UNIVERSITY OF ZIMBABWE

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

A PRELIMINARY ASSESSMENT OF THE WETLAND BIOLOGICAL INTEGRITY IN RELATION TO LAND USE: A CASE OF THE INTUNJAMBILI WETLAND, MATOBO DISTRICT, ZIMBABWE.

BY

NOBUHLE NDHLOVU

A Thesis submitted in partial fulfillment of the requirements for the Master of Science Degree in Integrated Water Resources Management

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DECLARATION

I, **NDHLOVU NOBUHLE** do hereby declare to the Senate of the University of Zimbabwe that this product is of my own investigation except where acknowledged.

To the best of my knowledge, this work has not been presented previously for any degree or similar award to this University or any other University.

Signed…………………………………………….

Date………………………………………………

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DEDICATION

This work is dedicated to my parents Mr and Mrs Ndlovu. May God richly bless you and supply your every need.

ABSTRACT

Research done in Zimbabwe on wetlands has tended to concentrate on hydrological aspects, agronomic practices, institutional arrangements, resource mapping, soil types, water quality and general conservation status. There is a dearth of knowledge regarding the nature, management and response of wetland biological integrity or health to agriculturally related activities and other land uses. The objective of the study was to assess and evaluate the impacts of land use practices on wetland health. This was done in Intunjambili wetland, in Matobo District, Zimbabwe. The wetland is approximately 30 ha in size, and is mainly used for cultivation, water abstraction, vegetable gardening, grazing, settlements, eucalyptus plantations, dam, brick making and sand abstraction. The study evaluated impacts of land use on wetland health, defined in the study as land cover changes, vegetation composition and NDVI, and macroinvertebrates abundance and diversity. Field visits and sampling were done in January and March 2009. There was a 57.9% increase in cultivated areas, a 48.5% decline in woodland, and a 50% decline in permanently wet areas, which indicated that the wetland was drying up from 1990 to 2008. There was a significant (p=0.00) decline in vegetation health with NDVI values as high as 0.64 in 1990 decreasing to values as low as 0.07 in 2008. Alien invasive species like *Lantana camara*, dry land plants like *Euphorbia sp* commonly known as Cactus and ruderal species like *Eragrostis enamoena* were found to replace wetland vegetation in some areas of the wetland. The macroinvertebrates habitat quality, characterised by pH, temperature, conductivity and dissolved oxygen and chemical parameters, BOD, ammonia, turbidity, nitrates, phosphates, total nitrates, total phosphates and total suspended solids, was found to be generally unpolluted, which determined the macroinvertebrates that were found. The 23 macroinvertebrates families that were identified demonstrated low taxa abundance and richness. Shannon Diversity Index that was calculated for the sites had values that were all below 1, indicating a poor diversity. The sensitivity of taxa calculated using the Biological Monitoring Working Party had values below 100 indicating some form of organic pollution. Chironomids and Oligochaetes, which are known to be the least sensitive taxa, dominated the communities. In conclusion it can be said that land use activities in Intunjambili wetland have had moderate impacts on wetland biological integrity. The impacts were mainly on vegetation, which has deviated from its perceived natural wetland vegetation and reduction of water. The impacts on macroinvertebrates communities are minimal.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
BMWP	Biological Monitoring Working Party
GIS	Geographical Information Systems
NDVI	Normalised Difference Vegetation Index
SAAE WQ	South African Aquatic Ecosystems Water Quality Guidelines
SDI	Shannon Diversity Index
TN	Total nitrogen
TP	Total Phosphorus
WBI	Wetland Biological Index

CHAPTER ONE

INTRODUCTION

1.1 Background

By their very nature, wetlands are fragile ecosystems that if not used sustainably, can easily be degraded. Wetlands are important in water resources management because of the ecosystem services they provide and that they are a source of livelihood (Ramsar, 2007). Wetlands are nature's purifiers which cycle and retain nutrients, pollutants and sediments, through unique, naturally adapted mechanisms including, biogeochemical reactions (reduction/oxidation transformations), phytoremediation (plant uptake of contaminants), bioremediation (microbial degradation) and sedimentation (Galbrand *et al.*, 2007). Wetlands are those areas where the water table is at, near, or above the land surface for a significant part of most years. The hydrologic regime is such that aquatic or hydrophytic vegetation usually is established, although alluvial and tidal flats maybe non-vegetated (Anderson *et al.*, 2001). Wetlands are defined as areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres (Ramsar, 1971). In Zimbabwe, wetlands are understood to be land that is subjected to permanent or seasonal flooding or areas of subsurface water accumulation through seepage such as in *vleis* or *dambos* (Masundire and Mackay, 2002).

The general characteristics of wetlands include shallow water, saturated soils and lowly decomposing organic plant material. The range of wetland habitats which come under the mandate of the Ramsar Convention is broad. The grouping of habitat types according to their basic biological and physical characteristics gives a number of wetland types which include; swamp forests, peatlands, lakes, marshes, freshwater, estuaries, floodplains and freshwater marshes. As can be seen, the group of ecosystems described as wetlands is heterogeneous (Dugan, 1994).

Wetlands are however, among the most threatened ecosystems worldwide due largely to destructive practices such as draining, infilling, drainage, infrastructure development, alteration of wetting/drying cycles and high exposure to pollutants and litter (Environment Australia, 2001). In developing countries such as Zimbabwe, wetlands are used in a variety of ways, such as agriculture, fishing, livestock, brick-making and collection of materials (such as wood, grass for thatch and crafts making). The main threats to the wetlands are extensive agriculture, overgrazing, gully erosion and fires, which could result in drying-up, siltation and pollution of wetlands. However natural factors like aridity may also affect wetlands (Chipps *et al.*, 2006).

The land-use practices in and around wetlands may have negative impacts on sustainability of wetland ecosystems such as their natural hydrological functions that include flood regulation, soil formation, climate regulation and water purification. This underlines the importance of wise use of wetlands, which is defined as the maintenance of the ecological character of wetlands that is achieved through the implementation of ecosystem approaches within the context of sustainable development (Ramsar, 2007). The sustainability of wetlands is under threat in developing countries due to limited awareness of the environmental services that are provided by wetlands (Masundire, 2008). For example, Zimbabwe has lost numerous hectares of wetlands and the trend is continuing as indicated by drying up of wetlands and siltation of dams and rivers (Matiza, 1994). This is because of over emphasis of agriculture ahead of ecosystem functions. Research conducted in wetlands has only looked at agronomic practices, institutional aspects, soil characterisation and mapping. There is no information on the biological integrity of wetlands in response to the land use practices.

1.2 Problem statement

Research done in Zimbabwe on wetlands has tended to concentrate on hydrological aspects (Owen *et al.,* 1995), agronomic practices (Mharapara, 1994), institutional arrangements (Sithole, 1999), resource mapping (Murwira, 1997), soil characterisation (Nyamapfene, 1991) and general conservation (Whitlow, 2004). There is a dearth of information and knowledge with respect to the nature, management and response of wetland health to land uses such as agriculturally related activities (Mharapara, 1998). The lack of published data on wetland biological integrity in response to the land use activities in wetlands is not only about the paucity of data, there are also challenges relating to the determination of the biological integrity since the most widely used bio-assessment or biomonitoring tool; the South African Scoring System ($SASS_5$) can not be used in wetlands but only in rivers and streams (Bowd *et al.*, 2004). Such is the case in Intunjambili wetland which is used in a variety of ways including water abstraction for domestic purposes, vegetable gardening, dry land farming, grazing, settlements, brick-making, sand abstraction and eucalyptus plantations. All of these wetland activities are presumed to impact negatively on the wetland ecosystem, which may affect plant and animal species and hence macroinvertebrates and vegetation were used as biological indicators for wetland health.

1.3 Justification

From a scientific point of view, the study will generate knowledge on the relationship between wetland health, and the various uses to which wetlands are put to. The study will also contribute to the development of wetland health bio-assessment methods. Practically, the knowledge acquired will assist in planning, sustainable utilisation and management of wetlands. Bio-assessments can also assist in monitoring, which will result in informed management decision-making in the protection, management and rehabilitation of wetlands.

1.4 Objectives

The main objective of the study was to assess and evaluate the biological integrity of Intunjambili wetland, Matobo District, Zimbabwe in relation to land use.

The specific objectives were to:

1. Determine changes in land cover and land use from April 1990 to April 2008
2. Assess changes in vegetation health from April 1990 to April 2008 and determine current vegetation species composition
3. Determine the existing water quality of the wetland and compare with the South African Aquatic Ecosystems Water Quality Guidelines;

4. Assess and evaluate the abundance ,diversity and sensitivity of macroinvertebrates communities and :
5. Determine overall wetland biological index.

1.5 Scope of study

A rapid bio-assessment protocol which provides a broad assessment of the integrity or health of wetland (Davies *et al.,* 2006) was used in Intunjambili wetland. The study was focusing on land cover changes, vegetation health and present vegetation status, current water quality, macroinvertebrates communities and wetland biological index. The study was also supposed to employ the quantitative sampling protocol (where replication of samples is essential) with regards to macroinvertebrates and water, but due to limiting funds, only the first assessment protocol was used and no replication of water and macroinvertebrates was done. The funds limit was exacerbated by the distance of the study area from Harare and high costs incurred in water quality analysis. However, one-off sampling of macroinvertebrates and water was adequate to give an indication of the condition or health of the wetland. The study was not focusing on water quality but, on the quality of the habitat that macroinvertebrates dwell in, since macroinvertebrates were used as the biological indicator of wetland health. This has also served as a pilot study of the wetland given that no published research has been conducted in the area. Further research in the area can now employ the quantitative sampling protocol because this study has provided the spatial variation of macroinvertebrates in the wetland. Satellite images were not readily available hence only three years were used in determination of land cover/use changes. The use of more images would give a good trend of the changes, especially if those for the period before cultivation began would be found. Despite the limited sampling with regards to water and macroinvertebrates, the study is conclusive on the impacts of land use on wetland health. The shortcomings could be on the temporal variation of macroinvertebrate communities and seasonal variation of the habitat quality, influenced by the quality of water. The "multimetric" approach was used in the analysis of macroinvertebrates data instead of multivariate analysis (Galbrand *et al.,* 2007). The multimetric approach involves defining an array of indices or metrics that individually provide information on diverse biological attributes and, when integrated, give an overall indication of the condition of the biological community. A biotic and a diversity index were used in the analysis.

1.6 Report Outline

The study is reported in six chapters. The first chapter has given an introduction to the study, the scientific problem, the justification and objectives. The second chapter gives an outline of literature about wetlands distribution, their ecosystem functions and impacts land use practices have on wetland ecosystem health. The chapter also discusses the indicators used in wetland assessments, tools and methods used in bio-assessment of wetland health and the analytical framework. The third chapter gives an overview of the geographical location of Intunjambili wetland, the climate, wetland description, population dynamics, vegetation and socio-economic activities of Intunjambili area. The fourth chapter outlines the methods used in collection of data, sampling methods and data analysis used for the four main aspects of the study, namely; land cover/land use changes, vegetation health and plant species composition, macroinvertebrates habitat quality (physical and chemical water parameters), abundance and diversity of macroinvertebrates. The fifth chapter discusses the findings of the study, possible explanations of the findings by comparing with results from other studies and conclusions drawn from the findings. The last and sixth chapter gives the conclusions of the study from the specific objectives and recommendations given the outcome or findings.

CHAPTER TWO

LITERATURE REVIEW

2.1 Distribution and uses of wetlands in southern Africa

In southern Africa wetlands are distributed along main river basins such as the Cunene, Cuito-Cubango, Okavango, Zambezi, Limpopo, Save, Orange, Ruvuma, and Lakes Malawi, Tanganyika and Victoria (Masundire and Mackay, 2002). Wetlands found in Southern Africa mainly fall into the following categories or types:

- Lakes, deep or shallow;
- Rivers, including floodplains;
- Dams, which convert stretches of a river into artificial lakes; and
- Palustrine areas (swamps, marshes, fens, bogs and *dambos*).

The types of wetlands that are found in the region are not the same in each country. In Zimbabwe, common wetland ecosystems include; dambos (locally known as mapani), flood plains, artificial impoundments (dams), and pans (Mharapara, 1998). Extensive swamps and floodplains do not exist because the river valleys are steep and narrow. The focus of this study was on *dambos*. *Dambo* is a Chichewa word used to describe a grassland area. It was adopted by the scientific community within the southern African region (SADC) for uniformity purposes (Mharapara, 1994). A *dambo* can also be described as a meadow grazing land, or more precisely, a seasonally waterlogged grass-covered depression (Heyns *et al.*, 1994). The savanna ecozone which is common in Southern Africa contains many *dambos*, (also known as *mbuga*, *molapo*, *naka* or *vlei*). These account for 10% of central southern Africa, including parts of Angola, Malawi, Mozambique, South Africa, Zambia and Zimbabwe. It is estimated that Zimbabwe is endowed with 1.28 million hectares of wetland areas of which a fifth is found in the communal areas (Mharapara, 1998).

By area almost 13% of Southern Africa is made up of wetlands and much of the rural settlement (which comprises of 60% of the population) is concentrated there (Heyns *et al.*, 1994). Economic activities in and around wetlands include tourism, fishing, flood recession farming, dry land farming, livestock rearing, production and sale of crafts, gathering of veldt products and traditional building materials (Masundire, 2008). The collection and use of “free” wetland resources forms a vital part of the livelihood of many people in southern Africa.

Wetlands, especially *dambos*, have soils that are generally more productive than surrounding upland soils because of a more reliable water supply, eroded soils and nutrients. The open water habitats of wetland ecosystems are used to carry goods and for public transport, and may serve as convenient alternative to normally more expensive forms of road transport. In some cases water ways are the only available means of transport and are consequently very important. The example is given by Central America’s coastal wetlands which provide cheap transport for the rural poor (Dugan, 1994).

In Zimbabwe *dambos* are widely used for grazing, cultivation, and as sources of domestic and productive water in communal areas. Pans are used for cattle grazing and are also important habitats for waterfowl birds in protected areas (Matiza, 1994), while floodplains are currently used for safari hunting and tourism (Mharapara, 1998). The utilisation of wetlands has been governed in Zimbabwe by the Natural Resources Act of 1951 and the 1976 Water Act, which sought to protect them from degradation, particularly through cultivation (Mharapara, 1998). The enactment of these restrictive pieces of legislation was a reaction to the mismanagement of these ecosystems by settler farmers who sought to grow conventional crops such as maize, wheat and tobacco (Mharapara, 1998). However, these have been replaced by the Environmental Management Act of 2000, which has maintained the ban on wetland cultivation.

2.2 Ecosystem services of wetlands

Wetland functions are commonly referred to as indirect wetland uses, and are difficult to quantify in terms of economic evaluation. The economic value of these functions is usually calculated by determining what it would take to replace these “free” services (Shaw *et al.*, 2004). Wetlands play an important role in maintaining biological diversity, and perform such ecological functions as biochemical transformation, storage, production of living plants and animals, and decomposition of organic material. They also provide critical habitats for plants, invertebrates, fish, birds and mammals, including rare and threatened species. In addition, they improve water quality, control floods, regulate global carbon levels, and have significant cultural and recreational values. Most wetlands, especially marshes serve, as stopping points for migratory species, especially birds (USEPA, 2002a). Ecosystem services provided by wetlands mainly fall into four categories namely regulating, supporting, provisioning, and cultural.

