polluted cities situated in wet regions (Teta, 2014).

The effects of human activities on water quality are both widespread and varied in the degree to which they disrupt the ecosystem and restrict water use. Pollution of water by human faeces, for example, is attributable to only one source, but the reasons for this type of pollution, its impact on water quality and the necessary remedial or preventive measures varied. Faecal pollution may occur because there are no community facilities for waste disposal, because collection and treatment facilities are inadequate or improperly operated, or because no-site sanitation facilities such as latrines drain directly into aquifers. The effects of faecal pollution vary, in developing countries, intestinal diseases are the main problem, while organic load and eutrophication may be of great concern in developed countries, that is, in rivers into which the sewage or effluent is discharged and in the sea into which the rivers flow or sewage sludge is dumped (Meybeck and Helmer, 1996).

A single influent may, therefore give rise to a number of water quality problems, just as a problem may have a number of contributing influents. Eutrophication results not only from point sources, such as waste water discharges with high nutrient loads principally nitrogen and phosphorus, but also from diffuse sources such as run-off from livestock feedlots or agricultural land fertilized with organic and inorganic fertilizers. Pollution from diffuse sources such as agriculture run-off and faecal pollution from unsewaged settlements are particularly very difficult to control (Meybeck and Helmer, 1996). As a result this was generally in agreement with the accepted principle that macroinvertebrate community structures can be used as indicators of aquatic system health as stated by different workers (Armitage, Moss, Wright and Furse, 1983; Friberg, Sandin, Furse, Larsen, Clarke and Haaese, 2006; Ortiz and Puig, 2007).

2.4 Aquatic macroinvertebrates

Invertebrates are animals without backbones and the word macro means visible with the naked eye. Macroinvertebrates form an important part of the aquatic ecosystem and are widely used as indicators of pollution when testing for stream health. The value of macroinvertebrates for the monitoring and assessment of stream health is widely accepted and is one of the best methods used to monitor the state of the aquatic ecosystem (Arimoro *et al*., 2008). Macroinvertebrate organisms form an integral part of an aquatic environment and are of ecological and economic importance as they maintain various levels of interaction between the community and the environment (Arimoro *et al*., 2008).

2.4.1 Aquatic insects as bio indicators of water pollution

A study to investigate aquatic insects as Bio Indicators of pollution in some Egyptian streams produced quantitative knowledge on the use of aquatic insects as bio indicators of pollution. Most Egyptian governorates contain a number of fresh water resources such as River Nile, ponds together with a network of streams (El Husseiny *et al*, 2015). All over the world, fresh water resources have been subjected to an increasing pollution load from contaminated runoff water originated from man-made activities like domestic and industrial (Benetti and Garrido 2010), agricultural with intensive use of fertilizers and pesticides (Garcia-criado, Tome, Vega and Antolin, 1999) and urbanization. These disturbances produce alteration in the chemical composition of water and in the structure of the communities of organisms living in these environments. The study found out that there is low variability of aquatic insect faunas. The streams in the study also suggested that biotic indices at the family level may overestimate water quality more than those based on species taxonomy level because family taxonomic level usually use intermediate species tolerance values.

Lenat and Resh (2001) also suggested that the family taxonomic level may be adequate in terms of cost-efficiency, especially when few taxonomic experts are available. The significant variation of the total number of aquatic insect assemblages collected from the three water bodies could be modulated by their different levels of sensitivity to pollution, together with many other physical and chemical factors in the water body ecosystem. In addition, physical and chemical disturbance, seasonal water flow, temperature, ion concentrations, food base of the stream, interaction with the stream biota and substrate were also major factors in determining the composition and abundance of aquatic insects (Ward and Stanford, 1979).

A study was carried out on small water bodies (SWBs) within Uasin-Gishu and Siaya Counties of Kenya to investigate the effects of water quality on species diversity and richness of macroinvertebrates in these areas (Ngodhe, Raburu, Matolla and Orwa, 2013). The water quality of the small water bodies was assessed in two dams in Uasin-Gishu County (Kesses and Kerita) and the other two in Siaya County (Mauna and Yenga) within Lake Victoria Basin. The study found out that there was both negative and positive change of macroinvertebrate composition and abundance between SWBs over time due to spatio-temporal variation of water quality parameters (Ngodhe *et al*., 2013). Overall, water quality seemed to have had effect on species diversity, dominance and richness of the invertebrate benthic community therefore can be used as a bio-monitor to aquatic health (Ngodhe *et al*., 2013).

2.4.2 Indicator species of water pollution

The abundance of Ephemeroptera, Plecoptera, Trichoptera and Chironomidae indicates the balance of community, since Ephemeroptera, Plecoptera and Trichoptera are particularly sensitive to water quality and Chironomidae less sensitive to environmental stress (Lenat and Penrose, 1996). Aquatic communities are considered to be good if the biotic conditions would display an even distribution among these four insect families, while aquatic community with disproportionately high number of Chironomidae may indicate environmental stress (Lenat and

Penrose, 1996). Nymphs and larvae of Ephemeroptera, Plecoptera and Trichoptera were considered an integral item of the undisturbed streams (Hynes, 1960).

Dube, Makaka and Sibanda (2010), did a study on the assessment of the effects of industrial and sewage effluent on aquatic invertebrates. In their study they used benthic macroinvertebrates for assessing water quality on urban streams in Zimbabwe. In their results on highly polluted sites they obtained chironomids, nematodes, Simuliidae as indicator species of polluted water, whilst on low polluted areas they obtained Trichoptera, and Plecoptera which indicated clean water.

Biotic indices are the most favourable indicators used to assess the health of water systems around the world. As human populations have grown, more and more categories of pollution of our surface waters have occurred (Zimmerman, 1993). One of the most common pollution categories is organic pollution caused by oxygen-demanding wastes such as domestic sewage, wood fiber from pulp and paper mills, effluent from food processing plants, and run-off from agricultural areas (especially hay, dairy, and cattle farms). The results obtained expressed that the slow sessile aquatic invertebrate organisms which cannot swim away from intermittent perturbations, can be used as biological indicators of water pollution because their presence or absence may reflect conditions not otherwise evident when the researcher checks the site (Zimmerman, 1993). Furthermore, they are probably best suited because they are numerous in almost every stream, are readily collected and identified, and can be classified as pollution sensitive and in the case of organic pollution, they are viewed to be tolerant (Zimmerman, 1993). It is a well-known fact that pollution of a stream reduces the number of species of the system that is species diversity, while frequently creating an environment that is favourable to a few species

(Zimmerman, 1993). In a polluted stream, there are usually large numbers of a few species, while in a clean stream there are moderate numbers of many species (Zimmerman, 1993).

