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Land use changes between 1972 and 2008 and current water quality of wetlands in Harare, Zimbabwe.

By

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DECLARATION

I, Memory Msipa, declare that this thesis is my own work, a result of my own investigation. All the sources that l have used or quoted have been indicated and acknowledged by means of complete references. To the best of my knowledge, this work has not been submitted before for any other degree at any other university.

Signed:.........................

Date:............................

DEDICATION

To my husband John and son Kupakwashe.

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ABSTRACT

Agriculture and other land use changes such as settlement adversely affect water levels and nutrient status hence influences wetlands ecosystems. To assess the impacts of land use changes in three selected urban wetlands Monavale, Mabvuku and Honeydew in Harare, Zimbabwe, aerial photographs (contact prints) for three time periods (1972, 1984 and 1995) were transferred into a Geographic Information Systems (GIS) environment. For a fourth time period, 2008 Google Earth SPOT images were used. These remote sensed images were used to analyse the temporal changes in the size of the wetland and land uses within the wetlands. Class level landscape metrics were calculated using Arcview patch analyst, in order to characterize wetland fragmentation. Results showed that dry land agriculture and settlement increased whilst wetland area decreased in all wetlands. The landscape became more fragmented with time as indicated by an increase in the patch number (NP) and a decrease in the mean patch size (MPS) of the unused wetland and wetland agriculture classes. Anthropogenic activities especially increase of agricultural land use were the main causes of wetland fragmentation. These human activities have contributed to urban wetland size shrinkage in the study area. Groundwater samples were collected from the wetlands in April and June 2009 to assess quality of the water and relate it to land uses. Water quality results showed that there was significance difference in TDS, conductivity, pH, salinity, and TP between the three urban wetlands in both sampling months April and June 2009. Sewage ponds were associated with high total dissolved solids, conductivity and nitrogen. A microbial analysis was carried out and all samples were positive for Escherichia *coli,* and faecal coliforms were present in varying amounts. Faecal coliform levels counted using the Most Probable Number (MPN) were between 3 and greater than 1100 and classified between low and very high risk in terms of the WHO drinking water guidelines. Both samples taken in April and June showed that all land uses in the study area had high faecal coliform counts except in a conserved wetland area. Results suggest that water from shallow wells would be unfit for drinking and quality can be improved by removing access by humans. The study provides information on the current status of the wetlands which can be the basis for motivating management and setting up a management plan.

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DEFINITION OF TERMS

Wetlands

The Ramsar Convention (1971) defines wetlands as areas of marsh, fen, peat land 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 meters. This definition, while emphasising types and features of landscapes is considered to have a wide applicability (Dugan, 1990).

The definition of wetlands for ecological studies by Cowardin *et al.*, 1979 "wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. Wetlands must have one or more of these three attributes, 1) at least periodically, the land supports predominantly hydrophytes, 2) the substrate is predominantly undrained hydric soil and 3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season each year.

Wetlands definition for management purposes particularly regulation refers to wetlands as areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions (US Army Corps of Engineering, 1977).

Land use

Natural scientists define land use in terms of syndromes of human activities such as agriculture, forestry and building construction that alter land surface processes including biogeochemistry, hydrology and biodiversity (Erle and Pontius, 2007). Social scientists and land managers define land use more broadly to include the social and economic purposes and contexts for and within which lands are managed (or left unmanaged) such as subsistence versus commercial agriculture, rented versus owned, private versus public land.

Dambo

Dambos are shallow, seasonally or permanently water logged depressions at or near the head of a drainage network or alternatively, many occur independently of a drainage system (Breen *et al.*, 1997).Whitlow (1984) defines a dambo as a valley grassland that is seasonally water logged, is characterised by a distinctive grass and sedge flora and is without trees. Other authors emphasize that true dambos do not have trees, while some have the view that dambos have no streams.

CHAPTER ONE

1.0 INTRODUCTION

Changes in land use date to prehistory and the direct and indirect consequence of human actions to secure essential resources (Cleveland, 2006). Though humans have been modifying land to obtain food and other essentials for thousands of years; current rates; extents and intensities of land use changes are far greater than ever in history; driving unprecedented changes in ecosystems and environmental processes at local, regional and global scales (Erle and Pontius, 2007). For example, Mitsch and Gosselink, (2000) estimated that agricultural and urban development has transformed half of the wetlands in the United States to uplands since presettlement times. These changes encompass the greatest environmental concerns of human populations today including climate change, biodiversity loss and pollution of water, soils and air. The remaining wetlands are threatened by development, erosion and pollution (USGS, 2002). Thus, management agencies must identify threats to existing wetlands and find ways to monitor both wetlands and water quality changes to determine viable strategies for wetlands restoration. Monitoring and mediating the negative consequences of land use changes, while sustaining the production of essential resources has therefore become a major priority of researchers and policy makers around the world.

1.1 Background of wetlands use

Wetlands provide millions of people with materials, products and means of livelihood. Ironically, these ecosystems are at the stage of environmental siege due to unsustainable use of resources (Breen *et al.*, 1997; Hecky, 1993). For example, half the wetlands were lost in the last 100 years (Cunningham and Cunningham, 2002).With the rapid increase in human population; the pressures on natural resources have become intense. In Zimbabwe, recurrent food shortages, water scarcity and general drought induced desiccation has forced many societies, both urban and rural, to focus on wetland ecosystems as providers of food and water and as extremely valued natural resources (Matiza and Crafter, 1994). Therefore, they may be considered to now form an integral part of the urban livelihoods in Zimbabwe. However, this may lead to degradation of these resources; hence there is a need for exploitation systems which can be sustained over a long time period. There is need for 'wise use' of these ecosystems for the benefit of mankind (Symoens, 1995).

Wetlands have intrinsic values to communities living around them (Denny, 1995). Africa, especially sub-Saharan Africa is continuously faced with chronic hunger which is wide spread over the region due to declining agricultural production (Morgan and Solarz, 1994). The combined impacts of adverse weather (frequent dry spells and generally below-normal soil moisture conditions) and severe economic constraints in Zimbabwe have induced hardship and food insecurity among both rural and urban populations (FAO, 2007). It is due to such influencing factors that have resulted in urban communities shift to intensive wetlands utilisation for food production as these areas have higher moisture contents. One model of wetlands alteration by (Keddy, 1983) assumes three main factors which influence wetland ecosystems; water level, nutrient status and natural disturbance.
The exploitation of wetlands for agricultural purposes in Harare is common as these areas where deliberately left out of residential development during town planning. Local

authorities focus more on protecting rivers, for example control of stream bank cultivation yet wetland protection is weak as evidenced by the fact that notices are put up written ‘no cultivation’ or ‘no dumping’ but you find crops grown or dump sites in these areas.

1.2 The Problem statement

Monitoring and assessing wetlands’ land use change at spatial and temporal scale is required to catalogue the diverse effects of these land use changes on the life history of wetlands. Agriculture and other land use changes such as settlement affect wetland size, nutrient status and water table levels through, draining, water abstraction, growing of crops with or without fertiliser application and cover clearance. There is need to balance the levels of exploitation of wetlands, as uncontrolled utilisation/exploitation may ultimately lead to loss of food security options. This can be achieved through assessing the changes in land use patterns and fragmentation in the wetlands over a long period of time. The potential of wetlands for augmenting terrestrial agricultural productivity is increasingly recognized (FAO, 1998) but can lead to degradation of the wetland. In Harare, wetlands have been lost or degraded because of disruption of the natural processes by agricultural intensification, urbanisation, pollution and dam construction and other forms of intervention in the ecological and hydrological system (Matiza and Crafter, 1994). However the study did not assess the causes of fragmentation in the urban wetlands. The ‘disappearance’ and shrinkage of urban wetland ecosystems due to over exploitation by urban communities needs proof through scientific investigations. Therefore there is need to analyse the changes in the wetland size, land use patterns (also revealed through landscape fragmentation matrices) and the relationship between land use and water quality.

1.3 Significance of the study

This study contributes to the understanding of urban wetlands, water quality and their changes over the past 36 years. Such information is needed by ecosystem managers trying to determine the recent rate of wetlands loss and water quality changes. The main focus of this project is to generate and analyze digital 'change images' that will show how much and where changes have occurred in Honeydew, Mabvuku and Monavale wetlands.

Understanding the complexity of landscapes require mapping the landscape through time, incorporating spatial relationships and quantifying its structure (Namuralani *et al.*, 2004). Application of Remote Sensing and GIS and landscape metrics can be combined to provide more spatially consistent and detailed information on landscape structure which will facilitate the identification of social and biophysical processes driving these changes (Brown *et al.*, 2000; Harold *et al.*, 2005). Land use change is influenced by temporal and spatial factors that interact.

Analysing these changes is critical to evaluate emerging land use and potential problems in water quality in the watershed (Institute of water research, MSU, 1997). Small isolated wetlands in urban areas, even if degraded can provide important islands of wildlife, as well as storm water regulation and water purification functions (Hunt, 2004).