2. 2. 1 Regulating functions

Wetland vegetation and floodplains regulate stream or river flow, helping to control local and downstream floods. Riparian vegetation in and adjacent to wetlands and rivers stabilises river banks by holding soil and preventing erosion. This in turn prevents sediments and sand, that could smother benthic organisms and cloud the water, from washing into the rivers. Water from wetlands can recharge adjacent underground aquifers. When an ephemeral river flows, the water can eventually seep through the river bed into the underground aquifer (Ramsar, 2007).Wetland ecosystems maintain good water quality in several ways. Aquatic plants such as papyrus filter pollutants and recycle excess nutrients while aquatic animals, particularly invertebrate filter-feeders and bacteria break down organic material. River sand can also filter water passing through it into underground aquifers (Galbrand *et al.,* 2007). Wetland vegetation can act as carbon reservoir and assists in reducing the amount of carbon dioxide in the atmosphere, decreasing the greenhouse effect and leading to a more stable climate. The overall hydrological, nutrient and material cycles and energy flows of wetlands may stabilise local climatic conditions, particularly rainfall and temperatures. This in turn has an influence on the stability of natural ecosystem and the wetland itself (Dugan, 1994).

2.2.2 Supporting functions

Wetlands tend to slow down the force of water, encouraging the deposition of sediments carried in the water. This is beneficial downstream where deposition of sediments may block waterways.

Nutrients are often associated with sediments and can be deposited at the same time. Nutrients mainly nitrogen and phosphorus mostly from agricultural sources, may accumulate in the sub-soil, be transformed by chemical and biological processes, or be taken up by wetland vegetation which can then be harvested and effectively removed from the system (Ramsar, 2007). Wetlands are reservoirs of biodiversity that includes a wide range of plant species. The plants are very useful in primary production and source of energy. Sediment retention and accumulation of organic matter are essential processes in formation of soil (Masundire, 2008).

2.2.3 Provisioning functions

Wetlands provide a variety of other forms of benefits to humans in form of products that can be exploited for human use. The range of products is enormous: fruit, fish, shellfish, deer, crocodile and other meats, resins, timber for building, fuel wood, reeds for thatching and weaving, fodder for animals etc. Wetlands also provide freshwater for various uses. Wetland animal and plant species play a significant role in the pharmaceutical industry. 80% of the world's population depends on traditional medicine for primary health care (Ramsar, 2007).

2.2.4 Cultural functions

The diversity of plant and animal life in many wetlands makes them ideal locations for tourists. Many of the finest sites are protected as National Parks or World Heritage Sites, and are able to generate considerable income from tourist and recreational uses. Recreational uses such as fishing, hunting and boating involve millions of people who spend a lot of money on these activities (Masundire, 2008). Many people find beauty and aesthetic value in some aspects of wetland ecosystem. Wetlands offer ideal locations for the general public, school children and academic researchers in hands-on learning experiences and also to raise awareness of environmental issues and conservation issues. Wetlands are now becoming a focus of increasing concern in terms of academic research, because most of them are threatened. Wetlands are also sources of inspiration: many religions attach spiritual and religious values to aspects of wetland ecosystems (Ramsar, 2007).

2.3 Wetland biological integrity

Wetland biological integrity is the health of a wetland, which is the ability of a wetland ecosystem to support and maintain a balanced adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of natural habitats (USEPA, 2002a). Healthy wetlands perform vital ecological functions in a watershed. But assessing their condition and ability to perform those functions is not easy, especially as wetlands are disappearing fast due to human encroachment (Smithsonian, 2007). Wetland biological integrity can be determined by observing the wetland's structure (its parts) and function (what its doing). Examples of wetland structure include: soil condition, geology, hydrology, topography, morphology, carrying capacity, species composition, food web support and nutrient content. Examples of wetland function include: surface and ground water storage, recharge, purification of water and reduction of erosion (Macfarlane *et al.,* 2008). The most direct and cost effective way to evaluate the biological integrity of a wetland is to measure the attributes of floral and faunal communities that inhabit the wetland (USEPA, 2002a). Wetland biological integrity can be achieved through wise use, which is the sustainable utilisation for the benefit of mankind in a way compatible with the maintenance of natural properties of the ecosystem or utilisation without compromising the ecosystem integrity.

2.4 Land use impacts on biological integrity

The relationship between land use and wetlands is an important one to explore. Land use is the human modification of natural environment into a built environment such as fields, pastures and settlements. Land use practices have a major impact on natural resources including water, soil, nutrients, plants and animals (Schenck, 2008). Amongst the most important are water diversions for irrigation, cultivation and settlements.

Agricultural activities such as tillage, drainage, intercropping, rotation, grazing and extensive usage of pesticides and fertilizers have significant implications for wild species of flora and fauna. Species capable of adapting to the agricultural landscape may be limited directly by the disturbance regimes of grazing, planting and harvesting, and indirectly by the abundance of plant and insect foods available. Some management techniques, such as drainage, create such fundamental habitat changes that there are significant shifts in species composition (McLaughlin and Mineau, 1995).

Agriculture, which is the most common land use, tends to alter slopes, which will either increase or decrease surface runoff (Mhlanga, 1995). Extensive clearing for agriculture removes the natural retardance resulting in reduced surface roughness, high runoff volumes, modification and loss of natural vegetation (Schenck, 2008). Clearing land for agriculture increases runoff and decreases infiltration rates, lowers the water table and compacts the soil (Heyns *et al.*, 1994). Uncontrolled cultivation affects soil structure which in turn changes the infiltration pattern of top soils. In most cases soils are compacted, leading to reduced infiltration and high runoff volumes (Mhlanga, 1995). All this is mainly a result of a reduction in natural woodland and other vegetation cover. Major impacts have been cited as increased salinities and changed hydrological patterns, with wetlands becoming dry for longer periods or completely (Brendonck and Williams, 2000). Impoundments of large river systems have widespread impacts on the structure and function of wetlands (Chipps *et al.*, 2006). Moreover, alteration of natural river flows disrupts river-floodplain connection, thereby reducing the abundance, productivity, and biodiversity of floodplain wetlands (Galat *et al.*, 1998).

For wildlife and ecosystems, however, it is the cumulative impacts of numerous pressures that determine actual effect on the abundance of species, including, but not limited to, infrastructure development and associated land use, forestry, agricultural practices, nitrogen pollution and climate change (UNEP, 2008). The ecosystem function of a wetland is closely related to its original species composition and abundance.

2.5 Sustainability indicators of biological integrity

2.5.1 Vegetation

Sustainability of wetlands can be deduced from the presence of wetland plants. Wetland plants are "all plants that tolerate or require flooding for a minimum duration of saturation/inundation" (Revenga and Kura, 2003). Many environmental factors, such as light, temperature, soil texture, soil permeability, and the level of disturbance, influence the distribution and abundance of plant species. Hydrology is recognized as exerting the overriding influence on the occurrence and abundance of plant species in wetlands (Lillie, 2000). Wetland plant species often exhibit distinct morphological, physiological and reproductive adaptations that allow a greater tolerance and survival within wetland areas. Plant species that are common to the wettest environments often exhibit the greater degree and most effective adaptations to wetland conditions, for example *Nymphea sp* and *Scirpus sp*.

The riparian vegetation balances the temperature in a healthy aquatic system. If the vegetation is cleared, it gives rise to more light penetration and an increase in turbidity from exposed soil (Water and Rivers Commission, 2001).

The South African WET-Health, a tool for rapid assessment of wetland health is mainly used to assess the status of vegetation against present and past land use practices in wetlands through identification of invasive and ruderal plant species. Present vegetation state is then assessed by evaluating the degree to which current vegetation composition has deviated from perceived natural or reference conditions. Assessing this deviation is based on what 'should not be there' (e.g. invasive alien species or a high abundance of ruderal (weedy) species) rather than on the composition of indigenous plants that 'should be there' (Macfarlane *et al.*, 2008).

A huge range of alien invasive species occur across southern Africa. The prevalence of particular species varies geographically. It is therefore important that assessors are familiar with and are able to identify alien invasive plants within the area they are working. These plants are perennial, and once they are well established, they generally persist at the expense of indigenous vegetation. However, these species may take longer to reach their greatest abundance and often continue to persist, particularly where they provide tall and dense cover to the exclusion of other species. Some of the common alien invasive species found in South African wetlands are shown in the table (Appendix E) (Macfarlane *et al.*, 2008). The hydric status or classification according to occurrence in wetlands is shown in the table (Appendix E).

Ruderal species are typically species that are adapted to rapidly colonized areas with disturbed soils (e.g. in cultivated lands). As such, these species commonly increase in abundance in response to disturbance, but are gradually replaced by later successional species as site recovers. These species vary in their hydric status and occurrence between different geographic areas. Some of the common ruderal species found in South African wetlands are shown in the table (Appendix E) (Macfarlane *et al.*, 2008).

2.5.2 Macroinvertebrates

Common invertebrates taxa in aquatic systems include: Odonata (dragonflies and damselflies), Plecoptera (stoneflies), Trichoptera (caddiceflies), Ephemeroptera (mayflies), Megaloptera (alderflies, dobsonflies, fishflies), Coleoptera (beetles), Diptera (two-winged, or true flies), Collembola (springtails), Hemiptera (true bugs) and Neuroptera (spongillaflies) (Revenga and Kura, 2003). There are many reasons for use of macroinvertebrates, the least of which is that they have successfully been used in monitoring stream and river integrity in southern Africa (Day, 2000). Invertebrates respond to a wide array of stresses to wetlands, such as pollutants in water and bottom sediments, nutrient enrichment, increased turbidity, loss or simplification of vegetation, siltation, rearing of bait or game fish, input of storm water or wastewater runoff, introductions of exotic species or alterations of the landscape around the wetland (Greenfield, 2004). Therefore, the richness of macroinvertebrate community composition in a water body can be used to provide an estimate of water body health. Many invertebrates are linked to wetland conditions and complete their life cycles within the wetlands. They are exposed to site-specific conditions. The high numbers of taxa permits the use of statistical ordination techniques that might even be more difficult with just a few species e.g. amphibians (USEPA, 2002b).

Environmental conditions or pollution can alter macroinvertebrate communities. Poor catchment management can exaggerate the turbidity of water. In highly turbid water, the light penetration is reduced affecting photosynthesis of plants. It also increases the temperature of the water. The suspended solids may clog respiratory surfaces or interfere with feeding appendages. High levels of suspended solids may begin to settle and change the composition of the bed of the water body as it coats rocks and vegetation. This can affect movement, feeding, habitat and reproduction of some macroinvertebrates (Water and Rivers Commission, 2001).

2.5.3 Biodiversity

Biodiversity is generally an indicator of sustainable practices. Biodiversity is defined as the average abundance of original species compared with their original abundance when ecosystems where hardly impacted by people. The abundance of a species means the population size of number of individuals in a group of species. This indicator is in accordance with indicators agreed upon under the Convention of Biological Diversity (UNEP, 2008). Biodiversity is valuable for a number of reasons that include, ecological stability, economic and cultural benefits. All living creatures are supported by interactions among organisms and ecosystems. A biologically diverse natural environment provides humans with the necessities of life and forms the basis for the economy. Most people feel connected to nature, often for reasons that can be hard to explain. Human cultures around the world profoundly reflect our visceral attachment to the natural world (Schenck, 2008).

Loss of biodiversity makes ecosystems less stable, more vulnerable to extreme events, and weakens its natural cycles. Habitat loss has been characterized by a decline and loss of freshwater species, to a point where the biodiversity of freshwater ecosystems is currently in far worse conditions than that of terrestrial systems. Habitat degradation, physical alteration through dams and canals, water withdrawals, overharvesting, pollution and the introduction of exotic species all contribute directly or indirectly to the decline in freshwater biodiversity (Revenga and Kura, 2003).

2.5.4 Habitat Quality

The quality of habitat or levels of pollution are determined by testing the quality of water for physico-chemical parameters and also biological parameters. Water quality is the biotic and abiotic characteristics of water that determine its use as an aquatic habitat. Water quality determines whether the wetland is performing its ecosystem function of water purification or not. Factors that may affect water quality relate to the common economic and social uses of wetlands. Water quality in wetlands is mainly affected by agricultural activities. Inorganic fertilisers can pollute both surface and ground waters, especially nitrates based compounds (Mhlanga, 1995).

This is also true for insecticides, whose residues may be washed into wetland surface water and some may infiltrate into groundwater. Although not a serious threat especially in pastoral systems, animal waste where there is high livestock density can be a threat to wetland water quality (Mhlanga, 1995). Water bodies in a region that has been deforested or having erosion will have different water quality than those in areas that are forested.

2.6 Techniques for bio-assessments and data processing methods

Various remote sensing techniques are used in bio-assessments. They are mainly used to show changes in land use, land cover, seasonal changes, vegetation changes *etc*.

2.6.1 Satellite imagery

Satellite imagery is a remote sensing technique that mainly relies on information that is acquired about an area or phenomena without actually being in contact with it. Scientific remote sensing uses sensors to gather information about surfaces for achieving analysis and assessment. This is accomplished by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information (Lillesand and Kiefer, 1995).

Data acquired from remote sensing is processed into images. The processed image is interpreted visually or digitally to extract information about the target. The final element of remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the area in order to better understand it, reveal some new information, or assist in solving a particular problem (Di Gregorio and Jansen, 2000).

To identify the land uses and determine land cover changes, image classification and analysis operations are performed. Classification is usually performed on multi-channel data sets. This process assigns each pixel in an image to a particular class or theme based on statistical characteristics of the pixel brightness values (Vanderpost *et al.*, 2005). There are a variety of approaches that have been taken to perform digital classification. Two generic approaches, which are used most often, are supervised and unsupervised classification. In a supervised classification process, the operator identifies some of the pixels belonging to the desired classes and then lets the computer find the rest. In an unsupervised classification, the computer itself decides on the classes to pick out based on pre-determined rules (Ringrose *et al.*, 2003).

A human analyst attempting to classify features in an image uses the elements of visual interpretation to identify homogenous groups of pixels, which represent various features or land cover classes of interest. Digital image classification uses the spectral information represented by the digital numbers in one or more spectral bands, and attempts to classify each individual pixel based on this spectral information. In either case, the objective is to assign all pixels in the image to particular classes or themes (e.g. water, coniferous forest, deciduous forest, corn, wheat, etc). The resulting classified image is comprised of a mosaic of pixels, each of which belong to a particular theme, and is essentially a thematic "map" of the original image (Vanderpost *et al.*, 2005).

Supervised classification is one of the most widely used techniques in remote sensing to determine land use and land cover changes (Anderson *et al.*, 2001). In a supervised classification, the analyst identifies in the imagery homogenous representative samples of the different surface cover types (information classes) of interest. These samples are referred to as training areas. The selection of appropriate training areas is based on the analyst's familiarity with the geographical area and their knowledge of the actual surface cover types present in the image (Ringrose *et al.*, 2003). Thus, the analyst is "supervising" the categorization of a set of specific classes. The numerical information in all spectral bands for the pixels comprising these areas are used to "train" the computer to recognise spectrally similar areas for each class (Anderson *et al.*, 2001). The computer uses a special program or algorithm to determine the numerical "signatures" for each training class. Once the computer has determined the signatures for each class, each pixel in the image is compared to these signatures and labeled as the class it most closely "resembles" digitally. Thus in a supervised classification, we are first identifying the information classes, which are then used to determine the spectral classes; which represent them (Vanderpost *et al.*, 2005).

To monitor the changes in vegetation health over a long time, the Normalised Difference Vegetation Index (NDVI) is used. The method is a remote sensing technique that is used to detect changes in vegetation health given satellite images. It is an image transform which has been used to monitor vegetation conditions on continental and global scales using the Advanced Very High Resolution Radiometer (AVHRR) sensor onboard the National Oceanic Atmospheric Administration (NOAA) series of satellites (Vanderpost *et al.*, 2005).

Spectral rationing is one of the most common transforms applied to image data and it serves to highlight subtle variations in the spectral responses of various surface covers. By rationing the data from two different bands, the resultant image enhances variation in the slopes of the spectral reflectance curves between the two different spectral ranges that may otherwise be masked by the pixel brightness variations in each of the bands (Vanderpost, 2008).