2.4.3 Influence of water quality on diversity and distribution of macroinvertebrates

One of the common resources for all life forms on the planet is water. Water is critical for sustainable livelihoods and it is impossible for a single life to live without water. However, there is a pressure to use these resources with maximum effort to feed the fast growing population and to improve the standard of living of citizens. However, it is argued that the physical and chemical condition of many streams in tropical countries is deteriorating as a result of human population explosions, changes in land use, intensified agricultural practices and increased industrialization all of which cause changes to natural flow regimes directly or indirectly (Pringle, Scatena, Paaby-Hansen and Nuñez-Ferrera, 2000).

Haileselasie and Teferi (2012) in Ethiopia calculated the diversity index for each sampled site given and the species diversity increased with the water quality, that is, the highest diversity is observed in the sampled sites with a good water quality.

2.5 Legislation to combat pollution

2.5.1 History

The current constitution of Zimbabwe (2000) has no specific clause that provide for the protection of the environment (Government of the republic of Zimbabwe, 2000). The natural resource (1941, Chapter 20:13 now repealed) did not directly cover Environmental impact assessments (EIAs) and consequently the EIAs were not a legal requirement in Zimbabwe and in recognition of this shortcoming the government of Zimbabwe published an EIA policy in 1997 and associated guidelines (Southern African Institute for Environmental Assessment, 2003). The policy was intended to complement any future EIAs and the promulgation of environmental management legislation. The water Act No. 31 of 1998 was put in place to regulate the planning and development of water resources and to provide a framework for allocating water permits. The water (Waste and Effluent Disposal) Regulations of 2000 which are associated with this act specify what quality is acceptable in terms of effluent release into rivers (Booth, Spoong and Walmsley, 2003).

2.5.2 Current legislation

In the year 2000 the government put in place the Environmental Management Act, 2002 (Chapter 20:27) developed with the purpose of complimenting and enhancing the Environmental Management Act so as to protect, manage and sustain other complementary acts pertaining to the environment (Government of Zimbabwe, 2002). At present pollution control environmental enforcement is spread across a number of central and local authorities. The Environmental Management Act, 2002 (Chapter 20:27) provided for the establishment of an Environmental Management Agency (EMA). EMA was formerly known as the Department for Natural Resources. Its responsibilities include the development of guidelines for national plans, environment management plans and local environmental action plans (LEAPs), regulating, reviewing, monitoring and approving environmental impact assessments, regulating and monitoring the management and utilization of ecologically fragile systems and the development and implementation of incentives for the protection of the environment amongst others. EMA therefore undertakes works deemed necessary for the protection or management of the environment where it appears to be in the interest of the public or where, in the opinion of the Agency, the relevant authority has failed to do so (Government of Zimbabwe, 2002).

In 2003, the Government of Zimbabwe developed the National Environmental Policy in line with its National Policy which seeks to alleviate poverty and improve the quality of the life of people of Zimbabwe (Government of Zimbabwe, 2003). The objective of the National Environment Policy therefore is to avoid irreversible environmental damage, maintain essential environmental processes and preserve the broad spectrum of biological diversity so as to sustain the long ability of natural resources to meet the basic needs of the people, enhance food security, reduce poverty and improve the standard of living in Zimbabwe. Amongst other specific goals, the policy conserves biodiversity and maintains the natural resource base and basic environmental processes to enhance environmental sustainability (Government of Zimbabwe, 2003).

2.5.3 Adherence of legislation by companies

EMA is responsible for ensuring that companies adhere to its regulations and that they do not discharge harmful effluent directly to the environment. In other cities such as Gweru, the city's tradewaste department is responsible for monitoring the quality of effluent discharged into the public water system from which the city obtains its water. The Environment Agency (Effluent and Solids Waste) Regulations statutory instrument of 2007 stipulates the acceptable limits of the various parameters under analysis and these limits are colour classified. These include Blue, Green, Yellow and Red permits, in which the Red permit is the most extreme and the Blue permit the least extreme (EMA, 2007).

2.5.4 Legislation in other Countries

In South Africa, the National Water Act, 1998 provides for the fundamental reform of the law relating to water resources to repeal the laws and to provide for matters connected therewith (Republic of South Africa, 1998). The Act ensures that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account, amongst other factors, meeting the basic needs of present and future generations, promoting the efficiency, equitable access, sustainable and protecting aquatic ecosystems and their diversity hence promoting dam safety. Part 4 deals with pollution prevention stating that where pollution occurs or where it might occur as a result of activities on land, the person who owns, control, occupies and uses the land in question is responsible for taking measures to prevent pollution of water resources. If these measures are not taken the catchment management agency concerned may itself do whatever is necessary to prevent the pollution or to remedy its effects and to recover all reasonable costs from the persons responsible for the pollution. The Act also establishes National Monitoring system on Water resources to provide for the collection of data and information to assess the Quality of water resources, the use of the water, the health of aquatic ecosystem and the atmospheric conditions that may influence the water resources (Republic of South Africa, 1998).

The Water (Prevention and control of pollution) Act, 1994 was enacted in India with the objective of preventing and controlling pollution in that country. The Act aims to establish boards vested with powers enabling them to carry out the purpose of the Act (Water Act, 1974). The Act also states the code of conduct to which companies, individuals and the government should adhere or else they face the law of which an imprisonment will be at least two years. In the United States of America, the Clean Water Act has been in place since the 1970s. The Act has provided the United States with cleaner water and this has taken the support of the government which increased the amounts of money for the Act every year since 1999.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study site

Figure 3.1: Location of sampling sites at Khami Dam.

Source: Google maps.

3.2 Characterization of sampling sites

The study was carried out at Khami dam located at Khami world Heritage National Monument in Matabeleland South Province, Umguza district, 22 km due west of the city of Bulawayo at a latitude of 20 09^0S and latitude 28 25^0E (Mguni, 1996). It lies in Zimbabwe's Agro-Ecological Zone IV (Burrett and Hubbard, 2013). It also lies in the central ecoregion based on the physical, biological and human activity attributes. This ecoregion has rainfall ranging from 700 to

1000mm per annum and temperatures ranging from 7^0C to 30^0C. The vegetation is tree and shrub savanna, dominated by various *Acacia* and *Combretum* species (Nobanda, 1998). Khami dam was built in 1928; it was Bulawayo's second water supply reservoir. It was a popular recreational dam until it was decommissioned in the 1970s. Currently, there are moves to clean up the dam by the Bulawayo city council though the exercise is not very effective (Burrett and Hubbard, 2013). The estimate terrain elevation above sea level is 1299 metres. The dam acts as a research site for both local people and the foreigners for different projects. People benefit a lot from the dam through fishing for household consumption. The city of Bulawayo also uses the dam as a dumping area for waste matter due to insufficient presence of treatment plants which deal with waste matter as a result water becomes polluted.