Water managers may be focusing on bigger issues such as pollution of Lake Chivero but there is also need for more attention in the management of small urban wetlands in Harare which are vital for purification of runoff into the main river systems. Investigation of environmental impact of the current and historical land uses on urban wetlands is useful for regulating exploitation by human beings, considering the value of the urban wetlands for water and food security.

Direct effects of climate change on wetlands are likely to be accentuated by human induced changes that will increase stress to wetland ecosystems. Land use change and water consumption patterns will accentuate climate change impacts on wetlands (IUCN, 1999).

A wetlands inventory is required for the sustainable management of these ecosystems. Hence this study measured some water quality parameters and changes in wetland sizes in relation to the land-uses in the Honeydew, Mabvuku and Monavale wetlands.

1.4 Main objective

To investigate the impacts of land uses changes and assess the current water quality of wetlands in urban communities.

1.4.1 Specific objectives

1. To determine changes in the area covered by the Mabvuku, Monavale and Honeydew wetlands over the period 1972 and 2008.

2. To assess the changes in the land use pattern within the Mabvuku, Monavale and Honeydew wetlands.

3. To determine the relationship between the water quality and land use in the wetlands.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Background on wetlands utilisation in Southern Africa

Wetland systems are integral to the socio-economy of the Southern Region supporting fisheries, pasture and agriculture, whilst also providing water for irrigation, power generation and means of transport (Breen *et al.,* 1997). Much of the Southern African region depends on wetlands for dry season farming. However demographic growth, rising poverty and climatic extremes have placed increasing pressure on natural resources such as wetlands. Wetland agriculture is common in Zimbabwe, Zambia, Malawi and Tanzania for growing vegetables, grain and fruit (Whitlow, 1985).

The use of wetlands constitutes demand on various resources of the ecosystems, whilst their conservation objectives by state and other interested groups constitute another. This has often resulted in conflict between demands created by livelihood activities and conservation (Salafsky and Wollenberg, 2000). There is need for a linkage by water managers between livelihoods and conservation of urban wetlands in order to realise sustainable use of these ecosystems.

2.2 Background on wetlands utilisation in Zimbabwe

Wetlands cover 4.6% of Zimbabwe's land (Whitlow, 1985). Vleis are the most widespread form in Zimbabwe and they cover 3.6% of the land area (Chenje *et al.,* 1998; Whitlow, 1985). Zimbabwe wetlands are small in size but very diverse and they include dambos, flood plains, riparian systems, pans and artificial impoundments (Matiza and Crafter, 1994).

It is apparent that wetlands have lost most of their functions, products and attributes in Zimbabwe (Matiza and Crafter, 1994). Issues and threats to Zimbabwe wetlands systems are deforestation of watersheds, overgrazing, eutrophication, pollution, land tenure and dam developments. In Zimbabwe, wetland ecosystems had and still have a strong link with the development of the society and a broad range of human activities.

In the history of human settlement, adequate water supply is an important factor, thus most large settlements in Zimbabwe like Harare are located in or near wetlands (IUCN, 1997). Harare, the capital city of Zimbabwe, is located on a network of streams (including the Marimba and Mukuvisi streams) that drain into Manyame River.

Dambos, a palustrine wetland widely distributed in Zimbabwe and covered an estimated area of 1.28 million hectares in the year 1992 is widespread within the boundaries of Harare City (Matiza and Crafter, 1994). The wet dambos that were wide spread throughout the country are now difficult to find**.** Wetlands have been lost or degraded because of disruption of the natural processes by agricultural intensification, urbanisation, pollution and dam construction and other forms of intervention in the ecological and hydrological system.

2.3 Importance of wetland resources and livelihood strategies

Wetlands are becoming increasingly recognised as important natural resources in developing countries because of their ability to fulfil a range of environmental functions and produce a number of products that are seasonally and economically beneficial to local communities (Dugan, 1990; Silvius *et al.*, 2000).Wetlands are natural parts of the landscape where water collects. Wetlands act like sponges, absorbing water during periods of high runoff, and gradually releasing it during dry periods. They also recharge ground water resources and this benefits surface communities by providing a stable flow of water to the surface. Their capacity to store water means they are able to support livelihood strategies, such as fishing, pastoralism and agriculture, as well as providing craft materials, clean drinking water and medicinal plants (Dixon and Wood, 2007). Such wetlands functions as biomass production and export are extremely important for food security enhancement and enable some wetlands produce food for both people and livestock (Hunt, 2004). Wetlands also serve as natural water filters, removing impurities and sediments. At one time the function of these ecosystems was relatively undervalued, and many wetlands were drained for agriculture and other forms of development (Mitsch and Gosselink, 2000).

Today, however, there is increasing recognition of the valuable ecosystem services provided by wetlands, from flood control to fisheries. In recent years, however, much attention has been focused on the need for the ‘wise use’ in the context of an increase in wetland exploitation and development fuelled by socio-economic, political and environmental change (van Koppen *et al*., 2007).

2.4 Global wetland area and wetlands loss

Wetlands vary spatially in size, ranging from small prairie potholes of a few hectares to large tracts of several hundreds of km^2 (Finlayson and Moser, 1991). Although this range in scale is not unique to wetlands, the question of scale is important for their conservation. Wetlands can be lost in large parcels, or more commonly, one small piece at a time in a process called cumulative loss. Different studies have shown varying estimated global wetlands coverage. Russian geographers estimated that more than 6.4% of the land surfaces of the world or 8.6 million km2 are wetlands (Ramsar, 1998). Almost 56% of this estimated total wetland area is found in tropical (2.6 million km^2) and subtropical (2.1 million km^2) region. Wetlands cover nearly 10% of the earth’s surface of which 2% are lakes, 30% bogs, 26% fens, 20% swamps and 15% floodplains (Ramsar, 1998). Mangroves further cover some 24 million hectares (ha) and coral reefs are estimated to cover 60 million ha. The largest remaining areas of wetlands are in the high latitudes and the tropics. The rate at which wetlands are being lost on a global scale is unknown (Mitsch and Gooselink, 2000). There are too many vast areas of wetlands where accurate records have not been kept and many wetlands in the world were drained centuries ago. It is probably safe to assume that we are still losing wetlands at a fairly rapid rate globally and that we have perhaps lost as much as 50 percent of the original wetlands on the face of the earth.

2.5 Mapping of wetlands and its importance

The three primary inventory techniques currently used to map wetland ecosystems are on site evaluations, aerial photo interpretation, and digital image processing (Baker *et al.*, 2006). Methods of wetland delineation require presence of three parameters hydric soils, wetlands hydrology and hydrophytic vegetation (Dewey *et al.*, 2006). For scientific purposes and as a means of evaluating methods of delineating wetland boundaries the NRC, (1995) defines wetlands as an ecosystem that depends on constant or recurrent shallow inundation or saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical and biological features reflective of recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils, and hydrophytic vegetation. These features will be present except where specific physicochemical, biotic or anthropogenic factors have removed them or prevented their development (NRC, 1995).

Accurate wetland mapping is an important tool for understanding wetland function and monitoring wetland response to natural and anthropogenic actions. Wetlands are often damaged or overwhelmed through increased surface flows in urban or suburban areas with high densities of impervious surfaces (Ehrenfeld, 2000, Wang *et al*., 2001). Wetland mapping is used to evaluate land use decisions and monitor the effectiveness of mitigation efforts (Muller *et al.*, 1993). Landscape scale mapping of these scarce habitats facilitates understanding of floral and faunal population dynamics (Semilitsch and Bodie, 1998). The susceptibility of wetlands to human activities and human dependence on the ecological contributions of wetlands illustrate the importance of mapping wetlands resources. Furthermore, establishing the role of wetlands in increasingly urban landscape requires an understanding of wetland density and distribution (Tiner, 2003).

Wetlands and riparian zones provide a variety of ecological services that contribute to ecosystem functions at local, watershed and regional scales (Semilitsch and Bodie 1998, Tabacchi *et al.*, 1998, Ehrenfeld, 2000, Mitsch and Gosselink, 2000). The shape, size and distribution of wetland and riparian zones are largely determined by geologic, topography and hydrologic conditions (Peck and Lovvorn, 2001, Toyra *et al.*, 2002). The ecological contributions of wetlands and riparian zones, if factored into land value, suggest that these ecosystems are more economically and ecologically valuable than most other land cover types (Mitsch and Gosselink, 2000). Therefore there is need to regulate utilisation/exploitation levels of wetlands to balance the livelihoods aspect and sustainable management of urban wetlands.

2.6 Significance of land use changes in wetlands and climate change

The major cause of wetland loss around the world continues to be conversion to agricultural use (Mitsch and Gosselink, 2000). When wetlands are converted to agricultural land, large quantities of CO_2 (carbon) and N_2O (methane) are released (GACGC, 1998). Land use therefore plays a major role in climate change at global, regional and local scales. The combination of climate and land use changes may have profound effects on habitability of the planet in more significant ways than either acting alone and are likely to affect natural ecosystems in complex ways (NRC, 2001d). While land use change is often a driver of environmental and climatic changes, a changing climate can in turn affect land use and land cover. Climate variability alters land use practices differently in different parts of the world, highlighting differences in societal vulnerability and resilience (NRC, 2001d).