NDVI is a simple numerical indicator that can be used to analyze remote sensing measurements, typically but not necessarily from a space platform, and assess whether the target being observed contains live green vegetation or not. Healthy vegetation reflects strongly in the near-infrared portion of the spectrum while absorbing strongly in the visible red. Other surface types, such as soil and water, show near equal reflectance in both the near-infrared and red portions (Ringrose *et al.*, 2003). Negative values of NDVI (values approaching -1) correspond to barren areas of rock, sand, or snow. Values close to zero (-0.1 to 0.1) generally correspond to water. Low positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests (values approaching 1). Thus discrimination of vegetation from other surface cover types is significantly enhanced. It is also able to identify areas of unhealthy or stressed vegetation, which show low near-infrared reflectance, as the ratios are lower than for healthy green vegetation (Sellers, 1985).

2.6.2 Data processing for macroinvertebrates

Several biotic indices have been developed for environmental studies. A biotic index takes account of the sensitivity or tolerance of individual species or groups to pollution, habitat alteration or environmental stress and assigns them a value, the sum of which gives an index of pollution for a site. The data may be qualitative (presence or absence) or quantitative (relative abundance or absolute density). They have been mainly used in assessment of organic pollution in aquatic systems (Mason, 1996). The common biotic indices are the Saprobien Index, Trent

Biotic Index and Chandler Biotic Score. The three have been largely superseded by the Biological Monitoring Working Party (BMWP) score. The BMWP was designed to give a broad indication of the biological condition of aquatic systems.

Sites are sampled, where possible by a 3-minute kick/sweep sample with a standard pond net, all major habitats (bottom substrata, vegetation, margins, etc) within the site being included. Identification of taxa is up to family level only and no account of abundance is taken. Each family is given a score between 1-10, depending on its susceptibility to pollution, habitat alteration or environmental stress. Those taxa least tolerant, such as families of mayflies and stoneflies, are given the highest scores. The BMWP score is the sum of the scores of each family present in a sample. The Average score per taxon is determined by dividing BMWP by the number of taxa present (Mason, 1996).

The performance of BMWP scores using macroinvertebrates from 268 sites in 41 rivers was tested in 41 rivers in England and Wales (Mason, 1996). Physical and chemical data were used to predict BMWP scores using multiple regression techniques. A higher proportion (65%) of the variance was explained in equations and used to predict BMWP scores (Chapman, 1996). The BMWP was developed in order to limit taxonomic requirements by earlier indices to identify macroinvertebrates up to species level. The BMWP was published as a standard method by an international panel (ISO-BMWP, 1993) (Chapman, 1996). A BMWP score greater than 100 in pollution studies is generally known to indicate a good water quality.

Biotic indices are mainly useful in measuring organic pollution, but may not be suitable for detecting other forms of pollution and environmental stress. Diversity indices are used to measure stress in the environment and habitat alterations (Mason, 1996). It is considered that unpolluted environments are characterised by a large number of species, with no single species making up the majority of the community. Maximum diversity is obtained when a large number of species occur in relatively low numbers in a community. Diversity indices and their application to aquatic studies were first described by (Metcalfe, 1989). Most species diversity indices take account of both the number of species in a sample and their relative abundances, but the sensitivity of individual species to particular pollutants is not allowed for. The most widely used diversity indices are those based on information theory, the most frequent measure being the Shannon index which assumes that individuals are randomly sampled from an indefinitely large population.

2.6.3 Biological assessments

Interest in biological assessments of aquatic systems is growing with the recognition that physical and chemical assessments are inadequate for establishing standards that ensure ecosystem integrity and for detecting cumulative impacts from diverse land uses (Karr and Chu, 1999). Over the past 15 years, stream ecologists have demonstrated the effectiveness and feasibility of using biological indicators to assess aquatic system integrity.

Wetlands are more than cultivated fields –they are also sources and sites of important biological resources to communities and to the ecosystem, hence the importance of undertaking biological assessment. A variety of bio-assessment techniques have been developed to assess effects of anthropogenic disturbance on aquatic ecosystems (Karr and Chu, 1999). Biological assessment is an evaluation of the condition of a water body using biological surveys and other direct measurements of resident biota in surface waters. This is because biological communities reflect overall ecological integrity. They integrate stresses over time and provide an ecological measure of fluctuating environmental conditions (USEPA, 2002a). Biological assemblages often integrate disturbance across large spatial and temporal scales, they can provide a better measure of ecosystem health than environmental conditions alone. Changes in floral and faunal community structure do occur due to anthropogenic activities. When the interaction of wetland plants and animals with their environment is disrupted, many of the functions provided by the wetlands are lost or diminished (USEPA, 2002a). Land use is often used as a surrogate for disturbance and has been correlated to with biological attributes in wetlands (Chipps *et al.*, 2006).

The most direct and cost effective way to evaluate the integrity of a wetland is to directly measure the attributes of the floral and faunal communities that inhabit the wetland. Bio-assessment methods developed for streams and rivers can be and have been adapted for use in the monitoring of wetlands, lakes and terrestrial systems (Karr and Chu, 1999). In recent years, biological-based approaches like the index of biotic integrity, wetland condition index and habitat integrity index have been applied with mixed success to wetlands (Chipps *et al.*, 2006). One of the most challenging aspects of developing wetland biomonitoring criteria has been accounting for the influence of hydrology on wetland biota. Seasonal and annual variation in wetland hydrology can have profound effects on plant and animal communities making it difficult to unravel the influence of natural variation from anthropogenic disturbance (Wilcox *et al.*, 2002).

In addition to the above, biomonitoring is truly an appropriate technology for the 21st century, because it makes use of existing, synthesised information already present, in the form of the animals and plants, in an aquatic ecosystem. Careful selection of tools can provide a quicker, cheaper and more integrated picture of water quality or ecosystem integrity than the expensive, routine monitoring of water chemistry (Day, 2000). In my view, biomonitoring is appropriate for sub-Saharan Africa where resources and funds for research are limiting. Biomonitoring provides a long term integrated view of biotic integrity and quality and it is cheap and reliable.

Bio-assessments have mainly been used in streams and rivers. Bio-assessments have also been acclaimed as being more sensitive and more reliable measures of ecosystem health and water quality than physico-chemical measurements (Day, 2000). Macroinvertebrates and vegetation have been used with success in assessing wetland health, by analysing their abundance and diversity (Lillie, 2000; Lillie *et al.*, 2002 and State of Victoria, 2006). The integrity of inland aquatic ecosystems (rivers and wetlands) has been the key target for most bio-assessments, and wetland ecosystem condition has been the key indicator for the target. It is very important to note, however, that when assessing macroinvertebrates, other physical, chemical and other biological data should be considered to support the water body assessment. Other biological measures could include riparian vegetation, fish, frogs, birds, algae and faecal coliforms (Water and Rivers Commission, 2001). Most widely used indicators in biological assessments include; colour, dissolved oxygen and temperature, extent of inundation, macroinvertebrates diversity and community composition, macroinvertebrates index, macroinvertebrates indicator species, nutrients (phosphorus and nitrogen), transparency and vegetation and phytoplankton (State of Victoria, 2006).

Use of biological assessments to determine wetland integrity comes with a lot of methodological challenges. In southern Africa, the most common widely used biomonitoring tool is the South African Scoring System Version 5 ($SASS_5$). However $SASS_5$ is unsuitable for assessing wetlands, unless if modified (Bowd *et al.*, 2004). A study was conducted in KwaZulu-Natal, South Africa to test the applicability of $SASS_5$ scoring and calculation procedure in assessing wetland health. The study yielded very low $SASS_5$ scores. The study concluded that the low $SASS_5$ scores were due to lack of biotope in wetlands compared to rivers (Bowd *et al.*, 2004).

2.7 Analytical Framework

The study took a broad approach in assessing wetland health in order to cater for both aquatic and riparian habitats of the wetland. The study determined land cover changes using supervised classification method. The supervised classification method is the one recommended when the analyst has been to the study area, unlike the unsupervised classification which is used when there is no knowledge of the study area. The selection of appropriate training areas is based on the analyst's familiarity with the geographical area and their knowledge of the actual surface cover types present in the image (Ringrose *et al.*, 2003). The supervised classification has been used widely in big wetland systems like the Okavango Delta (Vanderpost *et al.*, 2005).

The Present State of Vegetation (PSV) was assessed to determine the impacts of land use on vegetation health. It is recommended to use PSV if there is no knowledge of prior vegetation condition (Macfarlane *et al.,* 2008). There was no data on the previous condition of vegetation in Intunjambili wetland. The method used in the study was adopted from the Wet-Health manual for rapidly assessing wetlands in South Africa. Vegetation together with macroinvertebrates were used as biological indicators of wetland health. The concept of indicator species assumes that the occurrence of, or absence of, particular species indicates a specific disturbance regime (Mason, 1996).

Water quality being the biotic and abiotic characteristics of water that determine its use as an aquatic habitat was analysed to determine the quality of the habitat that macroinvertebrates dwell in. The quality of the water was useful in explaining the distribution, abundance and diversity of macroinvertebrates obtained in Intunjambili. A number of bio-assessments and biomonitoring methods recommend use of macroinvertebrates in wetlands assessments because of their sedentary nature (Mason, 1996; Dickens and Graham, 2002; and Davies *et al.,* 2006). There was no replication of macroinvertebrates and water samples as is recommended in a rapid biological assessment protocol (Davies et *al.,* 2006), which is less expensive and used in studies that are conducted in short periods of time. There are also published scientific researches in wetlands where replication of macroinvertebrates and water is not done, for example, the assessment of the constructed wetland biological integrity using macroinvertebrates by Galbrand *et al.,* (2007) in Dalhousie University, Nova Scotia, Canada did not replicate macroinvertebrates and water. A rapid bioassessment is particularly useful where a broad assessment of the 'state' or 'health' of one or more wetlands is required (Davies *et al.,* 2006). This was followed due to limiting funds; otherwise the quantitative sampling protocol could have been used. The Wetland Biological Index (WBI) was calculated for Intunjambili because the variables required for its calculation were determined in the study. It was also used because it's the only index developed so far for use in wetlands assessments in Southern Africa (Greenfield, 2004). The Australian wetland bioassessment manual by Davies *et al.* (2006) shows that, to describe the health of a wetland, abroad approach to assessment is the most appropriate. This authenticates or validates the approach used in the study.

CHAPTER THREE

STUDY AREA

3.1 Geographical location

Intunjambili wetland lies on the Tuli river sub-catchment of Umzingwane catchment. The Umzingwane catchment which is in the southern parts of Zimbabwe is part of the Limpopo River Basin. The wetland is in Ward 15, in the Matobo district of the Matabeleland South province and is shown in Fig 3.1. The Intunjambili wetland is located about 60 km from Bulawayo along the old Gwanda road, at 28°41' East and 20°27' South at an altitude of 1350 m above sea level. The area is adjacent Matopos National Park.

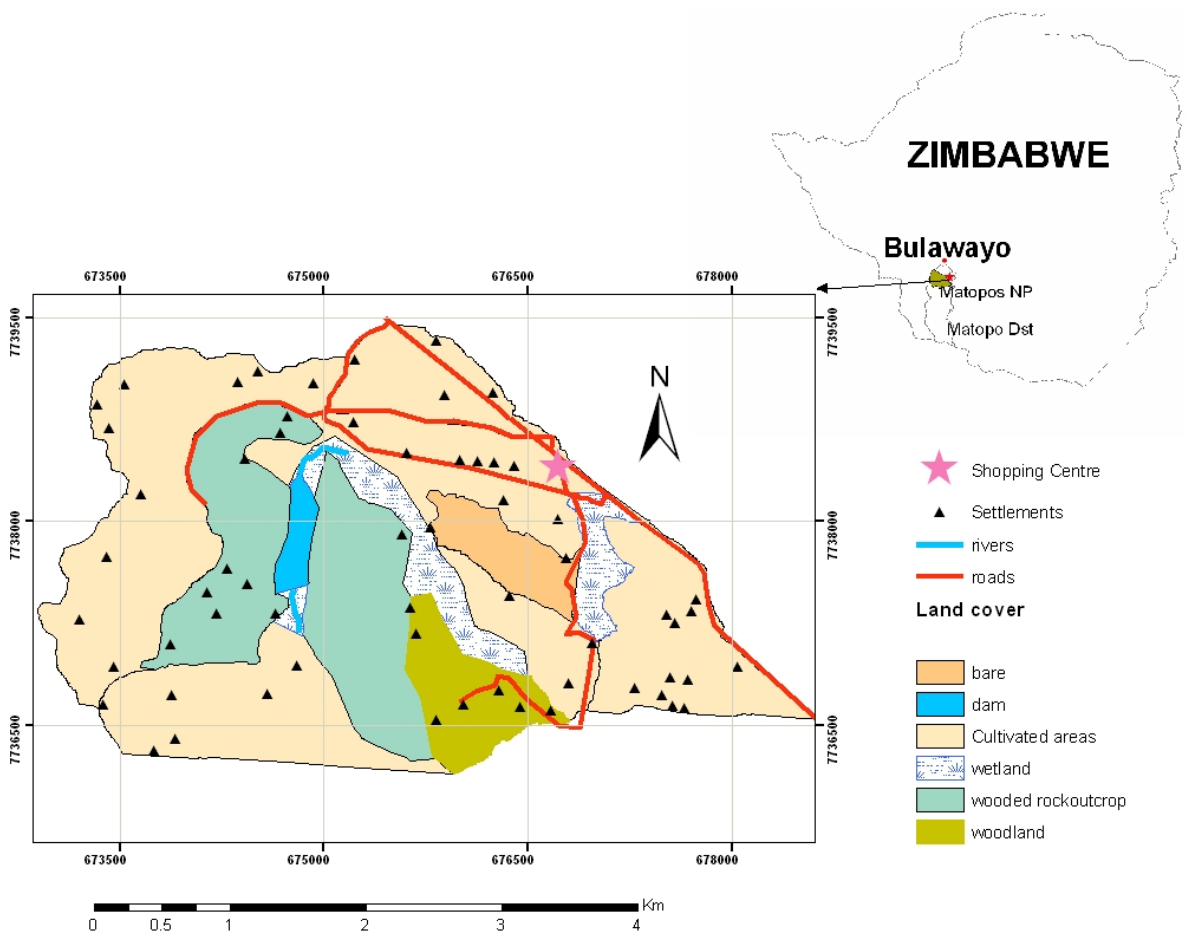

Figure 3.1: Map showing Intunjambili wetland area in Matobo, Zimbabwe

3.2 Climate

The catchment lies in agro-ecological region IV which is a semi-intensive farming region characterized by total amounts of rainfall that range from 450 to 650 mm. It is subject to periodic seasonal droughts and severe dry spells during the rainy season (Meteorological Services Department, 2007). The study area falls in zone B which has the least potential for run-off production. Mean annual run-off varies from 17-19 mm (i.e. the coefficient of runoff is typically about 3%) (Chenje *et al.*, 1998).

Like the rest of Zimbabwe, Intunjambili's climate is influenced by the presence or absence of the Inter-Tropical Convergence Zone (ITCZ) which is responsible for most of the rain. The ITCZ is an area of intense rain-cloud development created from a collision of the Southeast Trade winds (from the southern part of the region), the Northeast Monsoons (winds from the north), and the moist Congo air masses. The Intunjambili wetland climate is characterised by a short wet season and a very long and hot dry season (Chuma, 2007). Rainfall is the main source of water for the catchment where the wetland is situated. The area receives normal to above normal rainfall one in every five years. The rainfall is normally erratic and when it occurs it is usually associated with strong and localised convective storms. The rainy season occurs from mid-October through to mid-March with the rest of the year virtually dry .The thirty year rainfall records which were recorded from Matopos weather station are shown in Fig 3.2.