3.2 Water source

The Khami dam reservoir receives flows from Phekiwe and Kwelameva Rivers as well as other small streams, which flow into the Khami River. The Khami River source is about 40km from the reservoir and flows mainly through sparsely populated savanna bush land with some livestock farms as well as irrigated crop farms (Gumbo, 1997).

3.3 Study design

Macroinvertebrate collection and physico-chemical parameter measurements were made from three sites that had been chosen. These sites were chosen to reflect the gradient across the dam as the first site was located near the dam wall before the effluent discharge (reference point), site 2 at a location more or less at the middle of the dam and site 3 at the mouth of the dam (Fig 3.1)

3.4 Sampling plan

Water samples were collected over a period of six months from September 2015 to February 2016. Sampling was done once each month. Two replicate samples were collected for each parameter and the mean results were calculated. Samples for nitrates and phosphates were collected using a beaker. 1000ml of water was then poured into 1000ml schott bottles and placed in ice filled cooler boxes on site and then they were refrigerated in the laboratory at low temperatures (< $4^{o}C$) prior to analysis. Total nitrogen and total phosphorus concentrations were determined in the laboratory with Hach nutrient analysis kits and a Hach spectrophotometer (DR010 Hach Co, Loveland, Colorado, USA). Temperature readings were recorded at the dam using a mercury bulb thermometer, the bulb was placed in the water on each site and left to stand for 5 minutes. After the 5 minutes had passed the temperature readings were then recorded. A Mettler Toledo 320 pH meter was used to measure pH at the dam, a pH probe was placed in the water on all the sites at a depth of 40cm and left to stand for 5 minutes and the readings were recorded. An oxygen meter was used to measure the amount of dissolved oxygen at the dam, the probe was allowed to stand for 5 minutes inside the water on all the sites at a depth of 30cm and the readings were taken. A Mettler Toledo MC 226 conductivity meter was used to measure conductivity at the dam, the conductivity probe was allowed to stand for 10 minutes inside the water on all the sites at a depth of 30cm and readings were then taken. Total Dissolved Solids (TDS) was measured using a filter paper method. Initially a clean filter paper was weighed using a digital scale and recorded. 1000ml of composite sample was filtered on a filter paper and allowed to dry at room temperature ($25^{o}C$) for 5 days. After drying it was reweighed on a digital scale and recorded. The difference of the dried filter paper and that of the clean filter paper was the (TDS) units (ppm). Turbidity levels were measured in Nephelometric units (NTUs) using the

Hach 2100A turbidity meter at the dam, a turbidity probe was inserted at a depth of 40cm and allowed to stand for 15 minutes and readings for all the sites were recorded.

3.5 Sampling macroinvertebrates

A 50μm hand net (on a pole) was used to collect samples from the three different sampling sites namely site1, site 2 and site 3. The net was held vertically with the mouth facing offshore and sweeping through the water and vegetation was then done for four minutes. The contents of the net were then washed into a sampling container through a 250μm sieve and the organisms holding on to the net were transferred to the sample container by hand. 70% ethanol was then added to the sample container. Thorough washing of the net was done and the procedure repeated twice for each site. In pencil, a label with the date, name of the dam and sampling site was made. This was placed inside the sample container so that the writing could be seen from the outside.

3.5.1 Identification of macroinvertebrates

The samples were observed under a dissection microscope at x100 magnification and keys by Day *et al.* (2001) volume 1-10 were used to identify and arrange the macroinvertebrates by taxonomic group. The Relative abundance of each taxonomic family was then calculated by dividing the number present in that family by the total number of macroinvertebrates collected and then expressing as a percentage.

3.6 Data analysis

Analysis of variance (ONE WAY ANOVA) was used to compare the physical and chemical parameters amongst the three sites (SPSS version 21).

Diversity was calculated using Shannon-Wienner index and a result close to zero indicated poor diversity whilst that close to 4.6 shows higher diversity (Mandaville, 2002). Shannon's index accounted for both abundance and evenness of the species present.

The formula used to calculate H^l:

$$\mathbf{H}' = -\sum_{i=1}^{s} \mathbf{pi} * \mathbf{ln}(\mathbf{pi})$$

In addition, the evenness was calculated using the equitability index.

The formula used to calculate E: $\mathbf{E} = {}^{\mathbf{H}'}/_{\mathbf{In\ S}}$

CHAPTER 4: RESULTS

4.1 General results of physico-chemical parameters and benthic macroinvertebrates

A total of 1305 macroinvertebrates were collected during this study. Seven macroinvertebrates orders were observed and the macroinvertebrates were grouped according to families as shown in Table 4.1. The most dominant family across the sites was the Siphlonuridae family which recorded a total of 599 individuals (Table 4.1).

Table 4.1: Summary of benthic macroinvertebrate classes/families found at the 3 sites in Khami Dam from September 2015 to February 2016.

			Proportional Abundances					
Class	**Order**	**Family**	**Site1 (n)**	**(%)**	**Site2 (n)**	**(%)**	**Site3 (n)**	**(%)**
Insecta	Ephemeroptera	Siphlonuridae	10	13.512	222	44.048	276	37.964
Insecta	Coleoptera	Hydrophilidae	13	7.879	53	10.516	60	8.253
Insecta	Heteroptera	Corixadae	3	1.818	73	14.484	108	14.856
Insecta	Odonata	Gomphidae	18	10.909	56	11.111	108	14.856
Insecta	Plecoptera	Capniidae	7	4.242	20	3.968	14	1.926
Insecta	Hemiptera	Pleidae	9	5.454	13	2.579	28	3.851
Insecta	Diptera	Chironomidae	4	2.424	40	7.937	50	6.878
Gastropoda		Ampullaridae	10	6.061	27	5.357	83	11.4177
Total			**74**		**504**		**727**	
			GRAND TOTAL = 1305					

In terms of diversity, site 1 had the highest value H^l = 1.957 and on evenness site 2 had the lowest value 0.820 (Table 4.2). On the physical and chemical parameters, pH and temperature showed no significant differences ($p > 0.05$) whilst oxygen, phosphates, nitrates, turbidity, TDS and conductivity showed significant differences ($p < 0.05$) among the sites (Fig 4.1, 4.2 and 4.3).