2.7 Land use changes and wetland fragmentation analysis

Landscape fragmentation may be characterised by a reduction in the total amount of habitat or land cover and change in the spatial characteristics and configuration of remaining patches (Forman, 1995; Hansen *et al.*, 2001). The consequences of fragmentation become evident through changes in both composition and configuration of the landscape.

Landscape fragmentation analysis can be used to interpret the impact of land use changes on a particular habitat by calculating for each land use range of landscape metrics to describe fragmentation and spatial distribution, from satellite based classifications (Southworth *et al.*, 2004). Landscape structure analysis provides a spatial context of parcels of land that can help resource professionals better understand the complex interactions among the polygons comprising a landscape for example a wetland (Geoworld, 1999).

There is growing evidence that habitat fragmentation is detrimental to many species and may contribute substantially to the loss of regional and global biodiversity (Geoworld, 1999).

2.8 Land use changes and water quality in wetlands

Every land use virtually has potential to change water quality (Perry and Vanderklein, 1996). Land use changes are important drivers of water, soil and air pollution. The oldest being land clearance for agriculture and harvest of trees and other biomass which leaves soils vulnerable to massive increase in soil erosion by wind and water (Erle and Pontius, 2007). Modern agricultural practises, which include, intensive inputs of nitrogen and phosphorus fertilisers have substantially increased the pollution of surface water by runoff and erosion and the pollution of groundwater by leaching of excess nitrogen (as nitrate) (Hunt, 2004). Other agricultural chemicals; including herbicides and pesticides are also released to ground and surface waters by agriculture and in some cases remain as contaminants.

The wetlands function of maintaining water quality influences a much broader scale than that of the wetland ecosystem itself (Sather and Smith, 1984). Wetlands under favourable conditions remove organic and inorganic nutrients and toxic materials from water that flow through them because of the following attributes (Sather and Smith, 1984).

1. A reduction in water velocity as streams enter wetlands, causing sediments and chemicals sorbed to sediments to drop out of the water column.

2. A variety of anaerobic and aerobic processes in close proximity promoting denitrificarion, chemical precipitation, and other chemical reactions that remove certain chemicals from the water.

3. A high rate of productivity in many wetlands can lead to high rates of mineral uptake by vegetation and subsequent burial in sediments when plants die.

4. A diversity of decomposers and decomposition processes in wetland sediments.

5. A large contact surface of water with sediments because of the shallow water, leading to significant sediment-water exchange.

6. An accumulation of organic peat in many wetlands that causes the permanent burial of chemicals.

Wetlands are altered by pollutants upstream or local runoff and in turn change quality of the water flowing out through them. The chemical nature and concentration of various substances dissolved in the water determine its pH, hardness, salinity, nutrient content and other measures used to categorise water chemistry, and can have a significant impact on the flora and fauna of the wetland (van der Valk, 2006). The major sources of water in a wetland are determined by its geomorphic setting and local climatic conditions. In turn, the sources of the water in a wetland determine not only the amount present and when it is present, but also its chemistry. The water chemistry of wetlands whose primary source of water is precipitation will be very different from that of a wetland whose primary source of water is groundwater discharge. This can have a major effect on the species composition of the vegetation and its primary production.

2.9 Importance of wetlands hydrology

Hydrology which is the description of water level, flow and frequency of water is a very important aspect in wetlands studies because it is probably the single most important determinant of the establishment and maintenance of specific types of wetlands and wetlands processes (Mitsch and Gosselink, 2000). Hydrologic conditions are extremely important for the wetland's structure and function because they affect many abiotic factors including soil anaerobics, nutrient availability and salinity like in coastal wetlands. These in turn affect biota that develops in a wetland. In dry climate for example Southern Africa and most of Australia wetlands are often restricted to river channels and depressions (van der Valk, 2006). In many wetlands organisms must survive or endure water-level fluctuations, ice formation and even periodic absence of water. Finally, completing the cycle, biotic components are active in altering the wetland hydrology and other physio-chemical features (Mitsch and Gosselink, 2000).

Wetlands are shallow, even small changes in water levels which would be inconsequential in large lakes and rivers, can result in significant local environmental changes for sessile plants and animals (van der Valk, 2006). Therefore, changes in water inputs and outputs in wetlands in other words, their water budgets, and the water depths at any given place overtime and, the local water regime, are important descriptors of the entire wetland and of the physical environment experienced by organisms found at different elevation within a wetland. On the other hand, past and current depth of flooding is the major determinant of the distribution of plants and animals within a wetland. Water levels in wetlands are also important in wetlands studies as they can be used to estimate evapotranspiration using the Diurnal Method. Evapotranspiration from wetlands has also been calculated from observing the diurnal cycles of groundwater or surface water in wetlands (Mitsch *et al.*, 1977; Heimburg, 1984). The hydroperiod of a wetland has a significant effect on nutrient transformations on the availability of nutrients to vegetation, and on loss from wetlands soils nutrients that have gaseous forms.

Furthermore with records of water levels the following hydrologic parameters can be determined; hydroperiod, frequency of flooding, duration of flooding and water depth. Water levels in most wetlands are generally not stable but fluctuate seasonally (high order riparian wetlands), daily or semi-daily (types of tidal wetlands) or unpredictably (wetlands in low order streams and coastal wetlands with wind –driven tides) (Junk *et al.*, 1989).

The amount of precipitation in most parts of the world varies seasonally and from year to year. This variation is reflected in the amount of water in a wetland. As such number of terms are commonly used to describe the general hydrology of wetlands (Cowardian *et al.*, 1979) namely: Permanently flooded (standing surface water present through put the year), Intermittently exposed, (standing water present throughout the year except in years of severe drought), Semi-permanently flooded (standing water present throughout the growing season in most years), Seasonally flooded (standing water present for extended periods of time during the growing season) Saturated (the soil or substrate is saturated with water (water logged) to the surface during the growing season, but standing water rarely present), Temporarily flooded (standing water is present only for brief periods during the growing season), Intermittently flooded, (standing water is present periodically but without any seasonal pattern).

2.10 Sustainable resource use

Wetlands can be managed in their more or less natural state for certain objectives such as fish and wildlife enhancement, aquaculture production, water quality improvement, and flood control. Agricultural activities have had a considerable impact on natural ecosystems in many parts of the world. The concept of sustainability is a very challenging concept because a criterion varies with goals of sustainability (Pretty, 1995). The overall aim of sustainable resource use is to derive benefits for the well being of humans and maintain the environment while taking into consideration the needs for future generations. To achieve this, a careful manipulation of the natural resources to meet the socio-economic challenges with minimal impact on environment is needed. More often than not, sustainability is viewed in terms of an activity being in harmony with the environment. However, it goes beyond such oversimplification; for instance Lefroy *et al.*, (2000) and Smyth and Dumaski (1993) view sustainability as an integration of socio-economic principles with environmental concerns in order to maintain production, reduce the level of production risk, protect the potential of natural resource and ensure economic viability and social acceptability.

2.11 Managing wetlands in a changing climate

Wetlands will be affected in different ways by shifts in the hydrological cycle (IPCC, 1996). These include changes in precipitation, evaporation, transpiration, runoff and groundwater recharge and flow. These changes will affect both surface and groundwater systems and impact wetland requirements, domestic water supply, irrigation, hydropower generation, industrial use, navigation and water based tourism (IUCN, 1999). Arid and semi-arid areas are especially vulnerable to changes in precipitation as a decline in precipitation can dramatically affect wetland areas (IUCN, 1999). There is need to increase water storage for irrigation through development of infrastructure so as to lessen pressure on wetlands.

An important adaptation strategy is the prevention of additional stress that can reduce the ability of wetlands to respond to climate change. Reducing pollution, avoiding vegetation removal, and protecting wetland biological diversity and integrity are, therefore, viable activities to maintain and improve the resilience of wetland ecosystems so that they continue to provide important services under changed climatic conditions (Kusler *et al*., 1999). Another important adaptation strategy is preventing the fragmentation of wetlands. Connectivity between ecosystems allows migration of species to occur in response to climate change and therefore the maintenance of migration routes constitutes a wise approach (IPCC, 1996). Maintaining river flow characteristics, including low flows also represents an important approach to maintain wetland systems.

Wetland monitoring to collect specific information for management purposes and the use of these monitoring results for implementing management is required. Elements of an adaptation strategy should involve alterations in the management system as well as technological and institutional changes that can deal with changing conditions (IPCC, 1996).