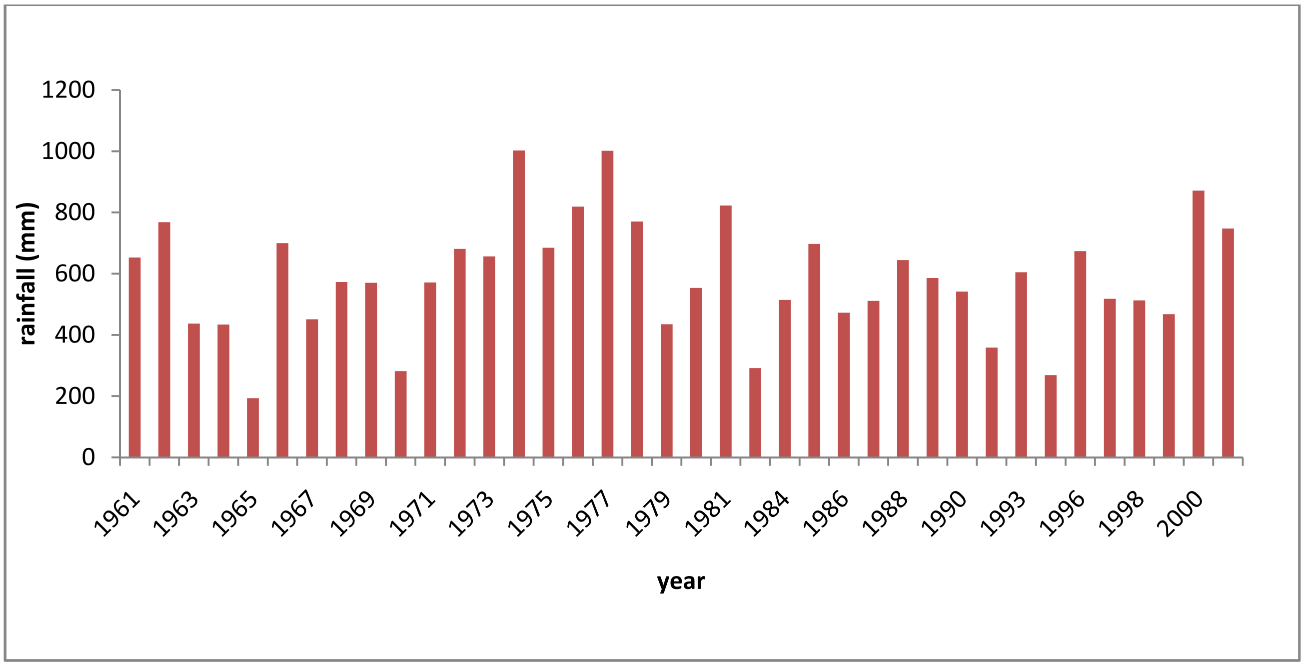

Figure 3.2: Fourty year rainfall records from Matopos weather station

3.3 Vegetation

The wetland is bordered by rock outcrops which are believed to contribute to most of the run-on that contributes to surface and sub-surface flow for the wetland. Certain sections close to the rock outcrops are permanently water-logged, while others have intermittent water on the surface, and in some the water table rises to the surface in very wet years.

Vegetation in the Intunjambili area is dominated by *Acacia fleckii* commonly known as blade thorn . Other species include (mopane) *Colophospermum mopane*, *Brachystegia spiciformis*, *Terminalia sericea*, *Julbenardia globiflora*, *Baikeiaea sp*. The physiogonm is savanna woodland. The shrub community is dominated by the invasive *Lantana camara* that occupies about 60% of the wetland area. The other shrub species is *Euphorbia sp.* commonly known as Cactus a dryland plant species. The cactus plant is presumed to be *Euphorbia halipedicola* (Moll, 1983). In the early 1980s the plant was not found in Zimbabwe (Moll, 1983).

3.4 Demographic features

The census results for 1982, 1992 and 2002 show total population in the Matopo district to be 53 534, 89 139 and 99 836 respectively. The population of Intunjamili wetland area increased rapidly from 1982 to 1992 and slightly less increase from 1992 to 2002 in the Matopo district as shown in figure 3 (Central Statistical Office, 1985; 1994; and 2003). The average rate of growth of natural increase is 25.8% (Central Statistical Office, 2003). The specific census results for ward 15 for 1982, 1992 and 2002 are 4 725, 5 345 and 5 490 respectively and are shown in Fig 3.

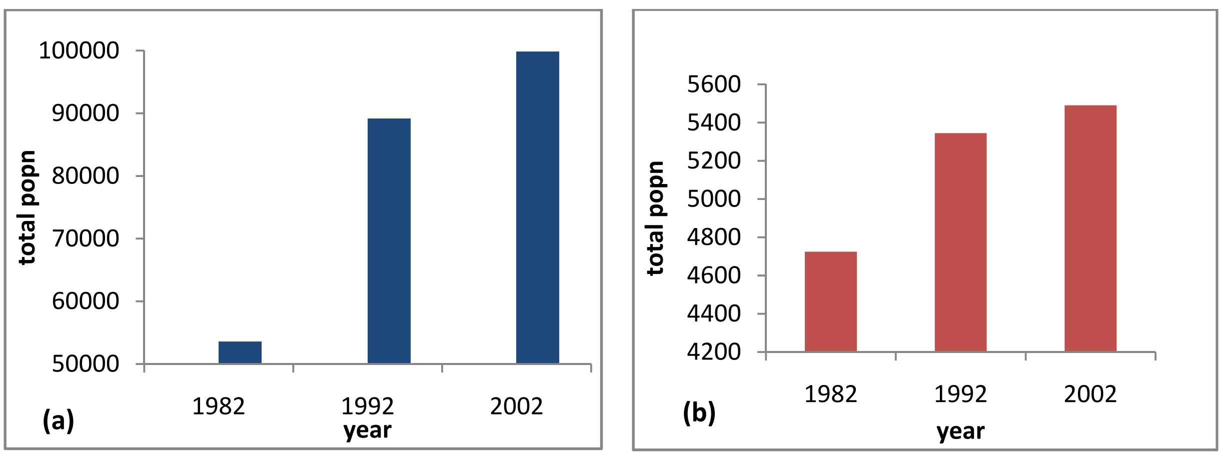

Figure 3.3: Total population dynamics for (a) Matobo district and (b) ward 15 in Matobo district

3.5 Socio-economic aspects

Intunjambili wetland supports a population of approximately 512 people, comprising of 180 households (Chuma, 2007). The community uses the wetland mainly for cultivation, provision of domestic water, livestock grazing, fishing, settlements, vegetable gardening, eucalyptus plantations and water abstraction for irrigation. The cultivation activities are shown in Figure 3.4. Cultivation activities mainly consist of vegetable gardening and maize crop farming. The vegetable markets for the people in Intunjambili wetland were said to be Botswana, the nearby Bulawayo city and Gwanda town (Chuma, 2007).

Figure 3.4: Cultivation in Intunjambili Wetland

The pictures show cultivation activities in Intunjambili wetland area. The first picture shows cultivation at the confluence of the stream with the dam and the second shows cultivation at the main wetland. The pictures show that during the dry season, cultivation is done in the water course, which is a threat and may lead to serious erosion and pollution problems.

CHAPTER FOUR

MATERIALS AND METHODS

4.1. Collection of data and analysis

4.1.1 Land cover/land use change determination

Landsat TM_5 satellite images for April 1990, June 2001 and MODIS satellite image for April 2008 were used to determine land use and land cover changes in Intunjambili wetland. Due to the difficulty in obtaining images, the three images were the only ones obtainable and used in the study. Images were given the same geo-reference. The map of the Intunjambili area was overlaid in all the three images and a subsample of only Intunjambili area was created. Supervised classification was used to determine percentage change in land cover/use. The Geographical Information System softwares used for the analysis were ILWIS 3.4 and ENVI 3.0. The available satellite images were geometrically corrected; subset to the study area to contain corresponding bands only, the MODIS image was re-sampled to 28.5 m x 28.5 m pixel size. Five land cover classes were used in the classification of images, namely; water, cultivated area, woodland, bare areas and grassland. The areas covered by the respective cover classes were generated in form of histograms for ILWIS software and used to determine percentage cover for each class.

Ground-truthing was done to check on accuracy of the land cover classes and corrections of images. The GPS coordinates collected from the field were compared by crossing with the April 2008 image to determine the accuracy levels. The April 1990 image was compared to the 1985 aerial photo visually.

4.1.2 Vegetation health change and species composition

A rapid assessment of vegetation was done to check for the presence of alien-invasive species, indigenous invasive, introduced and ruderal species according to the method by Macfarlane *et al.,* (2008) in the South African WET-Health, a method for rapidly assessing wetlands. Alien species and ruderal species, normally invade areas that have been disturbed and persist at the expense of indigenous vegetation. The method assessed the present vegetation state. There was no comparison with previous vegetation state because of lack of published data about vegetation or any other aspect on wetland biological integrity of the study area. Present vegetation state was assessed by evaluating the degree to which current vegetation composition has deviated from perceived natural or reference conditions. Assessing this deviation was based on what ‘should not be there’ (e.g. invasive alien species or a high abundance of ruderal (weedy) species) rather than on the composition of indigenous plants that ‘should be there’ (Macfarlane *et al.*, 2008. The assessment was mainly based on alien-invasive, indigenous invasive, introduced and ruderal species to show disturbance in Intunjambili. Plants were identified to species level using the guides by Ellery and Ellery (1997) and Cook (2004). Plant presses were made and specimens were kept for laboratory verification and identification for species that could not be identified in the field according to guides by Lillie *et al.*, (2002). Plants that were not identified at the field were identified at the Botany section of the Department of Biological Sciences.

Normalised Difference Vegetation Index (NDVI) was calculated for the 1990, 2001 and 2008 satellite images of Intunjambili area to determine changes in vegetation health. NDVI was calculated using Red (R) and Near Infra-Red (NIR) bands of the three images using the formula:

$$NDVI= (NIR-R)/ (NIR+R) \quad (4.1)$$

The independent t-test analysis of the NDVI values was done by box-plots to obtain the trend for the three years on SPSS version 14.0.

4.1.3 Location of sampling sites for macroinvertebrates and water

A total of 11 sites (4 from main wetland, 3 from stream and 4 from dam) were selected for macroinvertebrates and macroinvertebrates habitat quality sampling (Fig 4.1). Their selection was designed to cover the range of aquatic habitats and human-induced disturbances/land uses in the wetland, along a longitudinal (albeit curving) gradient (main wetland→ stream →dam).

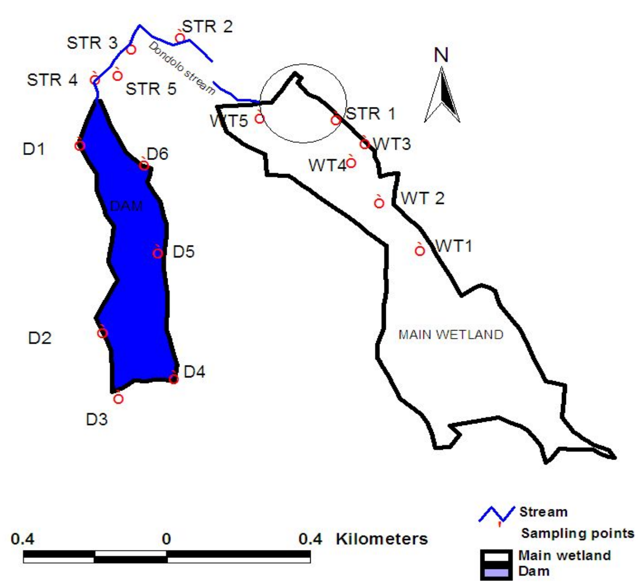

Figure 4.1: Intunjambili map showing sampling sites for macroinvertebrates and water

The encircled area (Fig 4.1), are where numerous channels from the wetland/marsh combine to form a stream. The area is filled with many dry-season shallow wells used to water vegetable gardens in the wetland. The break point of the stream was caused by failure to collect GPS points because the section was a fenced field. The description of sampling sites is given in Table 4.1.

A number of criteria were considered in site selection. Firstly; accessibility was considered. This was one of the major contributing factors owing to flooding conditions that prevailed between January and March 2009. Secondly, sites with representative microhabitats were selected, and for the stream site this corresponded roughly with biotopes used in the $SASS_5$ protocol (Day, 2000; Dickens and Graham, 2002). Finally, the ease of finding macroinvertebrates and water (in main wetland/marsh) and substrate at a wade-able depth (in dam) was also considered.

Macroinvertebrates were collected from areas less than 1m in depth. Macroinvertebrates and water samples were collected in January only due to limiting funds.

Table 4.1: Description of sampling points

WT1	The area is covered mainly by grasses (*Hyparrhenia sp* and *Eragrostis sp)*, though it was very close to the eucalyptus plantations and settlements.
WT2	The area is mainly covered by grasses though it is also surrounded by fields and gardens.
WT3	The area is covered by grasses, surrounded by fields and very boggy.
STRI	The biotope is mainly bedrock.
STR2	The site is located below the gauging weir.
STR3	The site is approximately 100m downstream STR2.
STR4	The last site at the stream, at the confluence of the stream with the dam.
D1	The site was at the point where the stream entered the dam.
D3	The site was the littoral vegetated zone near dam wall.
D4	The site was mainly a stream pool below dam wall.
D6	The site was a littoral vegetated zone opposite Dam1 site.

* NB: the sites missing in the table (WT4, WT5, STR5, DAM2 and DAM5) were only used for mapping the wetland, and were not necessarily sampling points.

4.1.4 Macroinvertebrates habitat quality

Habitat quality was determined by analysing selected water quality parameters. Parameters selected are those mainly affected by land use (Perry & Vanderklein, 2007). Water samples were collected only during the January 2009 field visit due to limiting funds. Surface samples for water chemistry analysis were collected concurrently with macroinvertebrates. At the stream and dam sites, grab samples of water at each site were collected in triplicates by immersing clearly labeled sterile polythene sampling bottles approximately 4-5cm under the water surface against the direction of flow. In the wetland water was mainly collected at the surface, near the soil. Water samples were collected from the main wetland, stream, farmed area and dam. Onsite measurements were done for pH, temperature, dissolved oxygen content and conductivity using electrometric probes HACH (2001). Turbidity was measured in the laboratory using a spectrophotometer.

Sample preservatives and labels were provided by the Department of Biological Sciences of the University of Zimbabwe. Samples were preserved by lowering their pH through addition of sulphuric acid (H_2SO_4). Samples were delivered to the Biological Sciences laboratory for the following analyses: nitrates, phosphates, sulphates, turbidity and ammonia. Upon analysis, samples were neutralized using sodium hydroxide (NaOH) as recommended by the HACH 2001 manual. BOD samples were preserved by freezing. Laboratory analysis was done according to Standard Methods for Water and Waste Water Examination HACH, 2001 Manual. Table 4.2 shows a summary of the methods used to analyse the physical and chemical water parameters.

Table 4.2: Methods of determining physical and chemical water quality parameters

Parameter	*Method used*	*Equipment used*
pH	Electrometric	HACH (2004) probes
Temperature	Electrometric	HACH (2004) probes
Conductivity	Electrometric	HACH (2004) probe
DO	Electrometric	HACH (2004) probe
Turbidity	Spectrophotometric	
PO_4^{2-}	Ascorbic Acid Rapid Liquid Method	Spectrophotometer
TP	Acid Persulfate Digestion Method	Spectrophotometer
NO_3^-	Cadmium Reduction Method	Spectrophotometer
NH_3	Nesler Method	Spectrophotometer
TN	Persulfate Digestion method	Spectrophotometer
TSS	Photometric Method (Non-filterable Residue)	Spectrophotometer

Spatial differences in macroinvertebrates habitat quality were investigated by comparing the mean values of each parameter among the major wetland habitats samples (wetland, stream and dam) using Kruskal-Wallis ANOVA since the data required non-parametric tests because of a relatively small sample size. All the variables from every sampling point were then pooled together and normalized to zero mean and unit variance. This was done in order to avoid misclassifications that arise from different orders of magnitude of both the numerical value and variance of the parameters analysed (Vega *et al.,* 1998), especially with respect to parameters like pH that are on a logarithmic scale. A correlation matrix was then calculated using the product-moment method on the normalized data, and correlations whose coefficient (r) was greater than 0.5 were considered to be statistically significant (at a significance level $p < 0.05$). The statistical programme Statistica version 8.0 was used for all the analyses, and graphic presentations were done using Sigma Plot 9.0 software.