Table 4.2: The diversity (H') and evenness (E) of benthic macroinvertebrates in Khami Dam

Sampling site	Number of families	H^l	E
1	8	1.957	0.941
2	8	1.705	0.820
3	8	1.777	0.855

The best highest diversity of taxa was at site 1 (H' = 1.957) compared to site 3 (H' = 1.775, which had a better diversity) and site 2 (H' = 1.705, which had the poorest diversity) respectively, (Table 4.2). The evenness of distribution of pollution sensitive taxa was low at site 1 (E = 0.941) compared to pollution tolerant taxa at sites 2 (E = 0.820) and site 3 (E = 0.855), respectively. Composition and spatial variation of benthic invertebrates between September 2015 and February 2016, benthic invertebrate fauna from seven taxonomic orders were collected from Khami dam. The most abundant taxa in terms of relative abundance were Ephemeroptera = 44.048 % at site 2 and 37.968% at site 3 followed by Heteroptera (14.484% at sites 2 & 14.856% at site 3) and Hemiptera was the least rare taxa (1.818 % at site 1) (Table 4.1).

Table 4.3: Physical and chemical parameters (Mean) of water from Khami Dam

Parameters	Site1(control)	Site2	Site3
pH (units)	8.4	8.2	8.3
Conductivity (µS)	160	466	487
Oxygen (mg L^{-1})	5.7	7.1	7.8
Temperature (°C)	27.88	30.32	29.12
TDS (ppm)	105	332	576
Phosphates (mgL^{-1})	0.81	6.72	10.65
Nitrates (mgL^{-1})	0.01	2.07	1.4
Turbidity (NTU)	-	0.2	0.5

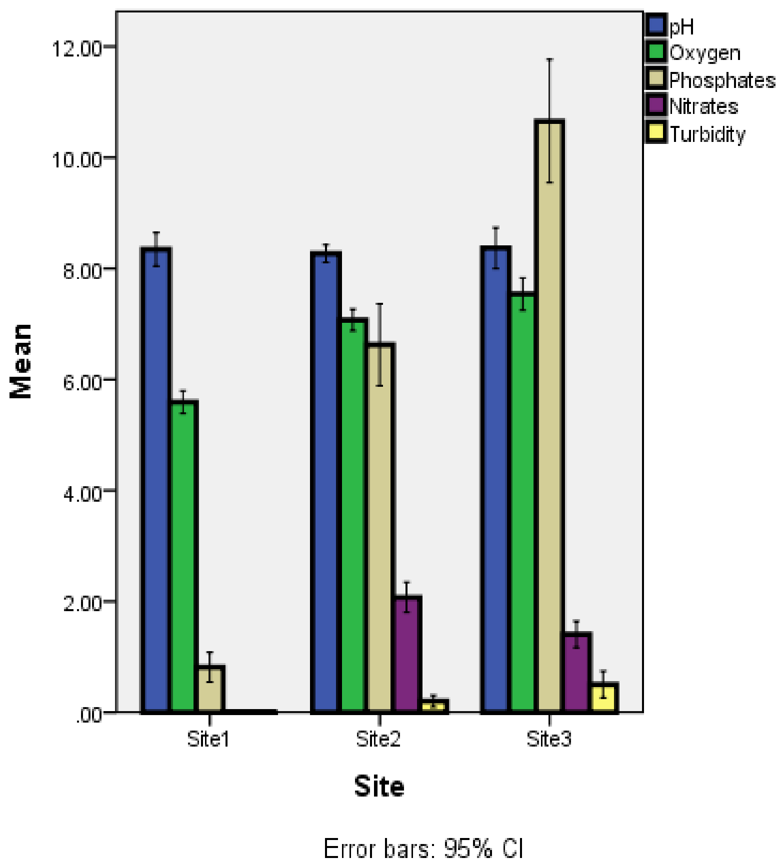

Figure 4.1: pH, oxygen, phosphates, nitrates and turbidity trends along the dam

4.2 pH, Oxygen, Phosphates, Nitrates and Turbidity

There were no significant differences among the Sites (Fig. 4.1; $p > 0.05$, Appendix 6) in pH. Site1 recorded the highest value with a mean pH of 8.4 units while the lowest pH was recorded on Site 2 with a mean of 8.2units (S1 > S3 > S2), (Table 4.3).

Oxygen levels also decreased from site 1 to site 3 (S1 > S2 > S3) (Table 4.3). There were significant differences in oxygen levels amongst the three sites (Fig 4.1; $p < 0.05$, Appendix 15).

There were significant differences among the Sites (Fig. 4.1; $p < 0.05$, Appendix 18) in phosphates. Site 3 recorded the highest value with a mean of 10.68mgL^{-1} while the lowest value was recorded on Site 1 with a mean of 0.81mgL^{-1} (S3 > S2 > S1), (Table 4.3).

Nitrate concentrations were high in site 2 (2.07 mgL^{-1}) and low in site 1 (0.01 mgL^{-1}) (Table 4.3). There were significant differences in nitrate concentrations amongst the three sites (Fig 4.1; $p < 0.05$, Appendix 21).

On the other hand, samples from site 3 and 2 were highly turbid (0.5 NTU and 0.2 NTU), whereas for site 1 it was normal, (S3 > S2 > S1) (Table 4.3). There were significant differences in the turbidity levels amongst the three sites (Fig 4.1; $p < 0.05$, Appendix 12).