CHAPTER THREE

3.0 Methods and materials

3.1 Study area

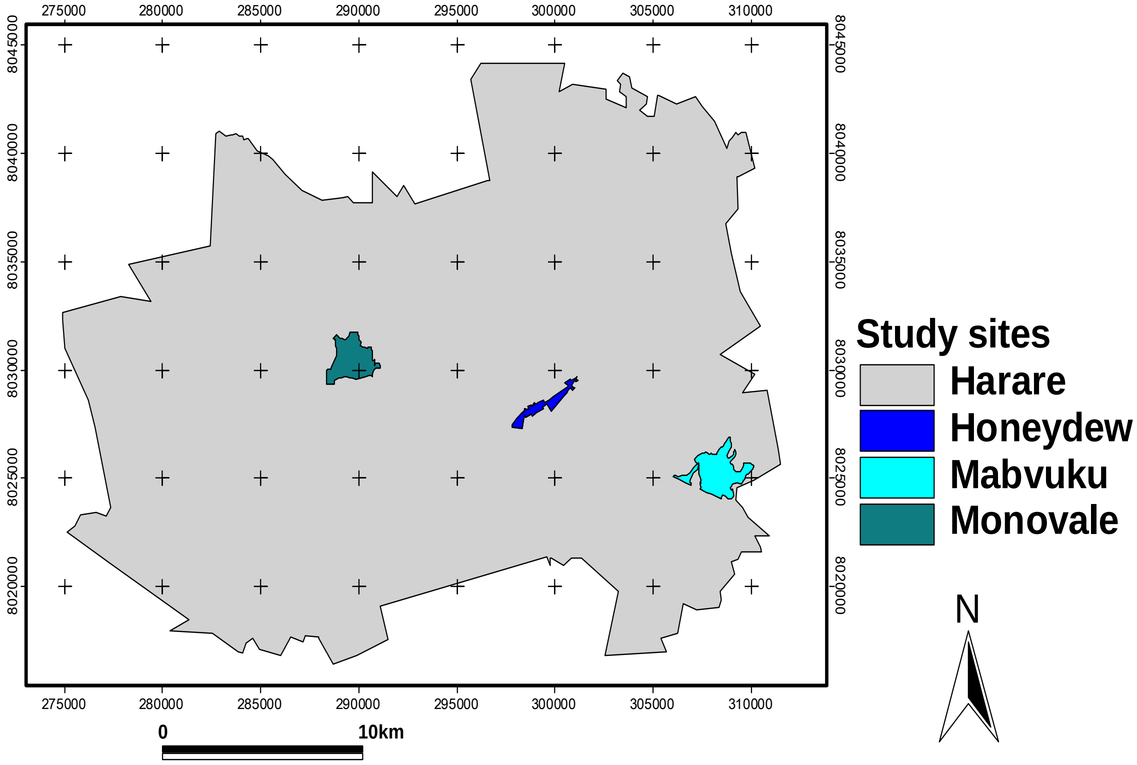


Figure 1: Map showing the boundary of City of Harare and the sampling sites Honeydew, Mabvuku and Monavale.

3.2 Description of the study area

The study area is Harare, the capital city of Zimbabwe. Three sites where selected in the following residential areas Mabvuku, Honeydew (Greendale) and Monavale (Figure 1).

Mabvuku is a wetland along the Harare- Mutare road near the Mabvuku turn off. This wetland is used for sewage processing (using ponds), subsistence farming, and drinking water abstraction. Use of this water may put the people at health risk if the water in the shallow wells is not fit for drinking water. Although the reliance on the wetland for domestic water supply could be temporary a continued reliance on ground water can be anticipated. Furthermore, there may be inadequate control of water abstraction which may lead to groundwater over abstraction.

The second site, Honeydew is in Greendale a residential area of Harare city. The area in the study included the Honeydew farm and adjacent areas used mainly for subsistence farming. Honeydew farm was a commercial vegetable farm. About 4 boreholes have been sunk in this wetland to irrigate the crops. The subsistence farmers grow mainly maize and sweet potatoes, and rely on natural surface water and shallow wells for crop irrigation.

The third site was in Monavale. Part of the Monavale wetland was protected by the residents whilst the adjacent areas are used mainly for subsistence farming and residential houses. A Vlei Ranger recruited by the residence to look after the protected area. The 2009 World Wetland Day commemoration were held at this site in recognition of the conservation efforts at this wetland. The protected area was covered by natural grasses and some wildlife such as fish, birds, wild pigs and grass snakes now use the area. This vlei has about 211 bird species and visitors as far as South Africa come for bird viewing (Jimmy Muropa, personal communication). The effect of the protection of the wetland on the wildlife changes as well as on water quality was of interest.

3.3 Period of the study

Data was collected for a period of four and half months between January and June 2009.

3.4 Determination of change in wetlands sizes and land use.

3.4.1 Choice of remote sensed image

The project component deals with the investigation using remotely sensed images, in digital format, to monitor changes in land uses, wetlands sizes in the Honeydew, Mabvuku and Monavale. The parameters that were of interest for monitoring are mentioned in section 3.5.2. The study included looking at digitized black and white aerial photography and not digital satellite images. This is because digital satellite images from the earlier years (especially before 2000) had low resolution for the intended purpose. Aerial photographs provide synoptic views of study areas, allowing “big picture” understanding of hydrology and vegetation patterns (Harvey and Hill, 2001). Older remote sensed data for many areas often exist only in the form of black and white aerial photographs, precluding any spectral analyses, but aerial photos possess excellent spatial detail (Erle and Pontius, 2007). Additionally in Zimbabwe, aerial photography archives are available at the Surveyor’s General’s office for the whole country but only up to 1995, providing a valuable historical record of past landscape conditions.

However many concerns are still associated with the use of aerial photos for wetland mapping, despite improvements in the quality of aerial photos (Harvey and Hill, 2001). Repeatability is another concern with human derived photo interpretation products. Results are determined by what the mapper is seeing. Another mapper cannot produce exactly the same results. Studies carried out for example by USGS, (2002) have shown that due to the size of the features of interest, particularly features such as small drainage channels, not only was the spatial resolution of the satellite images generally too low (30-meter), but that ground-based digital photographs should also be included. Historical aerial photographs were available for the area; however, because of their scale even their spatial resolution was questionable for detecting changes in wetland boundaries. These were the highest resolution image data available for the analysis.

3.4.2 Digitising aerial photographs and Google Earth image

Black and white Aerial photographs (APs) of the study sites acquired from the Department of The Surveyor General were scanned at 400DPI (Dots Per Inch). The APs used for all study sites were taken in 9 September 1972, 24 September 1984 and 8 June 1995. It is important to note that Aerial Photographs in Zimbabwe were taken once every year therefore it was very difficult to get photographs of the same month over year after year. The APs were imported into a Geographic Information System (GIS) environment-ILWIS 3.3. Aerial photographs were saved as tagged image file format (tif). Images were orthorectified using the Digital Elevation Model (DEM) of the area. Orthorectification is the process of geo-referencing APs. Georeferencing an orthophoto means to add coordinates to a scanned aerial photograph with fudicial marks. Corner fudicial marks were used were the aerial photographs' were taken with a photogrammetric camera with known principal distance and smaller DEMs were created to correct for tilt and relief displacement for each wetland site. This type of georeference was used to add coordinates to professional near vertical aerial photographs and for creating an orthophoto (resampling). The resample operation was carried out to convert a raster map from the map's current georeference to another target georeference. The resampling method used was nearest neighbour in order to combine scanned photographs.

From the resampled APs wetlands' boundaries were digitised through tone and textural analysis. Infrastructure developed in the wetlands such as sewage and residential areas were identified and also digitised. The land use change for the year 2008 was digitised from Google earth images taken during the dry season.

The digitised photographs were then polygonised to determine areas of the different land uses in each wetland.

3.4.3 Land use changes data analysis

Class level metrics were computed with Arc View Spatial Analyst extension to carry out fragmentation statistics of the wetlands. Class level landscape metrics represent the spatial distribution and patterns of a land use class such as wetland agriculture (Pan *et al.*, 2004). Therefore most of the class level metrics can be interpreted as fragmentation indices because they quantify the amount and distribution of a particular land use class (McGarigal *et al.*, 2002).

For the three selected wetlands, four landscape metrics at the class level that describe the spatial aspect of landscape fragmentation in four periods were used. These are class area (CA), number of patches (NP), mean patch size (MPS) and total edge (TE). The choice of the metrics was based on the scale of analysis (that is the wetland level), as well as knowledge of the study area (Forman, 1995; Turner *et al.*, 2001; Lausch and Herzog, 2002).

Table 1: Land uses description.

Land use	Description
Dryland Agriculture	Cultivation of any crop outside the wetland area.
Wetland Agriculture	Cultivation of any crop in the wetland area.
Protected wetland	Area specific to Monavale wetland were residents are protecting part of the wetland against any agriculture or settlement or any land use detrimental to the ecosystem health.
Unused wetland	Wetland area not cultivated or settled or put to any consumptive human use.
Bawling sports club	Lawn covered area used for bawling sport.
Golf course	Grass covered area used for golf sport.
Settlement	Built up area with residential and recreational use and including the greenhouses in the commercial agriculture in the Honeydew wetland.
Grassland	Includes lands covered by natural and herbaceous cover with grasses and herbs, sometimes with very scattered trees.
Sewage pond	Area under sewage pond including adjacent authority offices and houses at sewage works.

The matrices used in the analysis below are defined in Arcview 3.3.