4.1.5 Macroinvertebrates abundance, diversity and sensitivity

Macroinvertebrates were sampled from three different predominant habitats using a 1mm mesh hand net. The habitats were the upper and lower wetland, stream and littoral zones of the dam. Microhabitats containing emergent, floating, and submerged vegetation were sampled. The contents of each sample were washed to the bottom of the net and then tipped into a water-filled white tray. Macroinvertebrates were identified according to Gerber and Gabriel (2002), Day *et al.* (2003) and de Moor *et al.* (2003). Organisms were counted and scored as 1 (1 individual present), A (2-10 individuals present), B (11-100 individuals) or C (>100 individuals). Samples were obtained using the kick-method, where rocks and other benthic material were disturbed by foot to flow downstream into a soft 1mm mesh net.

The analysis of macroinvertebrates sensitivity was done using a biotic index and a diversity index. The Biological Monitoring Working Party (BMWP) scoring system method mainly uses the species sensitivity to environmental stress, pollution and habitat alteration. Taxa were assigned BMWP scores according to sensitivity to environmental stress, pollution, habitat alteration etc. Scores range from 1-10 and taxa least tolerant were assigned high scores (see Appendix D).

Shannon Diversity Index (SDI) was also used to analyse the data using their estimated abundance. The formula for SDI (H') is;

$$H = -\sum_{i=1}^{n} Pi \log Pi \quad (4.2)$$

Where Pi is estimated from N_i/N as the proportion of the total population of N individuals belonging to the *i*th species (n_i), i.e. the number of individuals in a given taxon is divided by the total number of organisms in the collection, the resulting ration being multiplied by the logarithm of that ratio. The results of the calculation are added together to provide the SDI of a site.

Macroinvertebrates diversity (mean Shannon diversity index values) was compared between the three main habitats/sites (wetland, stream and dam). The BMWP scores were computed and numerically compared between the different sampling localities. The differences between the diversity of the macroinvertebrates at the three different localities were analyzed by Kruskal-Wallis analysis of variance (ANOVA) computed by the Statistica 8.0 software and graphically presented using Sigma Plot 9.0 software.

4.1.6 Wetland Biological Index

The wetland biological index (WBI) was determined using the three recommended aspects namely; aquatic macroinvertebrates, habitat quality rating, and land use rating. The three scores were aggregated to provide the WBI.

$$WBI = A - B + C \quad (4.3)$$

Where:

A= macroinvertebrates score, B= habitat quality rating and C= Land usage rating (Greenfield, 2004).

Habitat quality rating scores were obtained by assigning weighted scores to percentage vegetation bank cover, percentage aquatic vegetation and percentage fringing/leafy vegetation. Weighted scores assigned fall within the following categories; 0-20% = 1, 21-40% = 2, 41-60% = 3, 61-80% = 4 and 81-100% = 5. The scoring is in Table 4.3.

Table 4.3: Habitat quality rating based on percentage vegetation cover

	Habitat quality rating				
	0-20%	21-40%	41-60%	61-80%	80-100%
% left bank cover			3		
% right bank cover			3		
% aquatic vegetation				4	
% left bank fringing			3		
% right bank fringing			3		
Total			**16**		

Land use rating was determined by assigning scores to each land use practiced in Intunjambili. The land use that has large impact scored zero and the land use with minimal impacts scored 2. The land use activities were rated from severe to minimal. The land usage rating is in Table 4.4.

Table 4.4: Land usage rating score

	Land usage rating		
	Severe	**Moderate**	**Minimal**
Agriculture	0		
Livestock grazing	0		
Settlements		1	
Sand abstraction		1	
Brick making		1	
Weir and dam		1	
Total		**4**	

Macroinvertebrates score was calculated from relative sensitivities of macroinvertebrates taxa according to the Biological Monitoring Working Party scoring system (Mason, 1996) (see Appendix D). The scores of taxa that were found in Intunjambili from the main wetland, stream and dam are shown in Table 4.5.

Table 4.5: Macroinvertebrates sensitivity score

Taxa	Sensitivity
Dytiscidae	5
Geridae	9
Nepidae	6
chironomidae	2
Ashnidae	8
Oligochaetes	1
Dytiscidae larvae	5
Gomphidae	8
Baetidae2spp	4
Culicidae	5
Velidae	6
Hydracarina	4
Corexidae	6
Naucoridae	6
Lestidae	8
Elmidae	3
Baetidae	4
Gyrinidae	5
Hydraenidae	6
Blestidae	10
Heptagenidae	10
Notonectidae	6
Diptera	4
Total	**131**

Macroinvertebrates score, A= 131

The three scores obtained were then placed in the Equation 4.3 as follows;

WBI = 131-16+ 4 = 119. The wetland biological index of Intunjambili is 119.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Land cover changes

The land cover changes from April 1990 to April 2008 which mainly show an increase in cultivated areas, a decrease in woodland and areas covered by water are described in Table 5.1. The accuracy assessment results of the land cover changes were as follows: average accuracy was 92.5%, with average reliability of 95.3% and overall accuracy of 90%.

Table 5.1: Percentage changes in land cover

Class	*Change from 1990-2001*	*Change from 2001-2008*
Bare	-26%	21%
Cultivated area	38.9%	19%
Grassland	-32.1%	8.26%
Water	-28%	-22%
Woodland	-19.2%	-29.5%

The most significant change was the increase in cultivated area and decrease in woodland and water. It can be noted that as population grew in the catchment (Fig 3.3), an increasing area of land cover types such as woodland and grassland were opened up for cultivation. The reduction in woodland explains the impacts of land use on vegetation. Clearing of bush for cultivation could be the major cause of reduction in woody cover. Declining productivity in other areas due to dry conditions could have prompted an expansion of cultivation in Intunjambili.

The land cover changes obtained in Intunjambili (Fig 5.1) were expected given the land uses practiced in the area. Clearing of vegetation may modify rainfall, leading to a drier climate. This is similar to observations by (Heyns *et al.,* 1994) in a study of freshwater resources in southern Africa, they found out that removing excess vegetation decreases evapo-transpiration, thereby decreasing moisture available for rain formation. The drying up of the wetland could be attributed to clearing of vegetation.

The reduction in water means reduction in permanently wet areas; this could be due to tillage or effects of climate change. The reduction of water or drying up of the wetland means loss of aquatic habitat and hence aquatic biota is affected. A study conducted in Australia revealed that; clearance of indigenous riparian vegetation and removal of woody species from streams and wetlands, combined with planting of exotic plant species, resulted in widespread detrimental effects on fluvial geomophorlogy and aquatic ecology of Australian rivers and wetlands (Webb and Erskine, 2003).

Generally there is also a reduction in grassland which is mainly grazing areas, probably due to the fact that more areas were claimed for cultivation or due to overgrazing. The changes in land cover in Intunjambili wetland may lead to catchment degradation. The most common causes of catchment degradation in southern Africa are; over-cultivation, overgrazing, deforestation and invasion of alien plants, which is often ignored (Mazvimavi, 2002). The increase in cultivation and deforestation in Intunjambili may lead to serious erosion problems. Soils in cultivated areas are susceptible to erosion and this may be particularly serious in vulnerable areas, for example on steep slopes or near stream banks (Mazvimavi, 2002).

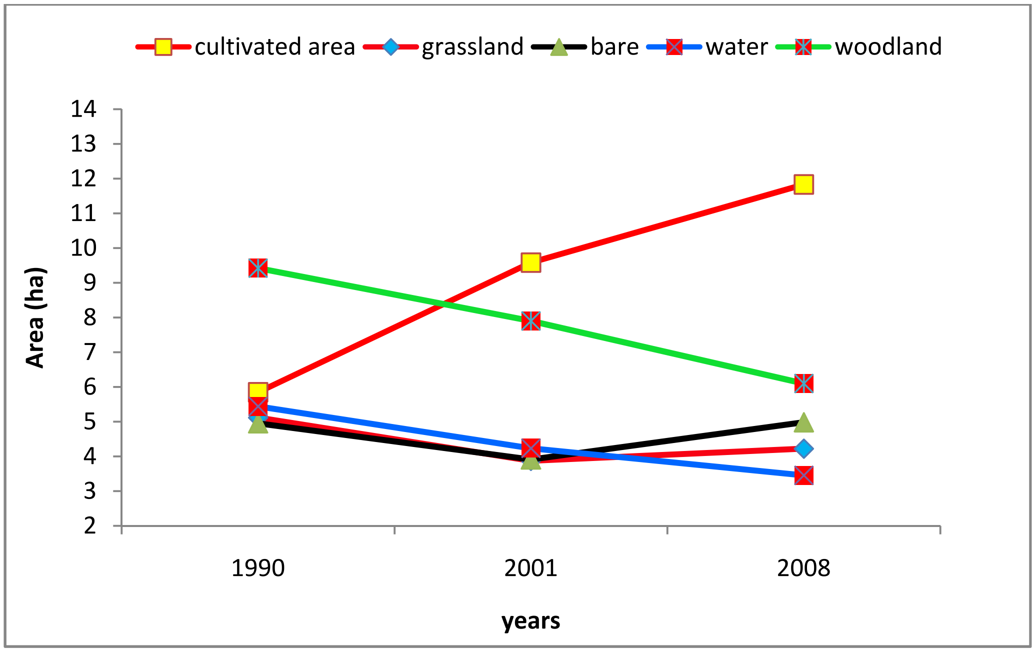

Figure 5.1: Changes in land cover from 1990 to 2008

From the land cover change analysis, it is concluded that the wetland is drying up given the 50% decline in areas covered by water and there is loss of vegetation cover mainly due to cultivation given the reduction in grassland cover and woodland cover. The reduction in woodland cover could also be due to wood harvesting for fuel, since wood is used as a source of fuel in most parts of rural Zimbabwe. The study used only three years in the analysis, use of more images would give a trend of the changes. It is therefore recommended that land use activities in and around the wetland be regulated and the extension of cultivation be stopped, in order to stop the drying up and loss of vegetation associated with it.

5.2 Vegetation health and species composition

5.2.1 Species composition

The species composition of Intunjambili wetland vegetation and visual estimates of the areas in which they occur is described in Table 5.2. There was no data on the previous vegetation composition.

Table 5.2: Species composition of Intunjambili wetland

Types of plants	Species	Occurrence
Common wetland Plants	**Wet areas** – *Nymphea sp* – *Scirpus sp* – *Typha sp*	➢ 35% of permanently wet areas
	Upland areas – *Pterocarpus sp* – *Eucalyptus sp* – *Acacia fleckii* – *Andropogon brazzae* – *Hyparrhenia rufa* – *Janthoniopsis pruinosa*	➢ 65% of the terrestrial or upland area
Invasive and introduced species	– *Lantana camara* – *Euphorbia sp* – *Guajava pisidium*	➢ *L. camara* and *Euphorbia sp* occurred in 55% ➢ *G. pisidium* was found in gardens
Ruderal species	– *Cyperus papyrus* – *Eragrostis enamoena* – *Juncus sp* – *Hyparrhenia dregeana* (silky thatching grass)	➢ *C. papyrus* and *Juncus sp* constituted 30% of vegetation in wet areas ➢ *H. dregeana* and *E. enamoena* constituted 70% of grass species

Acacia fleckii dominated the vegetation in the upland areas. The most important observation is the presence of ruderal and invasive species. Ruderal species are adapted to rapidly colonized areas with disturbed soils and they replace indigenous plants though succession (Macfarlane *et al.*, 2008). Alien invasive plants are perennial and once they are established they generally persist at the expense of indigenous vegetation (Macfarlane *et al.*, 2008).

The invasive *Lantana camara* occupies approximately 55% of the wetland area and now constitutes a greater percentage of riparian vegetation. The clearing of woody cover has probably led to a successful invasion by *Lantana camara*. The highly abundant *Lantana camara* in Intunjambili is known to be one of the top alien invading plants in South Africa. This was revealed in a preliminary assessment of alien invading plants and water resources. The assessment showed that alien invasive plants caused an estimated decrease of about 7% of the mean annual flow of South Africa (Versveld *et al.*, 1998). *Euphorbia sp* which is manly found in dry areas occurs in high abundance in Intunjambili wetland area. The *Euphorbia sp* is presumed to be *Euphorbia halipedicola*, a species that was never found to occur in Zimbabwe in the early

1980s (Moll, 1983). This indicates modification of the wetland area due to different land uses or the plant species could have been deliberately introduced in the area for particular reasons.

The presence of *Eucalyptus sp* could also be responsible for the drying up of the wetland (Fig 5.1) described earlier in land cover changes. *Eucalyptus sp* is believed and also known to have adverse effects on water table and flora found in an area (Webb and Erskine, 2003). The reduction in the area covered by water by 50% (from 1990 to 2008) is similar to observations by Heyns *et al.* (1994) who states that, conversion of indigenous forests to plantations of fast-growing pine and eucalyptus increases evapo-transpiration rates and reduces dry-season flow of streams. The observation is substantiated by the occurrence of *Euphorbia sp*, which is a dry land species.

The presence of alien invasive species in Intunjambili is a cause for concern. The other is their effects on water resources. An invasion by alien plants will alter the water balance of the catchment. In particular, the rates of transpiration are likely to be altered, which could have adverse effects on the available water resources (Mazvimavi, 2002). It is therefore recommended that alien invasive species be controlled.

5.2.2 Normalised Difference Vegetation Index

NDVI image for April 1990 is shown in Fig 5.2, while NDVI image for June 2001 is shown in Fig 5.3 and lastly the NDVI image for April 2008 is shown in Fig 5.4. The NDVI values of 1990 image show a significantly healthier vegetation with a mean of 0.3 indicating high abundance of shrub and grassland (Sellers, 1985). This could be attributed to the fact that, in 1990 the dam was not yet constructed, cultivation activities were minimal compared to 2001 and 2008. The wetland then had high amount of woody species than the other two years which were analysed in the study.

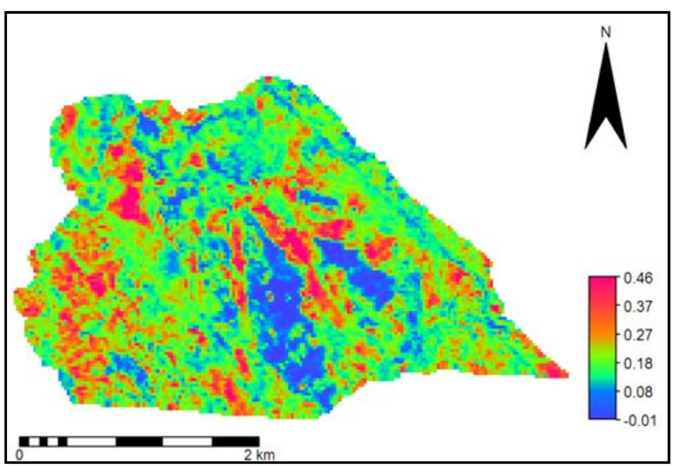

Figure 5.2: April 1990 NDVI image

The June 2001 image shows a significant (p=0.004) reduction in vegetation health compared to 1990 as shown by NDVI values. This could be due to the fact that, the April 1990 image used was taken at the end of the wet season and largely due to reduction in woodland and drying up of the wetland which is shown by reduction of amount of water (Fig 5.1).