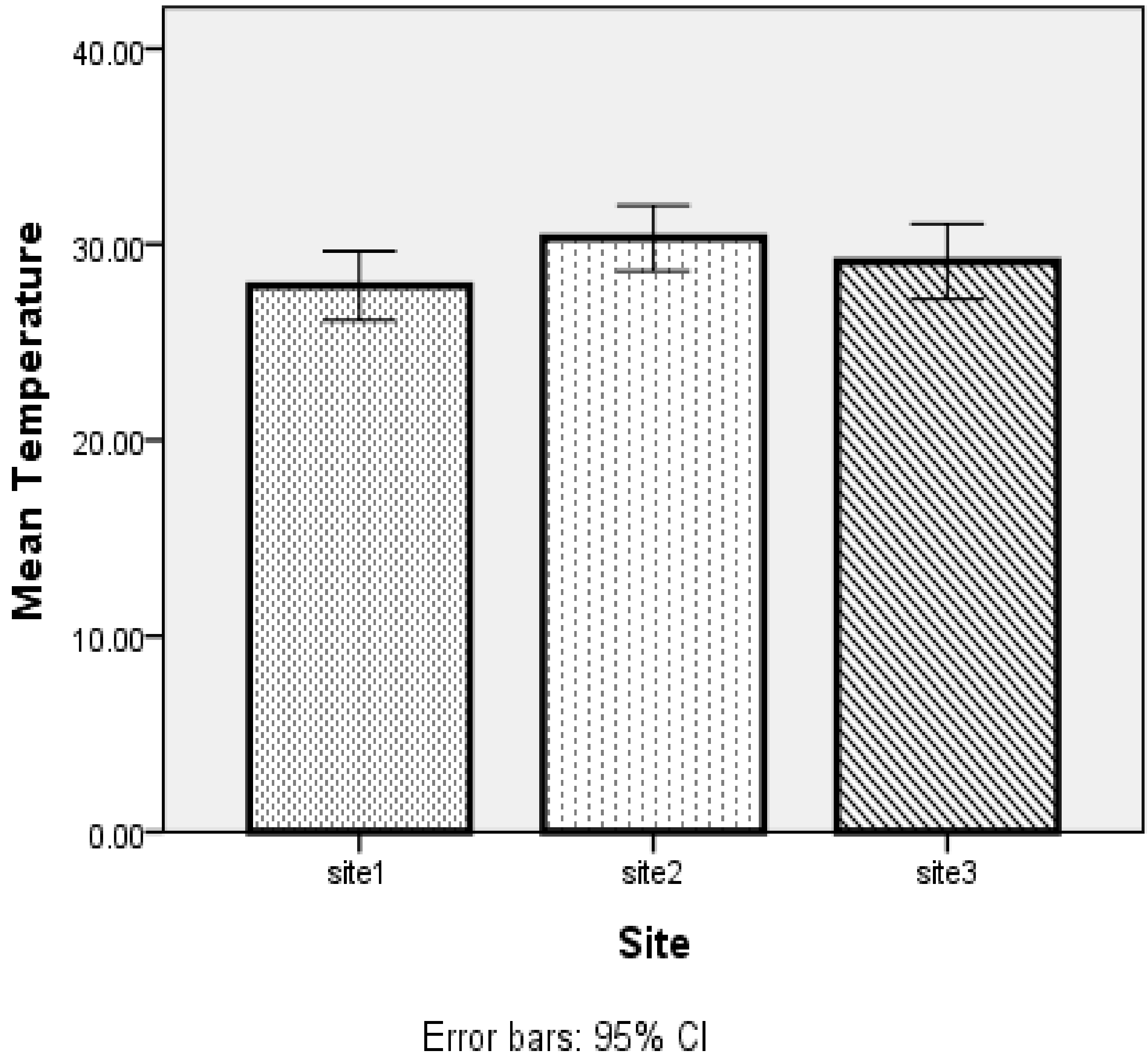

Figure 4.2: temperature trend along the dam

4.3 Temperature

There were no significant differences among the Sites (Fig. 4.2; $p > 0.05$, Appendix 26) in temperature. Site 2 recorded the highest value with a mean value of 30.32 ºC while the lowest value was recorded on Site 1 with a mean of 27.88 ºC (Table 4.3).

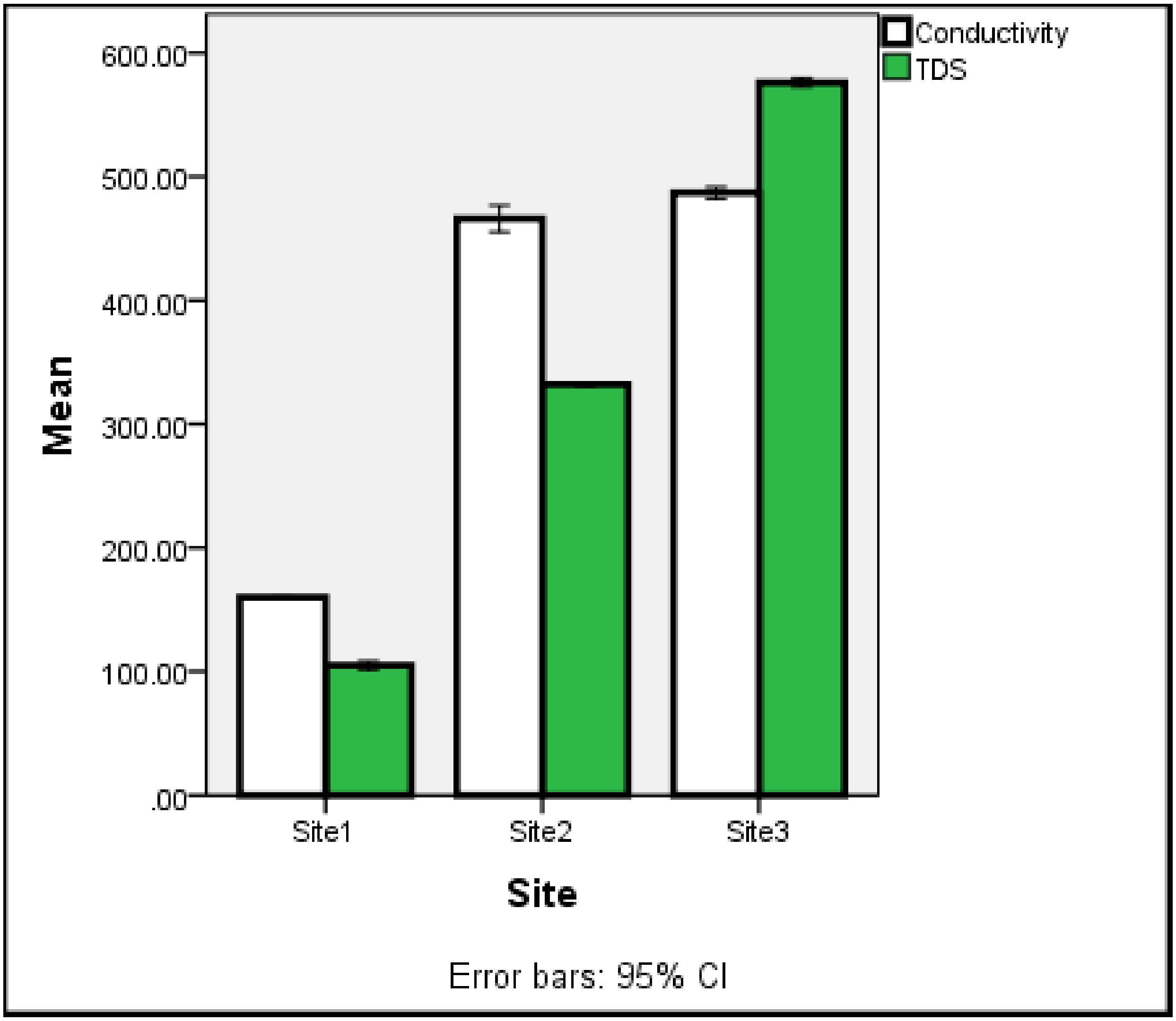

Figure 4.3: Conductivity and Total Dissolved Solids (TDS) trends along the dam

4.4 Conductivity and TDS

There were significant differences among the Sites (Fig. 4.3; $p < 0.05$, Appendix 9) in conductivity. The mean values for conductivity in sites 3 and 2 were higher (487 μScm^{-1} and 466 μScm^{-1}) whilst those from site 1 were very low 160 μScm^{-1} (S3 > S2 > S1), (Table 4.3).