1. Class Area is the area of class (land use for example wetland agriculture, dryland agriculture or settlement).

2. Number of Patches (NP) is the total number of patches in a class.

3. Mean Patch Size (MPS) is the total area occupied by a particular patch class divided by the NP of that class.

4. Total Edge (TE) is the perimeter of patches or it can be defined as the total perimeter of each patch in a class.

Average annual rainfall data in the study area from Belvedere Rainfall Station was obtained from ZINWA (Zimbabwe National Water Authority) for the period between 1970 and 2008. To analyse the rainfall trend between 1970 and 2008 the linear regression model was used. The numbers of periods with rainfall below the mean of the whole period were counted for each time period to give another measure of drying cycles. Analysing the rainfall patterns in the study area is important as wetlands are highly dependent on water levels, and so changes in climatic conditions that affect water availability will highly influence the nature and function of specific wetlands, including the type of plant and animal species within them (Mitsch and Gosselink, 2000).

Observations in the wetlands were made to determine land uses, agricultural practises and to ground truth maps,

3.5 Study design for water quality assessment

3.5.1 Sample points

The wetlands were stratified into different land uses and samples taken at points equidistant (as far as practically possible in the field) from each other in each stratum. In Monavale two strata were identified as subsistence agriculture and protected area (Figure 2). The strata in the Mabvuku Wetland were based on the use of the wetland for sewage primary treatment. Sampling points were placed above sewage, adjacent to the sewage ponds and far below sewage pond (Figure 3). Water samples were also taken from a deep well situated at the boundary of the wetland. In Honeydew, two strata identified were commercial and subsistence agriculture (Figure 4). The descriptions of these sampling points are given in Table 2.

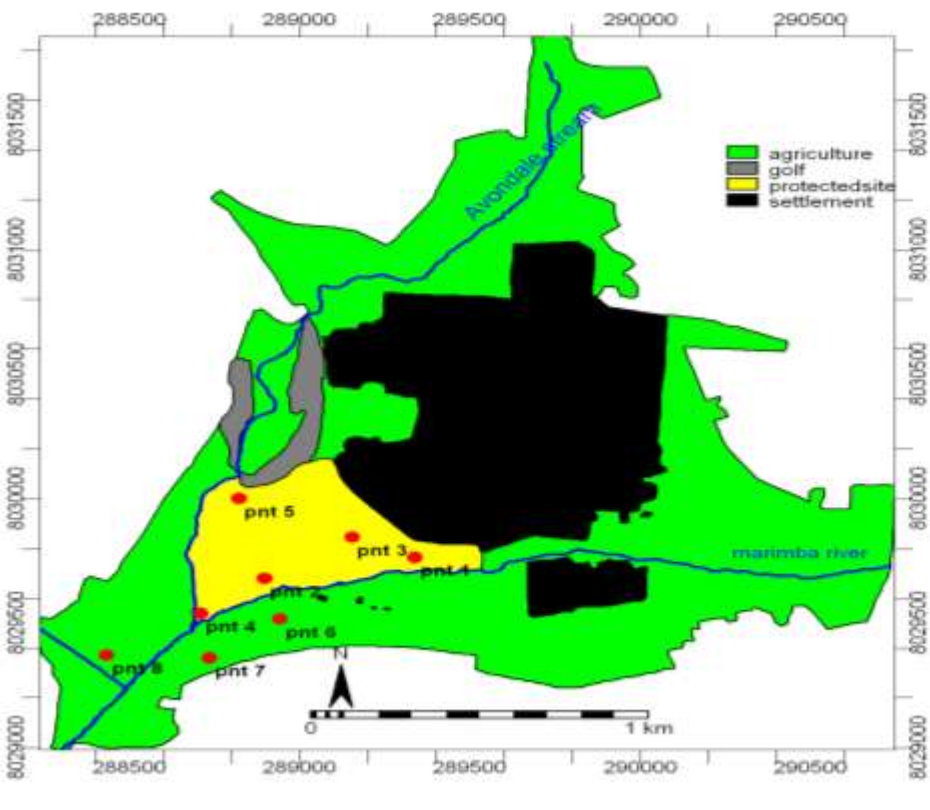


Figure 2: Monavale Wetland sample points (pnt) shown as red dots.

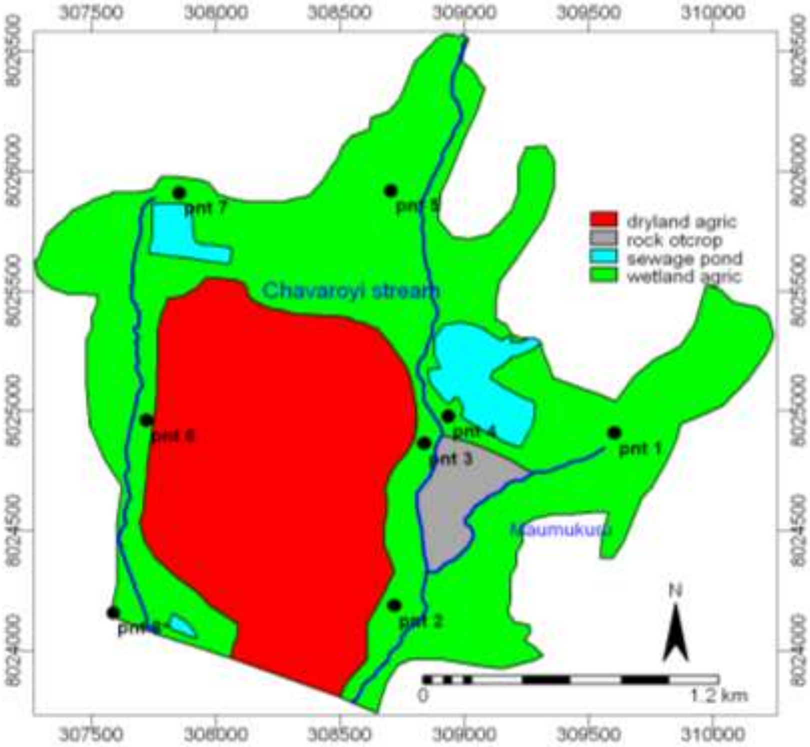


Figure 3: Mabvuku wetland sample points (pnt) shown as black dots.

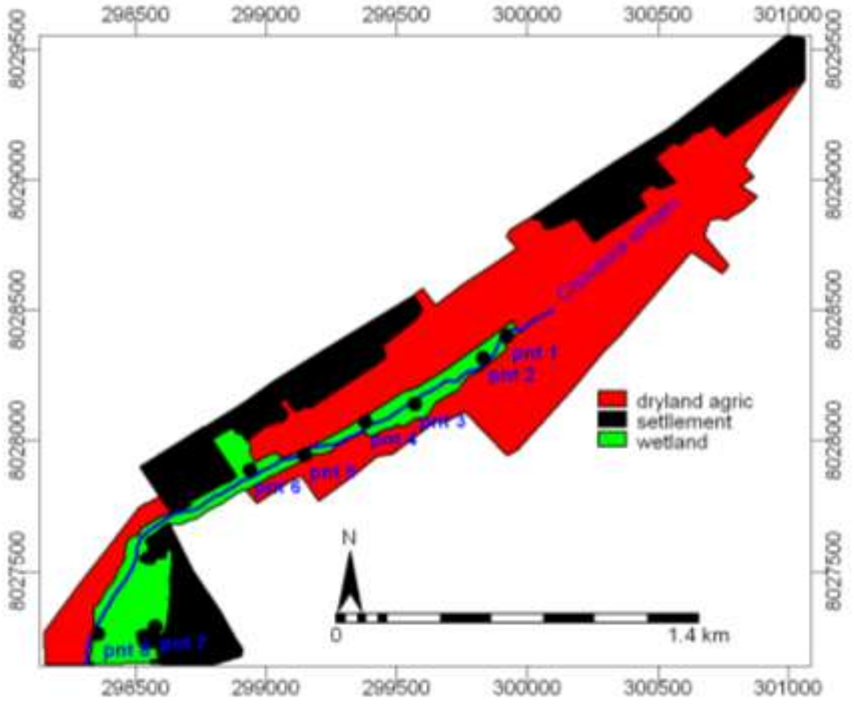


Figure 4: Honeydew wetland sample points (pnt) shown as black dots.

3.5.2 Selection of parameters

The physical parameters measured were conductivity, total dissolved solids, ORP and pH. The chemical parameters selected for the study were total nitrogen and total phosphates. A microbiological analysis to determine the presence of *Escherichia coli* and to estimate the number of faecal coliform was also done.

The water quality parameters selection was based on the effect they have on wetlands' water quality and productivity and also the type of pollution likely to be received due to the landuses in wetlands. Perry and Vanderklein (1996) listed ten common and critical water quality impacts that result from diferrent land uses: changes in suspended sediment load, organic matter and biological (and chemical) oxygen demand, bacteria and viruses, nutrient loads, temperature, heavy metals, toxins such as pesticides and herbicides, acidification (pH), salinisation, and changes in the water flow itself. The parameters analysed were selected based on the landuses within the wetlands which may be threat to water quality. For example, presence of sewage ponds were indicated by feacal coliforms, whilst total nitrogen and total phosphates were indicators of agricultural activities. Total dissolved solids were selected to show the pollution levels at each point. The Oxidation Reduction Potential (ORP) was selected as it indicates quantity of decaying organic matter. Therefore, this parameter would vary with landuses. For instance, in agricultural land uses ORP is expected to be lower than in areas adjacent to a sewage pond. ORP also has a bearing on the water holding capacity of the soil hence water levels (van der Valk, 2006). Finally pH was consisdered as general parameters, which affect physical, chemical and biological processes (Chapman, 1996).