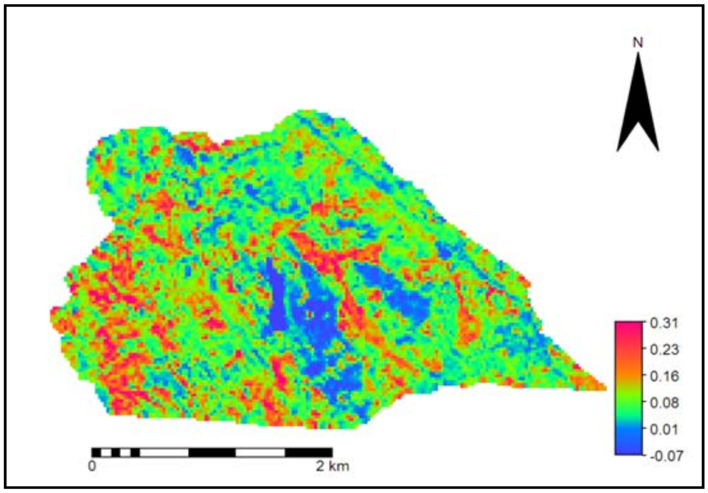

Figure 5.3: June 2001NDVI image

The April 2008 NDVI shows poor vegetation health compared to April1990 and June 2001. This could be due to very high cultivation activities in 2008, and also due to a big reduction in woodland species (Fig 5.1). The vegetation in Intunjambili wetland area is currently mainly dominated by shrub than woodland. The obervations are substantiated by the presence of *Euphorbia sp* and *Lantana camara* in up-land areas.

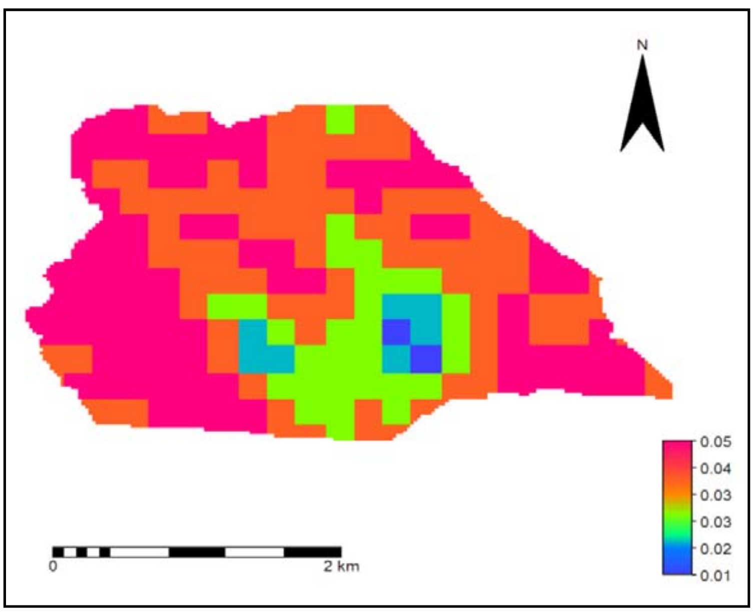

Figure5.4: April 2008 NDVI image

The comparison of mean NDVI values (Fig 5.5), shows a rapid decline in vegetation health from 1990 to 2008. Evidence shows that this is due to anthropogenic activities rather than climatic variabilitity. Even though Bachelet *et al.* (2001) in a study conducted in the United States says, 'larger, faster or more radical climatic changes are known to cause vegetation stress, rapid plant loss and desertification in certain circumstances', the changes in vegetation health in

Intunjambili are due to land use which is shown by increase in cultivated areas. The low range of values in 2008 is due to the low spectral resolution of the MODIS image that was used.

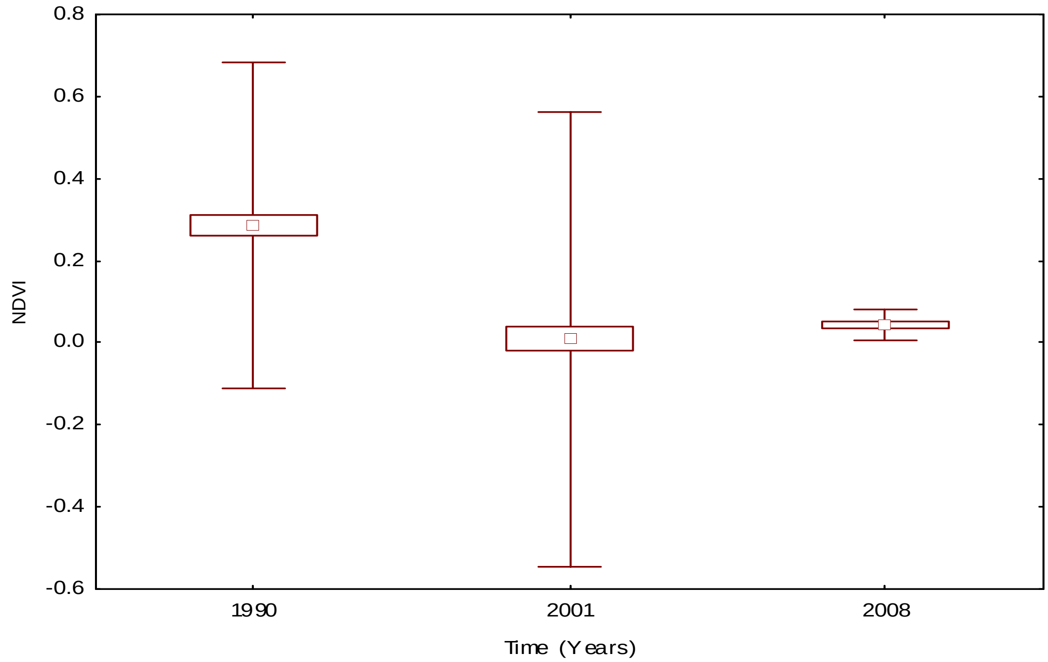

Figure 5.5: Comparison of mean NDVI values among the years

The independent t-test analysis that compared NDVI values for individual years (see Appendix G) shows the significant differences among years. Generally, it can be concluded that vegetation health has declined from 1990 to 2008 and this could be largely due to clearing of vegetation for cultivation. The study only monitored vegetation health changes in three years, if more images were available, the study would show the trend of the changes in vegetation health. It is recommended that impacts of climate change on vegetation be studied and quantified so as to separate the impacts of land use from impacts of climate change.

5. 4 Current Water quality status

Water quality variables used in determination of habitat quality are described in Appendix C. The results that are presented are for the sampled points within the three main sites or habitats (wetland, stream and dam). In cases where concentrations were below detection limits (low range), such as TN at some sites, these were recorded as zero for the purposes of statistical analysis. Mean values (±SD) for each parameter from the three habitats are graphically depicted in Fig 5.6 (a) - (f). Temperature was lowest in the stream and highest in the wetland. Temperature did not fall within the SAAE WQ (see Appendix F) guidelines because it varied by more than 2^oC. The difference between wetland and stream temperature was more than 4^oC. This could be attributed to water retention and storage function of wetlands. The slow moving water has more retention time to absorb the heat, compared to the fast flowing water in the stream, which actually loses heat.

Turbidity and TSS showed similar trends and were high in the wetland and low in the stream (Fig 5.6d). The TSS values for all sites complied to the SAAE WQ guidelines, which states that the TSS should be less than 100mg/L. The observation corroborates the fact that wetlands function to clarify and purify water (Davies and Day, 1998). TSS is known to affect the saturation concentration of oxygen, either chemically, through the oxygen-scavenging attributes of the suspended particles, or physically through reduction of the volume of water available for solution (DWAF, 1996). The high DO values (80 – 120% saturation) correspond to low TSS values. Highest DO values at the wetland sites compared to stream and dam sites could also be due to high amount of vegetation in the wetland. Presence of photosynthesising vegetation cause high dissolved oxygen levels (Mason, 1996). At the stream, vegetation was only found at the banks.

pH was high at the wetland and lowest at the dam. pH within dam points varied by > 0.5 and hence failed to comply to SAAE WQ guidelines (see appendix F). pH of freshwaters decrease by 0.1 of a unit for a temperature increase of $20^{o}C$, and therefore changes in temperature are unlikely to be of any significance in measure of pH in aquatic systems (DWAF, 1996). The pH differences were expected because of the differences in time of sampling.

Phosphorus (TP and PO_4^{2-}) complied with the SAAE WQ guidelines. The values were low but adequate to promote plant growth.

The low nitrate levels in all the sampled areas were not expected, given the agricultural activities in the Intunjambili area. Agriculture is known to be a major contributor to nitrate loadings in freshwaters (Chapman, 1996). High concentrations also occur under natural conditions e.g. mineral salts derived from rock and salt (DWAF, 1996). Under anaerobic conditions nitrate is reduced to nitrite and then molecular nitrogen by denitrifying bacteria. However, nitrites were not analysed in the study. The low nutrient levels could be due to the fact that, in summer growing plants utilise them for growth and hence are found in low concentrations in water. However, Intunjambili is in a predominantly rural based catchment and does not receive as much nutrient loading as compared to water bodies or aquatic systems in urban catchments (Moyo and Worster, 1997) and hence the low nutrient and pollution levels observed.

Ammonia (NH_3-N) levels at the wetland were higher than stream and dam (Figure 5.6f), an indication of boggy conditions that result from anaerobic processes when humus accumulates and excludes oxygen in its decomposition (Davies and Day, 1998). Under drier conditions this could lead to risk of pollutant accumulation due to a mix of decaying plant matter and animal excreta. However since we sampled in the rainy season, there was a lot of dilution; the levels were below the limits (Appendix C). The observation agrees with the fact that wetlands retain or absorb nutrients by trapping organic matter, thus purifying water that goes downstream. This principle has been used extensively in the control of water pollution in which partially treated sewage effluents are passed through constructed wetlands before being discharged into rivers (Davies and Day, 1998). In Intunjambili, the same principle applies because the stream drains from the wetland.

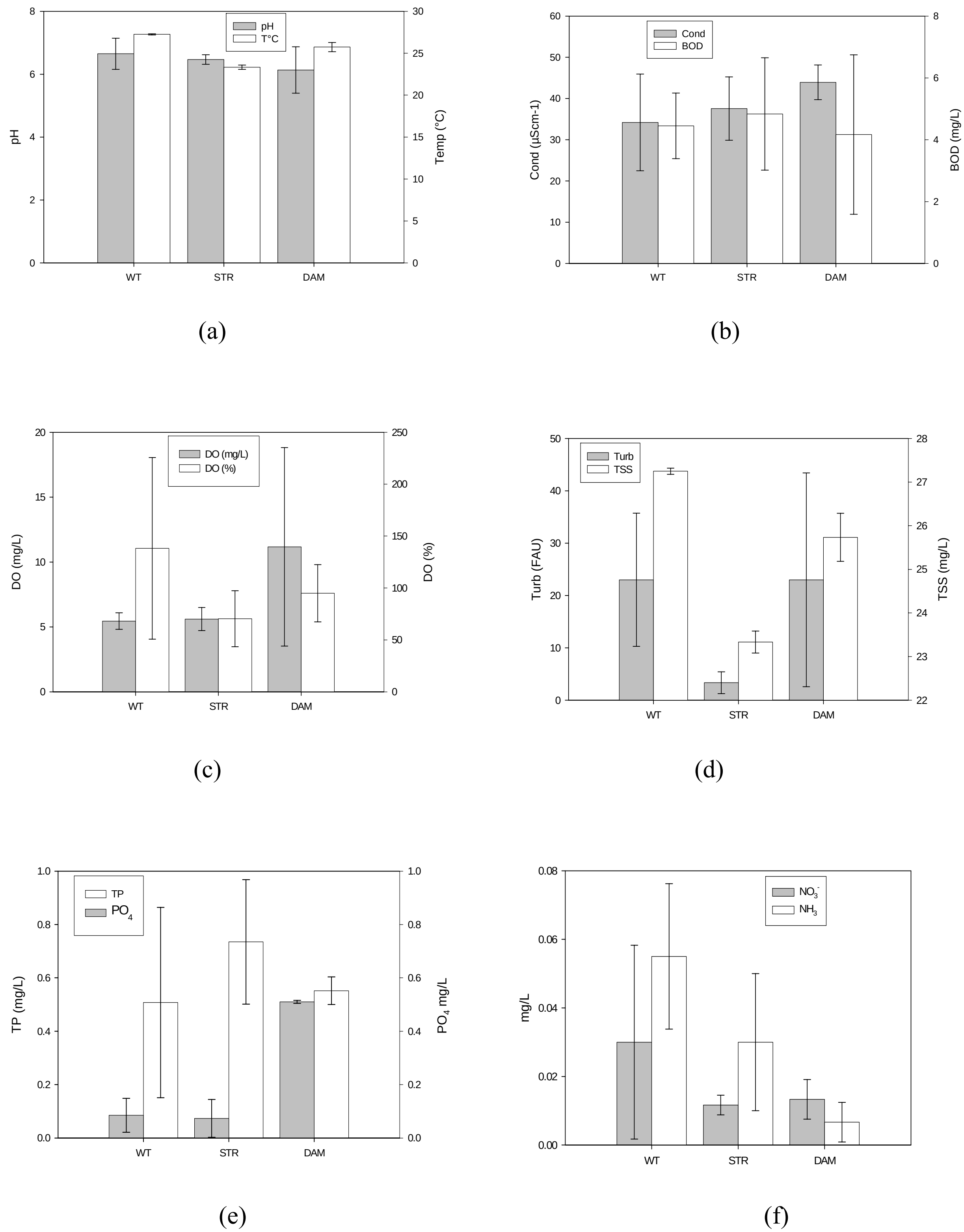

Figure 5.6: (a)-(f) Variation in water quality variables among the three main sites.

Solid bars represent means while error bars represent the range (min-max) measured as standard deviation from the mean. From the graphs, it was observed that only temperature, turbidity, total suspended solids (TSS), and total phosphorus varied among the sites.

The water quality parameters comply with South African Aquatic Ecosystems Guidelines. The habitat quality results show that Intunjambili is not a polluted system. This is expected since the wetland has a predominantly rural catchment and does not experience as much nutrient loading as wetlands with urban catchments. The pollution status above all shows that the wetland performs the ecosystem function of water purification.

A number of significant positive correlations (see Appendix H) also existed between parameters such as pH vs BOD/NO_3, DO vs NO_3, temperature vs turbidity/TN/TSS, PO_4 vs TP/NH_3 and TN vs TSS (r^2 = 0.51 to 0.93). Although these should be interpreted with caution since the matrix was drawn from pooled data from all sites (Vega *et al.*, 1998), the general trend seems to point out that physical parameters (pH, temp, turbidity) are always related somehow to chemical parameters and these show the impacts and magnitude of wetland use and degradation. From the same matrix, it was also found out that some parameters were significantly negatively related (ie inversely) to each other, such as conductivity vs PO_4/TP/NH_3, DO vs TP, turbidity vs TP, TP vs NO_3. From both analyses, some physical (TSS, turbidity) and chemical (TP, NH_3) seem to be dominating the significant analyses. Further multivariate analysis could help focus on the importance of these parameters as predictors of perturbation of wetland in relation to biological parameters (invertebrates, vegetation). The study was limited to one-off sampling or lack of replication over time. The study also required seasonal variation. A large number of samples collected would give the results a statistical dimension.

5.5 Macroinvertebrates taxa abundance, diversity and sensitivity

5.5.1 Taxa abundance

The abundance or total number of macroinvertebrates found in the three main sites is shown in Fig 5.7. Generally, the abundance of taxa was low across all sites compared to abundances obtained from other studies, for example a study by Chakona *et al.* (2007) in north-western Zimbabwe showed high abundances. One observation noted from the data was that oligochaetes and chironomids were more in comparison to other taxa especially at the wetland specifically from the wetland (Fig 5.7). Oligochaetes are known to be tolerant to organic pollution, environmental stresses and habitat alterations and respire at low oxygen tensions (Mason, 1996). Chironomids are detritus feeders which burrow into muddy and sandy bottoms (Moyo and Worster, 1997). The occurrence of these taxa in higher numbers (Fig 5.7) indicates some form of organic pollution or environmental stress in Intunjambili, which however was not detected in the study. In a study by Moyo and Worster (1997) in Mukuvisi River oligochaetes were found in poor quality rivers, and chironomids were abundant downstream of the point of discharge of sewage effluent.