However, Total dissolved solids (TDS) amounts increased from site 1 to site 3 (S1 < S2 < S3), (Table 4.3). There were significant differences in the TDS amounts amongst the three sites (Fig 4.3; $p < 0.05$ Appendix 23).

CHAPTER 5: DISCUSSION

5.1 Physical and chemical parameters at Khami dam

High effluent discharges have been reported into the Khami Dam as it is located downstream of the Umguza catchment. As a result there is major deterioration in water quality of the dam (Chenje, 2000). Physico-chemical parameters were relatively high at sites 1 and 2 compared to site 3 indicating high pollution levels. Industrial effluents contributed a relatively high percentage of pollutants in Khami Dam.

Water temperature is essential because it affects the rates of biological processes and chemical processes. Site 2 indicated the highest temperature as a result the optimal health of aquatic organisms from microbes to fish depends on temperature. If temperatures are outside the optimal range for a prolonged period, organisms are stressed and can die. Macroinvertebrates these include insects, crayfish, worms, clams, and snails will move about in the stream bed to find their optimal temperature. The results obtained are in harmony with a study done by (Dube *et al*., 2010). In their study they clearly expressed that the temperature of water also affects the volume of dissolved oxygen it can hold, that is the water's ability to contain dissolved oxygen decreases as water temperature rises.

All the sampled sites had normal average pH of 8.4 to ± 8.2 units (Table 4.3). The pH ranges obtained were in agreement with those of the State of Water Pollution in Bulawayo (Teta, 2014). Water with a pH of less than 4.8 or greater than 9.2 can be harmful to aquatic life. Most freshwater species prefer water with a pH range between 6.5 and 8.4 (Teta, 2014). The pH is also a useful indicator of the chemical balance in water. A high or low pH will adversely affect the availability of certain chemicals or nutrients in the water for use by plants. These include nitrates and phosphates.

The levels of dissolved oxygen were higher in polluted sites 2 and 3, presumably, due to the high proliferation of phytoplankton in the nutrient rich polluted dams. These findings are in line with those of the Impact of industrial effluent on water quality of receiving steams in Nakawa-Ntinda, Uganda (Walakira, 2011). Since sampling was done during day time, oxygen evolved from photosynthesising phytoplankton increased oxygen concentration in site 2 and 3. Aquatic plants tend to be concentrated on polluted areas and as such they produce high concentrations of dissolved oxygen (Teta, 2014).

Conductivity of water is directly related to the concentration of dissolved solids in the water. This is so because ions from the dissolved solids in water influence the ability of that water to conduct an electrical current (Teta, 2014). As a result, large amounts of TDS mean high conductivity; this is evidenced at site 3 which had the highest values for both conductivity and TDS. These results are in agreement with Walakira (2011). In his findings, he discovered that areas with high levels of pollutants had the highest value of conductivity.

Turbidity levels were high at site 3 and site 2 which clearly showed that these areas had a lot of pollutants, whilst on the other hand no turbidity value were recorded on site 1 (reference) indicating zero level of effluents on that area. These findings are similar to those of Dube *et al* (2010), because they obtained no turbidity value on the reference point and a high value on the polluted area.

Nitrate levels were high at site 2 as a result it fell under the Red category (Statutory Instrument, 2007). As for site 1 it had the least nitrate value hence it fell under the Blue category (Statutory Instrument, 2007), these findings were similar to those of the assessment of the effect of industrial and sewage effluent on aquatic invertebrates: a case study of a southern urban stream, Zimbabwe (Dube *et al*., 2010). Nitrate is a source of nitrogen (N), an important nutrient for plants and algae. As ammonia (NH_3) is broken down by bacterial action, nitrite is formed and is then converted to the more stable, much less toxic nitrate through a process called nitrification. Nitrates in water are typically low, natural levels of nitrates in surface water can be supplemented with nitrate from human sources. Nitrate from the fertilizer not taken up by crops in fields and grass in lawns can enter water bodies in runoff. Nitrate can also enter water bodies from wastewater discharge or runoff from feedlots. Once in the water, nitrates can stimulate excessive plant and algae growth as a result decomposition of the plant and algal material by bacteria can deplete dissolved oxygen, adversely impacting on aquatic animals such as fish and macroinvertebrates.

However, phosphate levels were extremely high at site 3 almost twice the value at site 2, which is also classified under the Red category (Statutory Instrument, 2007). The overall water quality through assessment by physico-chemical parameters were in the Blue range at site 1 compared to the Red classification of sites 2 and 3. Continued release of industrial effluent containing high phosphate and nitrate levels may contribute to the eutrophication of Khami dam (Mathuthu *et al.*, 2009).

5.2 Composition and spatial variation of benthic macroinvertebrates

The results obtained through chemical analysis of Khami Dam were directly related to those derived from the Shannon-Wienner index. Higher diversity of pollution tolerant species such as Siphlonuridae and Chironomidae dominated at sites 2 and 3. These organisms are able to survive under extreme toxic pollutant conditions including low oxygen levels.

At site 3 the environment is inhospitable since pollutant tolerant macro-invertebrates were also showing very low species richness. Site 2 was also dominated with pollutant tolerant organisms though there is resurgence of moderately sensitive macro-invertebrates. This might possibly be a result of dilution effect of site 1 from tributary rivers, Phekiwe River and Khwelameva River which contributes clean water into Khami Dam and the self-purification process (Gumbo, 1997).

The macro-invertebrates from site 1 included the Order Plecoptera which is strictly freshwater species with high susceptibility to toxic pollutants, inorganic pollutants and anoxic conditions (Allan, 1995). Its presence indicates good water quality implying that it is actually possible to maintain Khami Dam in good condition if strict measures are exercised on effluent disposal. These results are in agreement with those of Dube *et al*. (2010). In their study they obtained the following species chironomids, nematodes, Simuliidae on the polluted sites whilst on the low polluted area they obtained Trichoptera, and Plecoptera.