3.5.3 Sampling method and frequency

Two samples per site were collected. One sample for total nitrogen and total phosphorus was collected in clean 500ml white polyethylene plastic bottles whilst 400ml sterile glass bottles were used to collect the samples for microbial analysis. Samples for microbiological analyis were collected first at each site in order to minimize contamination of the water (SCA, 2002; Cheesbrough, 1998). Groundwater samples were collected in all wetlands as it reports longer term water quality status compared to surface water. Furthermore, surface water was not available in all wetlands at the time of sampling. Samples were collected twice in April and June 2009.

3.5.4 Water point selection criteria

The following factors were used in point selection:

- Type of land use and strata identified in each wetland. Water samples were collected mainly from agricultural land use because the major cause of wetland loss around the world continues to be conversion to agricultural use (Mitsch and Gosselink, 2000). The non agricultural land uses such as the protected area in Monavale wetland, points up or below sewage ponds in Mabvuku act as control sites for comparison of results. Accessibility of point was also considered.

3.5.5 Description and characteristics of sampling points

A total of 25 points from all the three wetlands were sampled. A Global Position System (GPS) was used to get geographic coordinates at each point and used to produce a map.

Table 2: Description of water sampling points in each wetland.

Wetland and sampling point	Point Description
Honeydew	
1	Located section 48c of commercial farm. Clay soil.
2	Located section 48c of commercial farm. Clay soil.
3	Located section 26 of commercial farm. Clay soil.
4	Located section 26 of commercial farm. Clay soil.
5	Located in subsistence agriculture strata sharing boundary with the commercial farm. Clay soil.
6	Located section 16 of commercial farm. Clay soil.
7	Located in subsistence agriculture strata about 100m away from Mutare road. Clay soil.
8	Located subsistence agriculture strata about 13m away from Chavaura stream. Clay soils.
Mabvuku	
1	Located upstream of sewage ponds 2. Subsistence agriculture.
2	Located downstream sewage pond 2 after Chavaroyi and Maumukuru stream confluence below granite rock outcrop. Top 15cm with clay soils with underlying light grey soil.
3	Located below sewage pond 2. Subsistence agriculture.
4	Located about 20m below sewage pond 2 and 10m away from Chavaroyi stream.
5	Located upstream sewage pond 2. Subsistence agriculture.
6	Located downstream sewage pond 1. Clay soil in top 10-15cm underlying light grey sandy soils.
7	Located just downstream of sewage pond 1.
8	Located at deep well were water is abstracted for domestic purposes.
Monavale	
1	Located in a protected stratum where no agriculture or settlement is allowed. The area is mainly used for bird viewing. Clay soils under tall grassland cover.
2	Located in protected stratum. Clay soils.
3	Located in protected stratum. Clay soils.
4	Located in protected stratum within 15m of Marimba river.
5	Located in protected stratum within 10m of Avondale stream. Clay soils.
6	Located in subsistence agriculture stratum. Clay soils.
7	Located subsistence agriculture stratum a. Clay soils.
8	Located in subsistence agriculture strata. Clay soils

3.5.6 Methods of water quality parameters analysis

a) Physical Parameters

The water samples on site were analyzed for the following variables; Total dissolved solids (TDS), conductivity, pH, and temperature. These parameters were measured using a WTW 330i conductivity meter and a HACH pH meter (APHA, 1996).

b) Chemical Parameters

Water samples were analysed for total phosphorus and total nitrogen in the laboratory. The nutrients were measured with a HACH water analysis kit (DR/2010 portable data logging spectrophotometer). Total phosphorus- was determined by the PhosVer 3 with acid persulfate digestion method (Test no.8190).The phosphates present in organic and condensed inorganic forms (meta-, pyro- or other polyphosphates) were converted to orthophosphates before analysis. Pre-treatment of the sample with heat acid and heat provided the conditions for the hydrolysis of the condensed inorganic forms. Organic phosphates were converted to orthophosphates by heating with acid and persulfate. Orthophosphate reacted with molybdate in an acid medium to produce a phosphomolybdate complex. Ascorbic acid then reduced the complex producing an intense blue colour. Absorbance was measured at 890 nm. The EDL for this test is 0.04 mgl^{-1} $PO4^{3-}$ and the precision level is ± $0.09mgl^{-1}$. Total nitrogen-was determined by the persulfate digestion method (Test no.10071).The alkaline persulfate digestion converted all forms of nitrogen to nitrate. Sodium metabisulphate was added after the digestion to eliminate halogen oxide interferences. Nitrates were reacted with chromotrophic acid under strongly acidic conditions to form a yellow complex with a maximum absorbance at 410nm. Precision is at standard deviation less than 1 mg l^{-1} N (APHA, 1996).

c) Microbial Analysis

The presumptive coliform test was used to indicate the number of coliforms in the samples collected from the three wetlands. Tubes were incubated at 44^{o} C since the bacteria of interest are thermotolerant. The Most Probable Number (MPN) was used to estimate the number of faecal coliform bacteria using three tubes with volumes 10, 1 and 0.1ml (APHA, 1960). The health risk was assessed using World Health Organization, 1997 guidelines (Table 3).

Table 3: Classification and colour code scheme for thermotolerant faecal coliforms and *Escherichia coli* (World Health Organization, 1997).

Risk Category	Coliform count per 100ml
Very high risk	> 1000
High risk	100-1000
Immediate risk	10-100
Low risk	1-10
Conformity to WHO guidelines	0

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Changes in size of wetlands

All the three wetlands significantly decreased in area (Linear Regression; $p < 0.05$) (Figure 5). The Honeydew, Mabvuku and Monavale reduced size to 11.6%, 37% and 63.9% of the 1972 size respectively (Table 4). However, the rate of change between each time period differed. A number of factors may have caused the changes in wetland size. Land use and climate changes were proposed as the drivers of the change. Other factors such as the topography may have been involved though their influence was not investigated in this study.

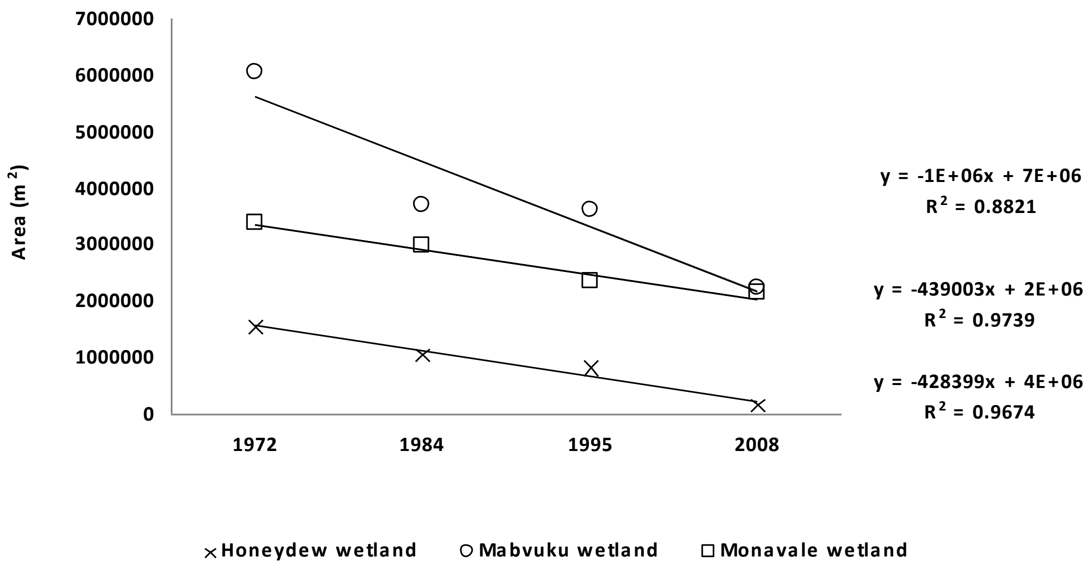


Figure 5: Change in the area of the Honeydew, Mabvuku and Monavale wetlands between 1972 and 2008 (Linear regression equations and R^2 shown).

The largest decrease in wetland size was noted for Honeydew wetland (Table 4). Between the periods 1972 to 2008 there was an 88% decrease in the area of this wetland. Much of this change in size (356%) occurred between 1995 and 2008.

This wetland was used by a commercial farm that has been in existence since 1970s. Hence, agriculture was likely to have contributed to the shrinkage of the Honeydew wetland. The change might have been due to intensive water abstraction and the movement of heavy agricultural machinery which may have compacted the soil leading to drying up of the wetland. Commercial agriculture using irrigation may cause the biggest impact on the wetland's rate of drying off. In Namibia for example, water abstraction and transfer is the most important issue threatening wetlands (Breen *et al.*, 1997). This large scale abstraction lowered the water table resulting in vegetation dying off. Without data on aquifer and abstraction rates in the Honeydew wetland it was impossible to confidently attribute the change in wetland size to water abstraction.