The abundance of taxa in Intunjambili shows that land cover changes discussed earlier could be responsible for the low abundance of taxa. Lake *et al.* (2000) suggested that any disturbances that affect catchment vegetation may lead to reduction in diversity and abundance of macroinvertebrates especially detritivores, which in turn may lead to significant alterations in aquatic production.

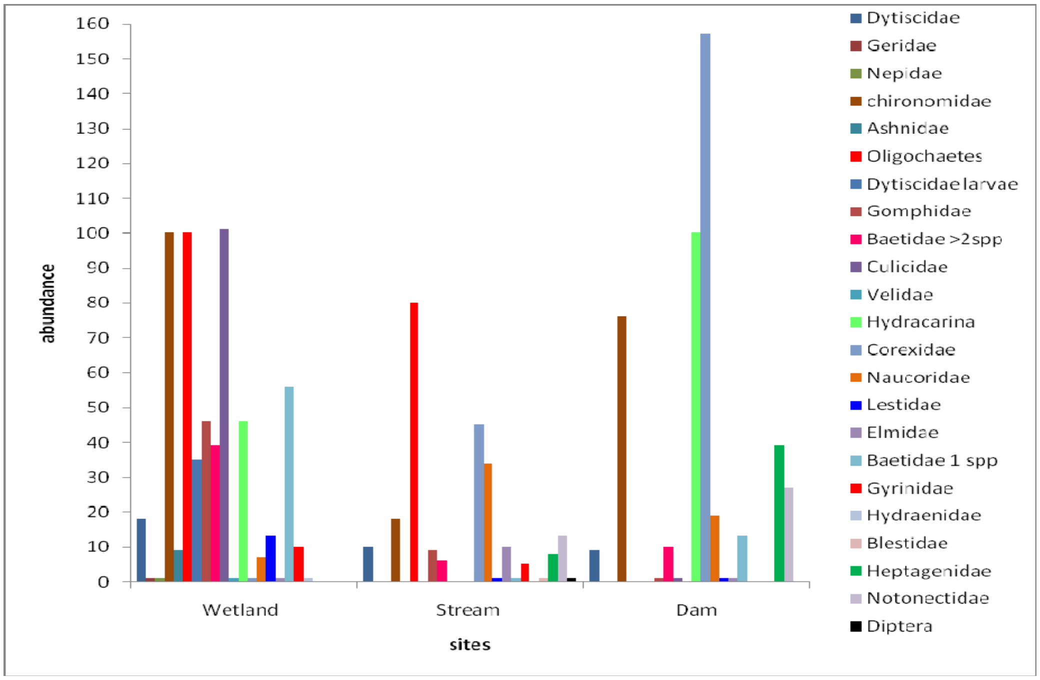

Figure 5.7: Abundance of taxa within sampling sites

5.5.2 Taxa diversity

A total of twenty three types of macroinvertebrates taxa were identified across the sampled sites (see Appendix B). The taxa richness is quite low, compared to findings from studies conducted in other wetlands *e.g.* a study conducted in the Nyl floodplain in South Africa, had a total of 35 taxa. The low taxa richness could be due to cultivation activities in the wetland that have altered the habitat of macroinvertebrates.

The Shannon diversity index (Fig 5.8) shows diversity across sampling points and diversity across sites is shown in Fig 5.10. All Shannon Diversity Indices (SDI) from the sampling points within the three sites were below 1. In water quality studies, SDI values less than 1 indicate pollution (Mason, 1996). As discussed earlier, no pollution was detected in Intunjambili as most water quality parameters complied with SAAE WQ guidelines except for pH. The low diversity could have been caused by land uses or habitat alterations as most of the wetland was claimed for cultivation (Fig 5.2).

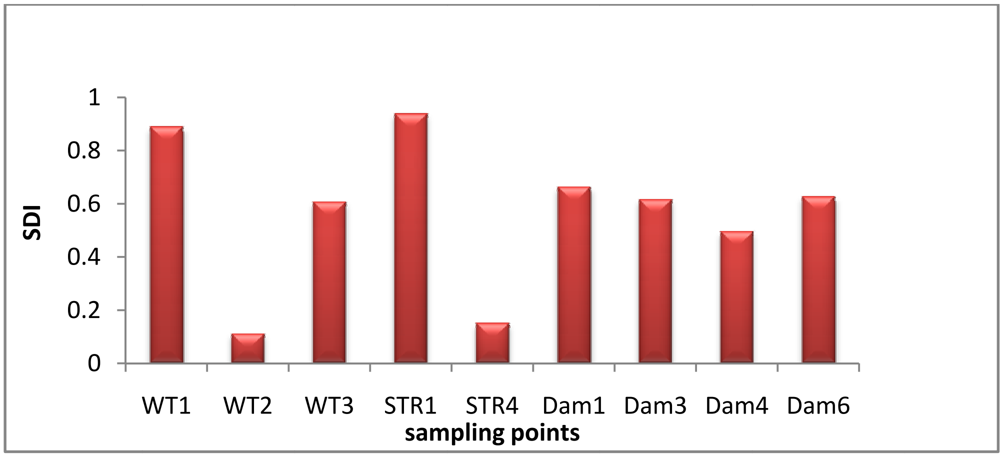

Figure 5.8: SDI values for different points

5.5.3 Taxa sensitivity

The analysis of macroinvertebrates data was also adapted from the Biological Monitoring Working Party (BMWP) scoring system (Mason, 1996). The BMWP scores for the different sampling points are shown in Fig 5.9. The variation of BMWP across sites is later shown in Fig 5.10. The low BMWP at WT2 and Dam 6 correspond to high turbidity values (see Appendix C) at these points. In highly turbid water, light penetration is reduced affecting photosynthesis of plants. In water quality studies, BMWP scores above 100 indicate good quality water (Chapman, 1996). All BMWP scores in Intunjambili sites were below 100, indicating poor quality water, but however it was not detected in the study. Macroinvertebrates receive reduced nutritional value and expend more energy to collect food. Reproduction of some macroinvertebrates is usually affected (Water and Rivers Commission, 2001). The observation is substantiated by low number of taxa at the points (see Appendix B).

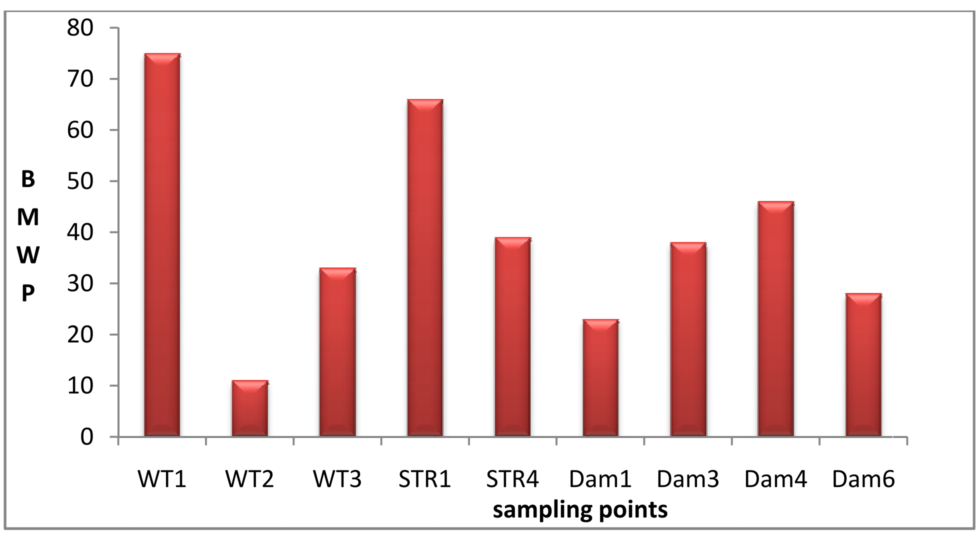

Figure 5.9: BMWP scores for different sampling points within the three main sites

The comparison of SDI and BMWP across the three sites or habitats is shown in Fig 5.10. Both SDI and BMWP show high diversity and high scoring taxa (taxa least tolerant to pollution and environmental stress) at the stream compared to dam and wetland. The findings are substantiated by habitat quality results (discussed earlier) which showed low TP, low turbidity and low TSS at the stream. The stream is a better habitat for macroinvertebrates compared to wetland and dam at Intunjambili. Streams and rivers have more biotopes that serve as substrates for macroinvertebrates compared to wetlands (Bowd *et al.*, 2004) and hence have higher diversity. Higher (NH_3-N) values obtained at the wetland and little vegetation found at the dam could also be attributed to low diversity at the two sites.

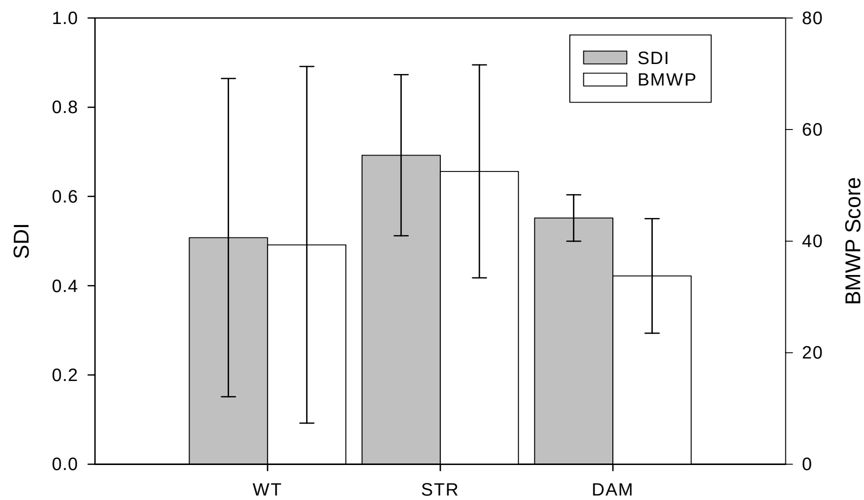

Figure 5.10: SDI and BMWP (mean ±SD) across the sites

The causes of low taxa abundance and diversity are not very clear, given that no pollution was detected in the study, but it can be concluded that they were due to land use activities upland. Cultivation, which is the major land use, could also have contributed to some form of environmental stress affecting abundance, diversity and sensitivity of taxa. The low abundance could also be due to the fact that some parts of the wetland are seasonally flooded, they don't have water during the dry season, and hence few species are found during the wet season. Sampling was done during the wet season in January. This suggests that if the wet conditions are prolonged, may be the abundance and diversity could improve.

The drying up of the wetland discussed earlier could also have impacted on the macroinvertebrates communities by reducing the size of the habitat. Revenga and Kura (2003) state that, habitat loss has been characterized by a decline and loss of freshwater species, to a point where the biodiversity of freshwater ecosystems is currently in far worse conditions than that of terrestrial systems. Habitat degradation, physical alteration through dams and canals, water withdrawals, overharvesting, pollution and the introduction of exotic species all contribute directly or indirectly to the decline in freshwater biodiversity. The focus in this study has been mainly on abundance (total number of taxa), diversity (as given by SDI) and sensitivity rather than richness (number of families). It is argued that richness cannot be used as an absolute measure of wetland condition, unless a trend overtime is recorded or baseline studies have been undertaken to establish numbers of taxa associated with undisturbed and degraded conditions in a wetland (Davies *et al.,* 2006). The types of taxa found were also looked at since the macroinvertebrates were used to indicate wetland health.

The analysis of macroinvertebrates communities in summary concludes that there is low abundance and diversity of taxa in Intunjambili wetland. The limitations to the macroinvertebrates community analysis were one-off sampling or lack of replication. It is therefore recommended that quantitative sampling and seasonal variation of macroinvertebrates be studied in order to understand the ecological processes influencing their abundance, diversity and behavior, and also to understand their temporal and spatial variation in the wetland.

5.6 Wetland Biological Index

The Intunjambili WBI obtained is 119. It was not clear how to conclude on the status of wetland health using the obtained score, because reference (maximum and minimal allowable) limits were not stated by the developer of the index (Greenfield, 2004). A comparison of the score obtained in Intunjambili wetland (119) and the scores obtained from a study in Nyl floodplain in South Africa was done and the WBI scores: were (164) in Abba wetland, (161) in Jasper wetland, (186) in Moordrift wetland and (161) in Haakdoring wetland. The Intunjambili WBI score is lower than the scores of the Nyl system and this could be due to low macroinvertebrates diversity. There were only 23 taxa obtained in Intunjambili compared to 35 taxa obtained in Nyl system of wetlands in South Africa. The high values in the Nyl floodplain were said to be due to lack of cattle in the area (Greenfield, 2004), and low WBI in Intunjambili could be due to presence of cattle in the area, implying the effect of grazing on macroinvertebrate communities. According to Lake *et al.* (2000) and Chipps *et al.* (2006), land uses that affect vegetation also affect the diversity and abundance of macroinvertebrates especially detritivores. The low score is mainly due to low macroinvertebrates score caused by low abundance and diversity of macroinvertebrate communities discussed above. The weakness of the index is that it does not specify the maximum or minimum limits. The index was developed and used in South Africa, its applicability to Zimbabwe was not tested, but it was used in the study because it's the only index for use in wetlands in southern Africa.

5.7 Overview

The shortcomings in the study were due to limited funding that affected the number of field visits. Macroinvertebrates and water had a one-off sampling. Despite the limited sampling, the work that was done in the study was able to give an indication of the biological integrity of the wetland. Further studies can be done and employ quantitative sampling, seasonal variation in order to get temporal variation of indicator organisms. More images would have shown a good trend of the changes. Proper delineation of the wetland catchment can also influence results because catchment activities affect wetland integrity. In addition to the above, there is also need to design wetland biological assessment protocols that look at wetland ecosystem health and biodiversity aspects, since the study had challenges relating to methods of assessments and these should incorporate various biota that include; fish, amphibians and abiotic aspects like sediments, erosion and also hydrological aspects. The methods of assessment should be designed to suit wetlands in Zimbabwe. Most studies that have been done in the past only focused on physico-chemical analysis of water quality, and these do not show wetland ecosystem health/integrity because they focus only on the water and ignore organisms found in water. Predictive modelling also can be used as an absolute assessment of the wetland as part of a surveillance operation to assess change over time. Simple indices of wetland disturbance can be developed as an additional means of wetland assessment.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From the study and limitations discussed, the following can be concluded;

1. The determination of land cover/use changes show that the wetland is drying up and vegetation cover has been reduced due to land use activities, mainly cultivation.
2. The vegetation assessment suggests that vegetation has deviated from natural perceived wetland vegetation with the presence and abundance of alien and ruderal species'
3. The water quality assessment showed that Intunjambili wetland is not a polluted system.
4. The assessment of macroinvertebrates communities suggests that different land use activities have impacted on diversity, and richness of macroinvertebrates communities.
5. The low wetland biological index is due to the low abundance and diversity of macroinvertebrates.

6.2 Recommendations

From the findings and discussions, the following recommendations are made,

1. There is need for more satellite images to show the trend of changes in land cover, since the study only used three years. Comparative studies are also recommended so that findings are compared with wetlands in other areas.
2. Impacts of climatic variability on vegetation need to be determined since this affects the determination of land use impacts on wetland vegetation.
3. The replication of water samples is recommended and also to widen the range of parameters in water quality analysis.
4. Replication of macroinvertebrates sampling is required and capturing seasonal variations is essential in order to have an in-depth understanding of ecological processes in terms of time and space.