5.3 Chief pollutants at Khami dam

Regulating effluent discharge from the industries and sewage works will significantly reduce the risk of pollution at Khami dam and the accumulation rate of these nutrients will continue than it can be naturally controlled through the self-purification process. The distance from the discharge sites to Khami dam is less than 4 kilometers upsteam implying that it is difficult for self-purification of Khami dam to be effected (Gumbo, 1997). This is a result of high accumulation rates coupled with diffuse cases of sewage leakages from the surrounding residential areas Mganwini, Nkulumane, Tshabalala Extension and Pumula South (Gumbo, 1997). With failure to treat effluent the nutrient concentrations will continue to rise as the volume of sewage effluent increases caused by increasing population density in the city and the need to increase the production in the industrial areas.

5.4 Conclusion

Overall, the study has shown that the effluents from industries and domestic sewage have a big impact on the water quality of the Khami dam. This is evidenced by the fact that there is a general increase in concentration of the parameters analysed from the site 1 (referral point) to site 3. Although the values in some cases were lower than the maximum allowable limits by Statutory Instrument (2007), the continued discharge of un-treated effluents in the dam may result in severe accumulation of the contaminants. With the present primitive processing of sewage at Phekiwe treatment plant, continuous disposal of raw sewage and bursting of sewage pipes the pollutants find their way into the dam through nearby water channels. Effluents by companies and fertilizer runoffs from farms near the Khami dam will continue to enrich the dam with high amounts of key nutrients and easily degradable carbon compounds, leading to further oxygen depletion in dam. This is a situation that should alert the Zimbabwe National Water Authority (ZINWA) to continuously monitor industrial effluents and enforce Zimbabwe’s polluter pays principle (Statutory Instrument, 2007).

5.5 Recommendations

The results suggest that the effluents being discharged into the dam have considerable negative effects on the water quality. With increased industrial activities in Bulawayo, the load of nutrients and pollutants entering the dam will continue to increase and further diminish the quality of water. Introduction of cost-effective cleaner production technologies must be enforced, such as on-site waste separation and reduction, and effluent recycling.

It is however recommended that careless release of the wastes should be discouraged and there is need for each industry to install a waste treatment plant with a view to treat wastes before they are discharged into the dam.

There is need for ZINWA to closely monitor the effluents from industries and domestic sewage. It has been noted that wetlands contribute greatly to the purification of waste water therefore measures should be taken to construct artificial wetland near the Khami dam.

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APPENDICES

1. Total number (n) of aquatic macro-invertebrates caught at Site 1

Family		Population abundance on Site1				
	Sept	Oct	Nov	Dec	Jan	Feb
Batidae	3	1	0	1	2	3
Hydrophilidae	2	1	0	0	6	4
Corixidae	0	0	0	1	0	2
Gomphidae	5	2	3	4	3	1
Gerridae	1	0	3	2	0	1
Pleidae	0	0	3	0	1	0
Chironomidae	0	0	2	0	0	1
Ampullaridae	4	0	1	3	0	2

2. Total number (n) of aquatic macro-invertebrates caught at Site 2

Family		Population abundance on Site2				
	Sept	Oct	Nov	Dec	Jan	Feb
Batidae	55	34	43	29	28	33
Hydrophilidae	12	1	7	0	19	14
Corixidae	23	6	11	18	13	2

Gomphidae	10	4	22	8	3	9
Gerridae	5	2	3	0	3	7
Pleidae	0	1	5	4	2	1
Chironomidae	3	8	8	7	8	6
Ampullaridae	1	0	0	8	11	7

3. Total number (n) of aquatic macro-invertebrates caught at Site 3

Family		Population abundance on Site3				
	Sept	Oct	Nov	Dec	Jan	Feb
Batidae	56	43	57	39	38	43
Hydrophilidae	13	3	9	1	20	14
Corixidae	26	16	22	28	14	2
Gomphidae	12	5	22	9	12	19
Gerridae	1	6	9	1	2	2
Pleidae	11	3	4	7	3	0
Chironomidae	4	12	10	8	9	7
Ampullaridae	18	16	11	28	10	7

4. Normality p values for pH on all the sites
Tests of Normality Ph

	Site	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
pH levels	Site1	.192	6	.200*	.964	6	.852
	Site2	.254	6	.200*	.866	6	.212
	Site3	.350	6	.021	.843	6	.138

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

5. p-value for homogeneity of variances for pH between sites
Test of Homogeneity of Variances pH

pH levels

Levene Statistic	df1	df2	Sig.
2.788	2	15	.093

6. p-value for anova for pH on all sites
ANOVA pH

pH levels

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.033	2	.016	.217	.807
Within Groups	1.135	15	.076		
Total	1.168	17			

7. Normality p values for conductivity on all sites
Tests of Normality conductivity

	Site	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Conductivity	Site1	.333	6	.036	.827	6	.101
	Site2	.219	6	.200*	.935	6	.618
	Site3	.245	6	.200*	.915	6	.467

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

8. p-value for homogeneity of variances for conductivity between sites
Test of Homogeneity of Variances

Conductivity

Levene Statistic	df1	df2	Sig.
2.366	2	15	.128

9. p-value for anova for conductivity between sites
ANOVA

Conductivity

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	402012.000	2	201006.000	4770.712	.000
Within Groups	632.000	15	42.133		
Total	402644.000	17			

10. Normality p values for turbidity on all sites
Tests of Normality[a] turbidity

	Site	Kolmogorov-Smirnov[b]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Turbidity	Site2	.176	6	.200*	.917	6	.486
	Site3	.167	6	.200*	.954	6	.773

*. This is a lower bound of the true significance.

a. Turbidity is constant when Site = Site1. It has been omitted.

b. Lilliefors Significance Correction

11. p-value for homogeneity of variance for turbidity between sites
Test of Homogeneity of Variances

Turbidity

Levene Statistic	df1	df2	Sig.
5.679	2	15	.015

12. p-value for anova for turbidity on all sites
ANOVA

Turbidity

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.759	2	.380	18.295	.000
Within Groups	.311	15	.021		
Total	1.071	17			

13. Normality p values for oxygen on all sites
Tests of Normality oxygen

	Site	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Oxygen level	Site1	.226	6	.200*	.912	6	.452
	Site2	.238	6	.200*	.950	6	.737
	Site3	.224	6	.200*	.882	6	.276