Faulkner and Lambert (1991) summarised the hydrological content of a study by the Dambo Research Unit (1987), in order to evaluate the impact of increase in dambo cultivation and irrigation on the water balance. The data was collected at Chizengeni dambo in Chihota communal area. The authors calculated, based on direct observation of meteorological variables, that cultivation without irrigation was unlikely to increase evaporative water use but irrigation would increase evaporation. The drop of groundwater levels varied with the irrigated dambo area as percentage of the total catchment area, and with changes in the crop coefficient. From their results Faulkner and Lambert (1991) recommended a safe limit on the extent of irrigated cultivation on a dambo of 10% of the catchment area or 30% of the dambo area which ever was smaller. Considering this assessment the wetland cultivation in the study was beyond sustainable levels.

The decrease in total area of Mabvuku wetland was approximately 63% from the period 1972 to 2008. Initial changes of 64% from 1972 to 1984 may have been associated with agricultural activity and perhaps also the construction of the sewage works. Recent change of 61% between 1995 and 2000 may have been a consequence of agricultural activity.

The main crops grown in the Mabvuku wetland were maize and sweet potatoes. Wetlands in countries such as Malawi, Zambia and Zimbabwe are mostly used for growing grain, tubers, vegetables and fruit (Scoones *et al*., 1996; Whitlow, 1985). For these to grow well the farmers create ridges to prevent water logging (FAO, 1998). Similar drainage system was observed in the Monavale and Honeydew wetlands. These ridges encourage runoff thereby reducing seepage into the soil. Hence, over time, water levels in the wetland may go down causing wetland shrinkage. Estimates of the loss of wetland in industrialized regions indicated that up to 60% of these have been destroyed in the last 100 years due to drainage, conversion, infrastructure development and pollution (Mitsch and Gosselink, 2000).

The decrease in total area of Monavale wetland was approximately 36% from the period 1972 to 2008. The largest decrease in the wetland size was between intervals 1984 and 1995 of 26% (Table 4). The main cause of the decrease may have been increase in settlements. The settlement land use increased from 16% in 1972 to 44% in 2008.

Monavale experienced the least reduction in wetland size. Using the 1972 as baseline, 63.9% of the wetland area remained in 2008. Subsistence agricultural activities flourished only recently between the periods 1995 to 2008. Therefore, it may be a reason why the wetland has dried up at the slowest rate as compared to the other two wetlands (Honeydew and Mabvuku). Another crucial factor to which the smooth decrease in overall size of Monavale may be attributed was that about 6% of the 2008 total wetland area was conserved by some local residents. Within the conserved area no agriculture or other forms of land conversion was allowed by the Monavale wetland committee. Results indicated that conservation of an area by limiting human activity may be critical to the conservation of the wetlands. Therefore, the recent use of the Monavale wetland for agriculture present a threat to the existence of that wetland.

Table 4: The area of Honeydew, Mabvuku and Monavale wetlands and the percentage change in area since the previous year measured

Year	Area (m^2)	Proportion of 1972 area (%)	Between interval % change in wetland area
Honeydew wetland			
1972	1560496	Baseline	Baseline
1984	1072370	68.7%	-46%
1995	822724	52.7%	-30%
2008	180368	11.6%	-356%
Mabvuku wetland			
1972	6057098	Baseline	Baseline
1984	3697100	61.0%	-64%
1995	3623605	59.8%	-2%
2008	2244022	37.0%	-61%
Monavale wetland			
1972	3383220	Baseline	Baseline
1984	2981482	88.1%	-13%
1995	2360621	70.0%	-26%
2008	2162178	63.9%	-9%

4.2 Rainfall patterns

There was a general decrease in rainfall in the study area between the period 1972 and 2008 (Figure 6). However, this decrease was not significant (Linear Regression; $p<0.05$). This lack of correlation does not mean that a change in the water balance was not involved in the drying up of the wetlands because not all factors involved were considered in this study. The contribution of such factors as temperature and evapo-transpiration many need to be investigated in future work. Furthermore, the system may have been affected by the increased episodes of droughts.

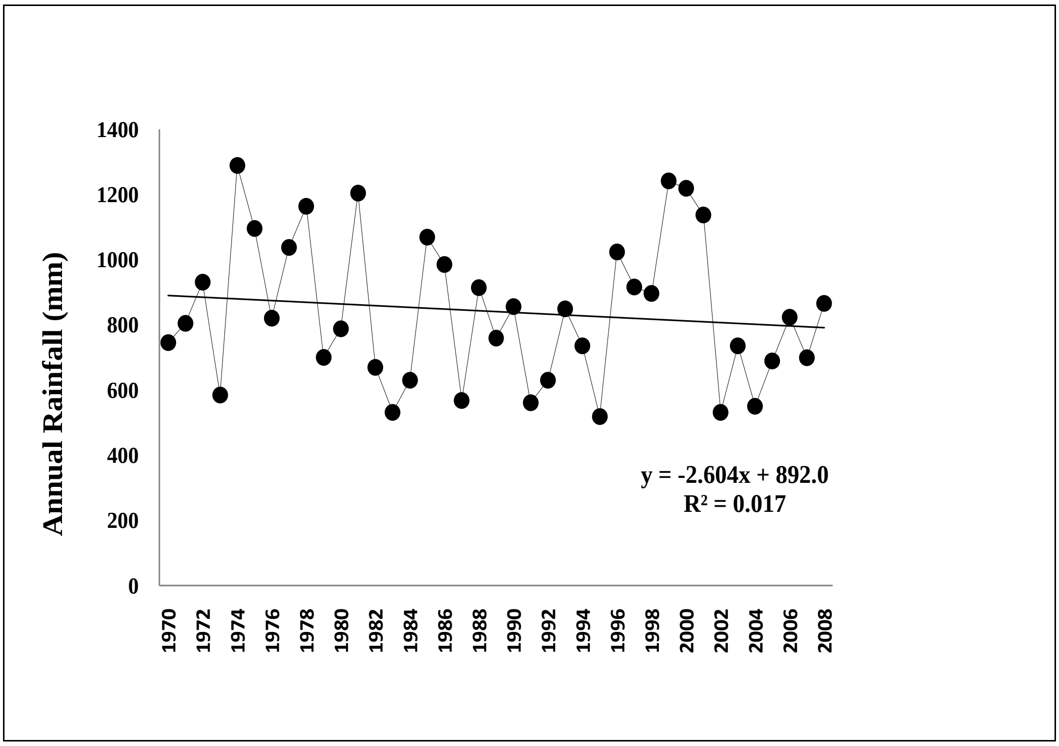


Figure 6: Rainfall patterns at Belvedere Rainfall Station in Harare from 1970 to 2008.

There were generally more periods with rainfall amounts that were less than the mean for the study period (1970 -2008) in the more recent years (Figure 7). Between the period 1972 and 1984 there were four periods with below the mean rainfall and four periods above the mean whilst from 1984 to 1995 period there were three main periods below the mean rainfall and two periods that were above the mean. The 1995 to 2008 period had 4 periods below mean rainfall and two above. This analysis indicated that there was an increase in the number of drier period in the more recent years. An increase in the number of years with low rainfall may have contributed to the drying up of the wetlands. The most severe drought in the study was experienced in 1992. The low rainfall episodes combined with anthropogenic activities may have lead to conversion of wetland to dryland. For example, during the dry periods the lands became accessible to agriculture preventing the wetland from recovering to the previous state following a wetter period.

The rainfall patterns analysis in the study area is important as the status of inland wetlands depends largely on changes in flow regimes and water levels. Arid and semi-arid areas are especially vulnerable to changes in precipitation as a decline in precipitation can dramatically affect wetland areas (IUCN, 1999). This study indicated a need to monitor the water balances of the Harare wetlands.