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APPENDIX A: GPS coordinates for sampling points

Sampling point	GPS Geographic Coordinates		Elevation
WT1	S 20^{o} 27. 137'	E 028o 41. 209'	1496m
WT2	S 20^{o} 27. 059'	E 028^{o} 41. 149'	1494m
WT3	S 20^{o} 26. 961'	E 028^{o} 41. 127'	1490m
WT4	S 20^{o} 26. 997'	E 028^{o} 41. 106'	1487m
WT5	S 20^{o} 26. 919'	E028^{o} 40. 970'	1482m
STR1	S 20^{o} 26. 922'	E028^{o} 41. 083'	1486m
STR2	S 20^{o} 26. 786'	E028^{o} 40. 850'	1483m
STR3	S 20^{o} 26. 805'	E028^{o} 40. 777'	1478m
STR4	S 20^{o} 26. 856'	E 028^{o} 40. 722'	1475m
Dam1	S 20^{o} 26. 064'	E 028^{o} 40. 699'	1477m
Dam2	S 20^{o} 27. 273'	E028^{o} 40. 723'	1474m
Dam3	S 20^{o} 27. 382'	E028^{o} 40. 758'	1482m
Dam4	S 20^{o} 27. 349'	E028^{o} 40. 840'	1480m
Dam5	S 20^{o} 27. 141'	E028^{o} 40. 816'	1479m
Dam6	S 20^{o} 26. 997'	E028^{o} 40. 796'	1475m

APPENDIX B: Macroinvertebrates taxa of Intunjambili wetland

No of taxa	Taxa	WT1	WT2	WT3	STR1	STR4	Dam1	Dam3	Dam4	Dam6
1	Dytiscidae	Dytiscidae		Dytiscidae larvae	Dytiscidae		Dytiscidae larvae			
2	Geridae	Geridae								
3	Nepidae	Nepidae								
4	chironomidae	chironomidae			Chironomidae	Chironomidae	Chironomidae	chironomidae	Chironomidae	Chironomidae
5	Ashnidae	Ashnidae								
6	Oligochaetes	Oligochaetes			Oligochaete	Oligochaete				
7	Dytiscidae larvae	Dytiscidae larvae								
8	Gomphidae	Gomphidae		Gomphidae	Gomphidae	Gomphidae			Gomphidae	
9	Baetidae2spp	Baetidae2spp			Baetidae2spp				Baetidae 2sp	
10	Culicidae	Culicidae		Culicidae	Gyrinidae				culicidae	
11	Velidae	Velidae								
12	Hydracarina	Hydracarina						Hydracarina	Hydracarina	Hydracarina
13	Corexidae	Corexidae			Corixidae	Corixidae	Corixidae	Corixidae	Corixidae	Corixidae
14	Naucoridae	Naucoridae			Naucoridae			Naucoridae		Naucoridae
15	Lestidae		Lestidae			Lestidae			Lestidae	
16	Elmidae		Elmidae		Elmidae				Elmidae	
17	Baetidae			Baetidae		Baetidae 1spp	Baetidae 1spp	Baetidae 1spp		Baetidae 1 spp
18	Gyrinidae			Gyrinidae						
19	Hydraenidae			Hydraenidae						
20	Blestidae				Blestidae					
21	Heptagenidae				Heptagenidae			Heptagenidae		
22	Notonectidae				Notonectidae	Notonectidae	Notonectidae	Notonectidae	Notonectidae	Notonectidae
23	Diptera					Diptera				

APPENDIX C: Raw water quality data

Site	*In-situ* parameters						Laboratory analysis				
	pH	Cond (μScm^{-1})	DO (mgL^{-1}) and %		Temp (°C)	Turb (FAU/NTU)	PO_4^{2-} (mg/l)	NO_3^- (mg/l)	TP (mg/l)	NH_3 (mg/l)	TSS (mg/l)
WT1	6.3	25.9	5.0	76.3	27.3	14	0.13	0.01	0.73	0.07	15
WT3	7.0	42.5	5.9	200	27.2	32	0.04	0.05	0.25	0.04	11
STR1	6.3	29.6	6.3	89.1	23.3	1	0.15	0.01	1.25	0.05	13
STR2	6.6	38.2	5.9	82.5	23.1	5	0.01	0.015	0.35	0.01	6
STR3	6.5	44.9	4.6	39.4	23.6	4	0.06	0.01	0.96	0.03	7
Dam 1	6.4	45.0	20	121	25.2	7	0.09	0.02	0.38	ND	8
Dam 3	6.7	39.3	6.8	66	26.3	16	0.08	0.01	0.82	0.01	27
Dam 6	5.3	47.5	6.7	97.5	25.7	46	0.08	0.01	0.33	0.01	ND

APPENDIX D: Biological Monitoring Working Party (BMWP) Scores

Types of macroinvertebrates	*Families*	*Score*
Mayflies	Siphlonuridae, Heptageniidae, Leptophlebiidae, Ephemerellidae, Potamanthidae, Ephemeridae, Taeniopterygidae, Leuctridae, Capniidae, Perlodidae, Perlidae, Chloroperlidae,	10
River bug	Aphelocheridae	
Caddisflies	Phryganeidae, Molannidae, Beraeidae, Odontoceridae, Leptoceridae, Goeridae, Lepidostomatidae, Braccentidae, Sericostomatidae	9
Cray fish	Astacidae	8
Dragonflies	Lestidae, Agriidae, Gomphidae, Cordulegasteriade, Aeshnidea, Corduliidae, Libellulidae,	
Caddisflies	Psychomidae, Philopotamiidae	
Mayflies	Caenidae	7
Stoneflies	Nemouridae	
Caddisflies	Ryacophilidae, Polycentropidae, Limnephilidae	
Snails	Neritidae, Viviparidae, Ancylidae,	6
Caddisflies	Hydroptilidae	
Mussels	Unionidae	
Shrimps	Corophiidae, Gammaridae,	
Dragonflies	Platycnemididae, Coenagriidae	
Water bugs	Mesoveliidae, Hydrometridae, Gerridae, Nepidae, Naucoridae, Notonectidae, Pleidae, Corixidae	

Water Beetles	Haliplidae, Hygrobiidae, Dytiscidae, Gyrinidae, Hydrophilidae, Clambidae, Helodidae, Dryopidae, Elminthidae, Chrysomelidae, Curculionidae	5
Caddisflies	Hygropsychidae	
Craneflies	Tipulidae	
Blackflies	Simuliidae	
Flatworms	Planariidae, Dendrocoelidae	
Mayflies	Baetidae	4
Alderflies	Sialidae	
Leeches	Piscicolidae	
Snails	Valvatidae, Hydrobiidae, Lymnaecidae, Physidae, Planorbidae	3
Cockles	Sphaeriidae	
Leeches	Glossiphoniidae, Hirudidae, Erpobdellidae	
Hoglouse	Asellidae	
Midges	Chironomidae	2
Worms	Oligichaeta (whole class)	1

APPENDIX E: Common Invasive and Ruderal Species

Alien invasive species commonly found in South African wetlands

Species	Common name	Hydric status
Pinus elliotti	Slash pine	f
Guajava psidium	Guava	fd
Acacia elata	Peppertree wattle	w
Lantana camara	Lantana	fd
Solanum mauritiunum	Bug weed	fd
Canna indica	Indian shot	f

Ruderal species commonly found in South African wetlands

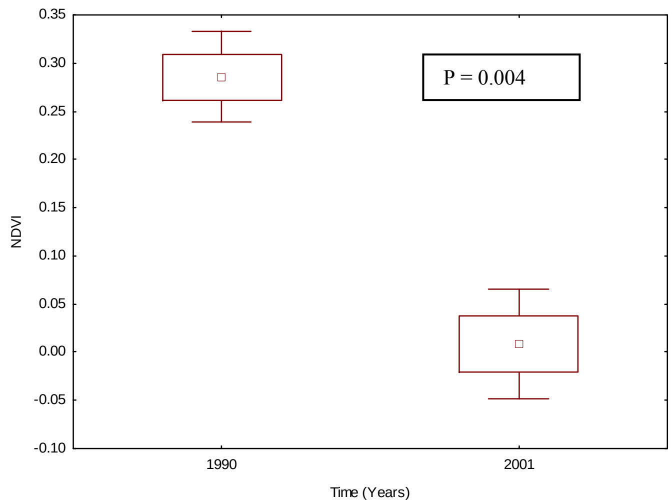
Species	Common name	Hydric status
Agerutum conyzoides	Blue weed	fd
Persicaria hydropiper	Water pepper	w
Rumex crispus	Curly dock	fw
Bidens pilosa	Common blackjack	fd
Cyperus esculentus	Yellow flowered water grass	fd
Eragrostis plana	Fan love grass	fd/fw
Juncus effessus	Soft rush	w
Vulpia bromides	Squirrel tail fescue	fw

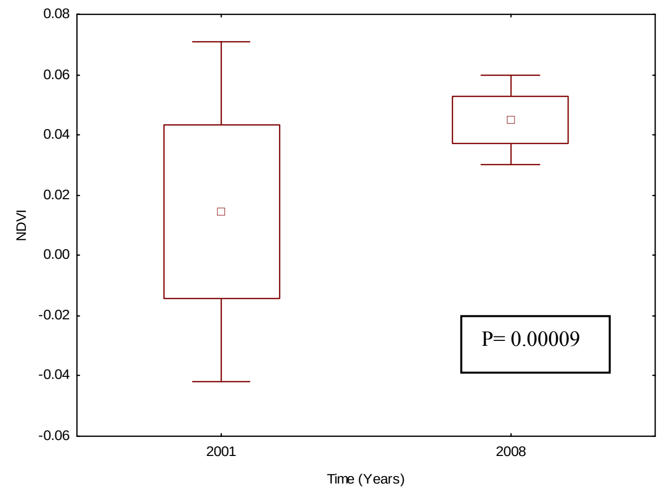
f	facultative species, are equally likely to grow in wetland and non-wetland areas (34-66% of occurrences)
fd	facultative dryland species, usually grow in non-wetland areas but sometimes grow in wetland areas (1-34% of occurrences)
fw	facultative wetland species, usually grow in wetlands (67-99% occurrences), but are occasionally found in non-wetland areas
w	wetland species, almost always grow in wetlands (99% occurrences)

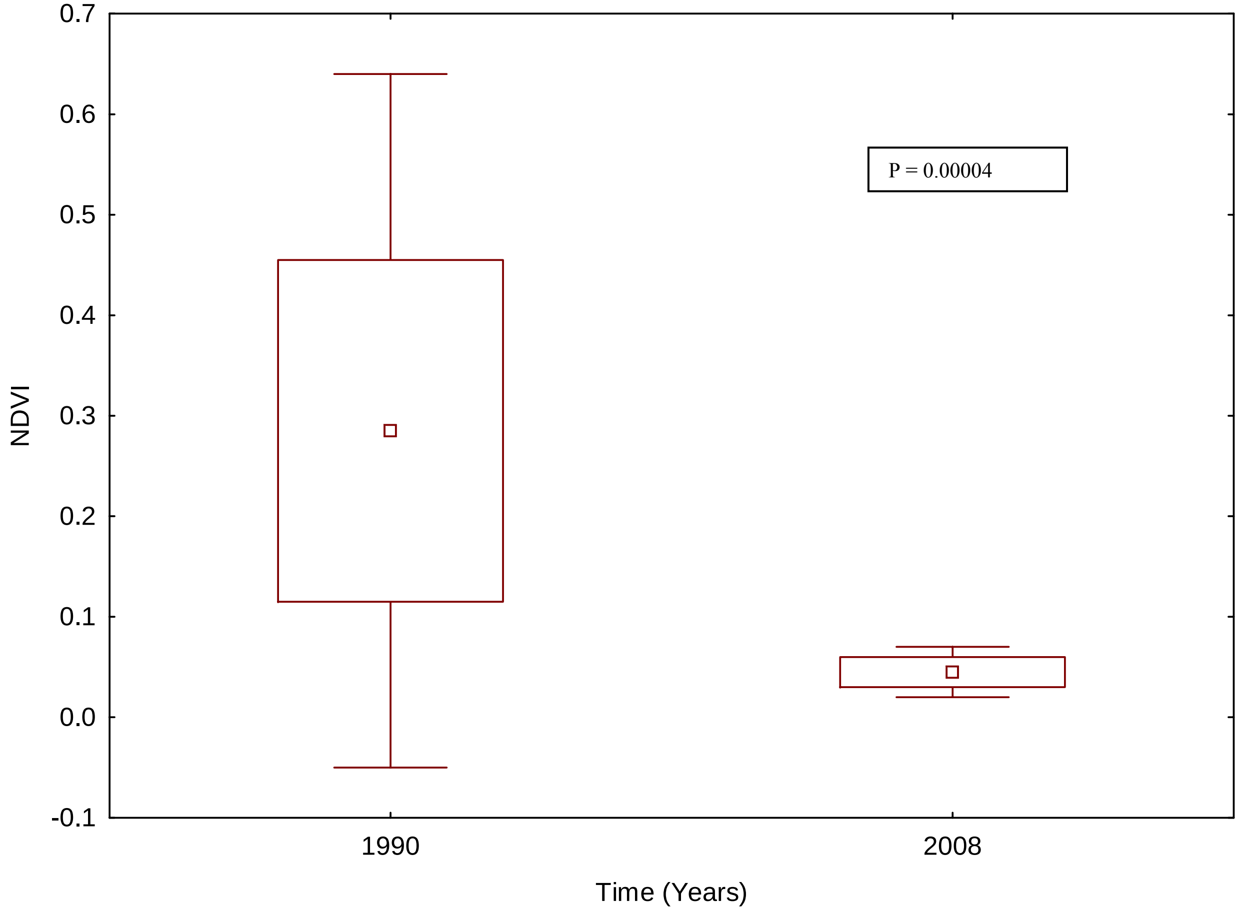
APPENDIX F: South African Aquatic Ecosystems Water Quality Guidelines

Parameter	Acute Effect Value	Chronic Effect Value	Target Water Quality Range (TWQR)
Aluminium (µg/L)	100	10	5
Ammonia (mg/L)			0.007
Arsenic (µg/L)	130	20	10
Atrazine (µg/L)	100	19	10
Cadmium (µg/L)	13	0.8	0.4
Chlorine (µg/L)	5	0.35	0.2
Chromium (µg/L)	200	14	7
Dissolved Oxygen (%)			80-120%
pH		Should not vary by > 0.5	
TSS		An increase in TSS should be limited to	
Zinc	36	3.6	0.2
Temp		Should not vary by >2^{o}C or by>10%	
Total Dissolved Solids (mg/L)		<100	Increase should be <10% of background TSS
Selenium (µg/L)	5	30	0.2

APPENDIX G: Independent t-test analysis of NDVI values among years






0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
NDVI
P = 0.00004
1990
2008
Time (Years)

APPENDIX H: Correlation matrix for all pooled water quality variables.

	pH	cond	DO	DO %	temp	BOD	turbidity	PO_4^{2-}	TP	NO_3^{2-}	TN	NH_3-N	TSS
pH	1.00												
cond	**-0.17**	1.00											
DO	-0.03	0.33	1.00										
DO%	0.28	0.20	0.24	1.00									
temp	0.06	-0.06	0.01	0.46	1.00								
BOD	**0.70**	-0.09	-0.01	-0.10	-0.03	1.00							
turbidity	-0.46	0.43	-0.16	0.46	**0.60**	-0.50	1.00						
PO_4^{2-}	-0.33	**-0.59**	0.09	-0.22	0.13	0.14	-0.17	1.00					
TP	0.05	**-0.53**	-0.31	**-0.60**	-0.37	**0.58**	**-0.58**	**0.65**	1.00				
NO_3^{2-}	**0.53**	0.25	0.09	**0.93**	0.41	0.12	0.34	-0.42	**-0.55**	1.00			
TN	0.48	-0.39	-0.09	0.10	**0.58**	0.14	-0.11	-0.06	-0.18	0.26	1.00		
NH_3	0.14	**-0.77**	**-0.52**	0.03	0.26	0.15	-0.13	**0.53**	0.45	0.06	0.48	1.00	
TSS	0.41	-0.21	0.05	0.06	**0.70**	0.42	0.09	0.13	0.01	0.11	**0.51**	0.05	1.00

Significant correlations (at $p < 0.05$) are marked in **boldface** ($r^2 > 0.5$), and negative values depict inverse correlations.