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

14. p-value for homogeneity of variances for oxygen between sites
Test of Homogeneity of Variances

Oxygen level

Levene Statistic	df1	df2	Sig.
1.336	2	15	.292

15. p-value for anova for oxygen on all sites
ANOVA

Oxygen level

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	12.441	2	6.221	123.587	.000
Within Groups	.755	15	.050		
Total	13.196	17			

16. Normality p values for phosphates on all sites
Tests of Normality phosphates

	Site	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Phosphate levels	Site1	.188	6	.200*	.886	6	.299
	Site2	.223	6	.200*	.912	6	.451
	Site3	.186	6	.200*	.890	6	.319

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

17. p-value for homogeneity of variances for phosphates between sites
Test of Homogeneity of Variances

Phosphate levels

Levene Statistic	df1	df2	Sig.
2.940	2	15	.084

18. p-value for phosphates on all sites
ANOVA

Phosphate levels

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	293.657	2	146.829	263.282	.000
Within Groups	8.365	15	.558		
Total	302.022	17			

19. Normality p values for nitrates on all sites
Tests of Normality nitrates

	Site	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Nitrate level	Site1	.278	6	.162	.856	6	.177
	Site2	.167	6	.200*	.930	6	.582
	Site3	.167	6	.200*	.954	6	.773

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

20. p-value for homogeneity of variance for nitrates between sites
Test of Homogeneity of Variances

Nitrate level

Levene Statistic	df1	df2	Sig.
4.494	2	15	.030

21. p-value for anova for nitrates between sites
ANOVA

Nitrate level

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	13.258	2	6.629	164.929	.000
Within Groups	.603	15	.040		
Total	13.861	17			

22. p-value for homogeneity of variances for TDS on all sites
Test of Homogeneity of Variances

TDS

Levene Statistic	df1	df2	Sig.
1.143	2	15	.345

23. p-value for anova for TDS between sites
ANOVA

TDS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	665812.000	2	332906.000	42318.559	.000
Within Groups	118.000	15	7.867		

Total	665930.000	17				

24. Normality p values for temperature on all sites
Tests of Normality temperature

	Site	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Temperature	site1	.167	6	.200*	.958	6	.803
	site2	.167	6	.200*	.982	6	.962
	site3	.167	6	.200*	.984	6	.969

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

25. p-value for homogeneity of variances for temperature on all sites
Test of Homogeneity of Variances

Temperature

Levene Statistic	df1	df2	Sig.
.037	2	15	.963

26. p-value for anova for temperature between the sites
ANOVA

Temperature

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	17.862	2	8.931	3.073	.076
Within Groups	43.600	15	2.907		
Total	61.462	17			

27. mean and standard deviations for parameters measured

Sites		pH (units)	Oxygen (mg L^{-1})	Conductivity (μScm^{-1})	Temperature (^0C)	TDS (ppm)	Phosphates (mg L^{-1})	Nitrates (mg L^{-1})	Turbidity (NTU)
Site1	Mean	8.3433	5.5833	160.0000	27.8800	105.0000	.8100	.0093	.0000
	N	6	6	6	6	6	6	6	6
	Std. Deviation	.28577	.19408	.63246	1.68231	3.16228	.25526	.00480	.00000
Site2	Mean	8.2667	7.6667	466.0000	30.3200	332.0000	6.6217	2.0700	.2017
	N	6	6	6	6	6	6	6	6
	Std. Deviation	.15055	.18619	10.29563	1.58677	1.41421	.70004	.26184	.10128
Site3	Mean	8.3667	7.5333	487.0000	29.1200	576.0000	10.6500	1.4000	.5000
	N	6	6	6	6	6	6	6	6
	Std. Deviation	.35024	.28048	4.47214	1.83628	3.40588	1.05728	.22804	.22804
Total	Mean	8.3256	6.7278	371.0000	29.1067	337.6667	6.0272	1.1598	.2339
	N	18	18	18	18	18	18	18	18
	Std. Deviation	.26210	.88105	153.89913	1.90142	197.92007	4.21498	.90298	.25095

28. pH values obtained from September 2015 to February 2016

Months	pH values	Site1	Site2	Site3
Sept		8.16	8.1	8.2
Oct		8.2	8.3	8.2
Nov		8.4	8.5	8.7
Dec		8	8.3	8.9
Jan		8.8	8.3	8
Feb		8.5	8.1	8.2

29. conductivity values obtained from September 2015 to February 2016

Months values	Conductivity	Site1	Site2	Site3
Sept		160	463	480
Oct		160	469	487
Nov		161	466	494
Dec		160	450	487
Jan		159	482	486
Feb		160	466	488

30. Oxygen values obtained from September 2015 to February 2016

Months	pH values	Site1	Site2	Site3
Sept		5.3	7.1	7.4
Oct		5.7	6.9	7.4
Nov		5.4	7.2	7.8
Dec		5.7	7.1	7.7
Jan		5.8	6.8	7.1
Feb		5.6	7.3	7.8

31. temperature values obtained from September 2015 to February 2016

Months values	Temperature	Site1	Site2	Site3
Sept		27.88	29.21	29.12
Oct		25.65	31.43	26.49
Nov		30.11	30.32	31.75
Dec		26.43	30.32	29.12
Jan		29.33	28.07	27.89
Feb		27.88	32.57	30.35

32. TDS values obtained from September 2015 to February 2016

Months	TDS values	Site1	Site2	Site3
Sept		105	330	576
Oct		102	334	571
Nov		108	332	581
Dec		105	332	576
Jan		101	331	574
Feb		109	333	578

33. Phosphate values obtained from September 2015 to February 2016

Months	Phosphate values	Site1	Site2	Site3
Sept		0.81	6.13	9.4
Oct		0.54	7.31	11.9
Nov		1.08	6.72	10.65
Dec		0.81	6.72	11.76
Jan		0.51	5.52	9.54
Feb		1.11	7.33	10.65

34. Nitrate values obtained from September 2015 to February 2016

Months	Nitrates values	Site1	Site2	Site3
Sept		0.018	2.07	1.4
Oct		0.008	1.82	1.2
Nov		0.01	2.32	1.6
Dec		0.005	2.07	1.1
Jan		0.005	1.74	1.7
Feb		0.01	2.4	1.4

35. Turbidity values obtained from September 2015 to February 2016

Months values	Turbidity	Site1	Site2	Site3
Sept		0	0.2	0.3
Oct		0	0.1	0.7
Nov		0	0.3	0.5
Dec		0	0.08	0.5
Jan		0	0.33	0.2
Feb		0	0.2	0.8