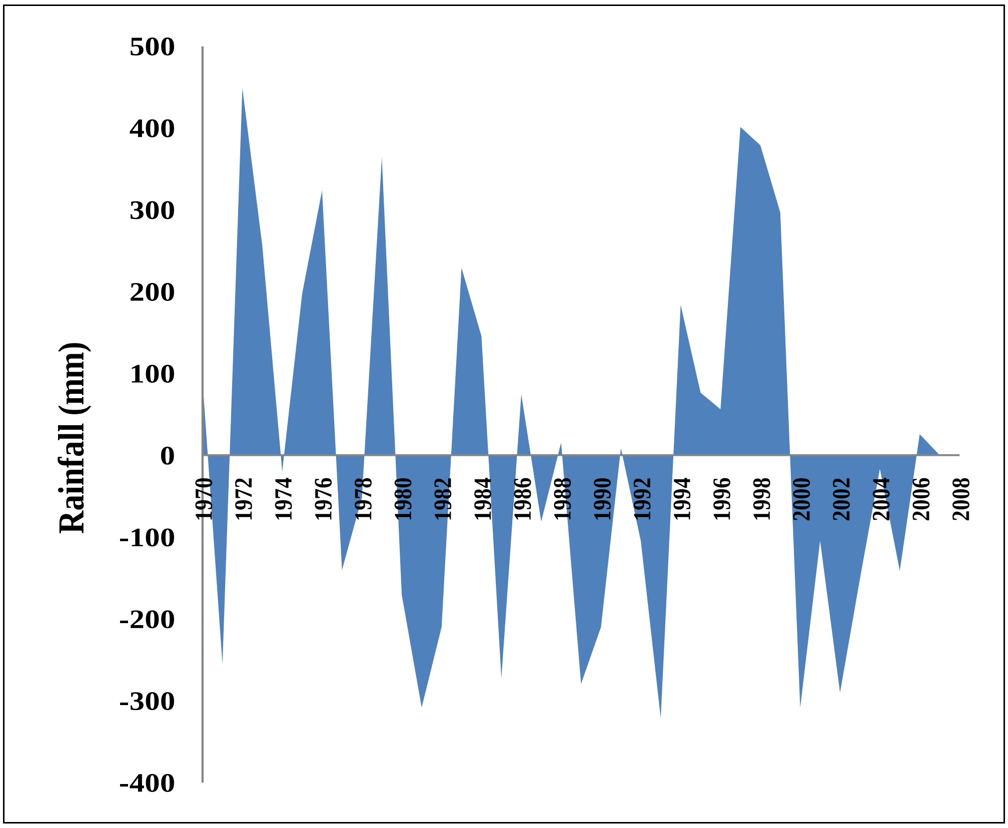


Figure 7: Harare Belvedere Rainfall deviation from the mean of rainfall from 1970 to 2008.

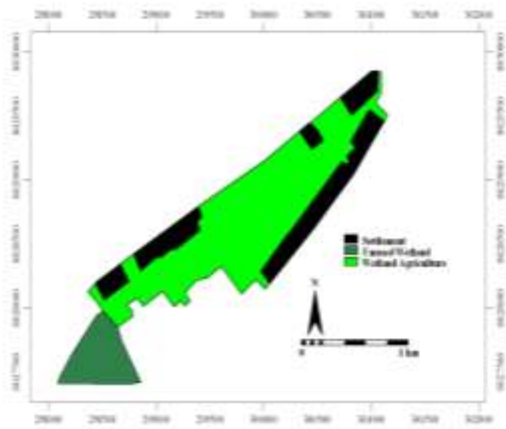
Major land use changes occurred in the Honeydew wetland (Figure 8). Most of the changes were in the amount of land used for agriculture and settlement. The area under settlement increased from 23% to 42% between 1972 and 2008 respectively (Table 5). Some of the increase in settlement area may have been due to changes in the number of greenhouses rather than permanent dwellings. This may explain the large reduction of land used for settlement from 54% in 1995 to 42% in 2008. The reduction in settled area was particularly noticeable on the commercial farming section of the wetland (Figure 8c and d).

The type of agriculture changed from wetland to dryland during the study period. In 1972, 64% of the honeydew wetland was under wetland cultivation but the area had reduced to 9% in 2008 (Table 5). There was no dryland agriculture in 1972 but by 2008, 47% of the wetland was under dryland agriculture. Therefore, dryland agriculture replaced wetland agriculture as the wetland dried up. The change to dryland agriculture must have increased the need for irrigation of crops particularly during the dry months. Increase irrigation may have exacerbated the drying process.

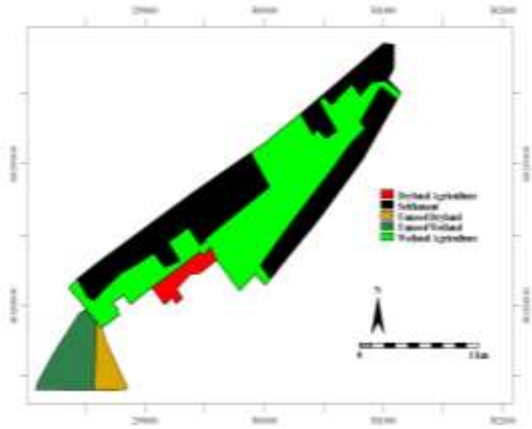
4.3 Land use changes within selected urban wetlands.

a) Honeydew Wetland

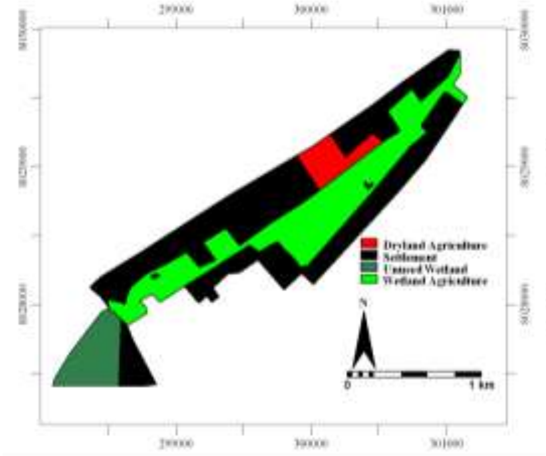
a) 1972



b) 1984



c) 1995



d) 2008

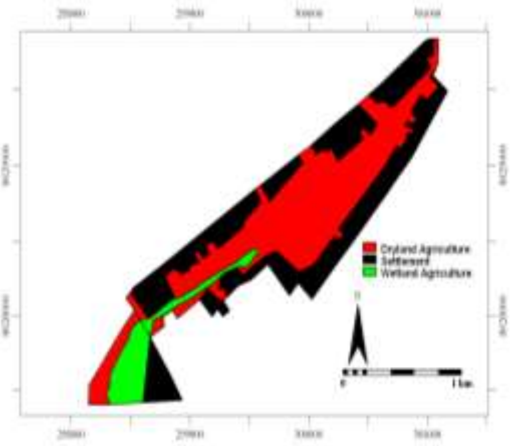


Figure 8: Maps of Honeydew showing land use pattern in a) 1972, b) 1984, c) 1995 and d) 2008

Another important change in land use occurred in the amount of unused wetland. Though 12% of the wetland was unused in 1972 there was no unused wetland in 2008 (Table 5). All the available land in this wetland was under agriculture or other forms of land use. The natural function of this wetland must have been severely affected by human use. Hence, in addition to reduction in the size of the Honeydew wetland there was an increase in the level of human utilization mainly for agriculture and settlement.

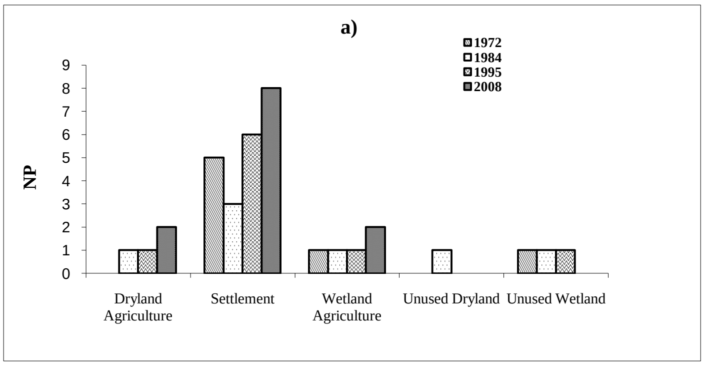
Table 5: Honeydew wetland class area, proportion of area and % change between time intervals for each year.

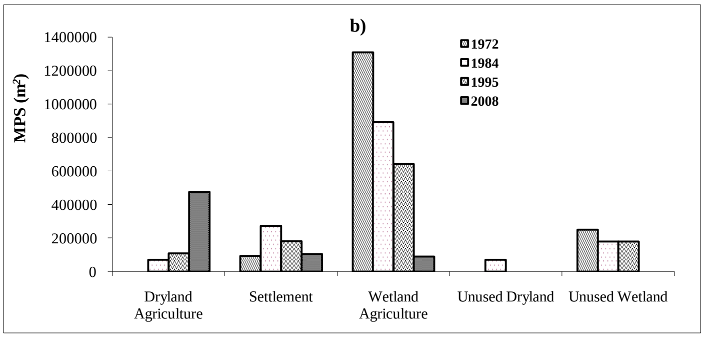
Year	Class Area (m^2)	Proportion of Class Area (%)	Between Interval Class area change (%)
Dryland Agriculture			
1972	0	0%	
1984	70921	3%	100%
1995	109223	5%	35%
2008	953093	47%	89%
Settlement			
1972	475300	23%	
1984	820775	40%	42%
1995	1098407	54%	25%
2008	846149	42%	-30%
Wetland Agriculture			
1972	1309434	64%	
1984	892792	44%	-47%
1995	642747	32%	-39%
2008	180368	9%	-256%
Unused Dryland			
1972	0	0%	
1984	71815	4%	100%
1995	0	0%	0%
2008	0	0%	0%
Unused Wetland			
1972	251062	12%	
1984	179577	9%	-40%
1995	179977	9%	0%
2008	0	0%	0%

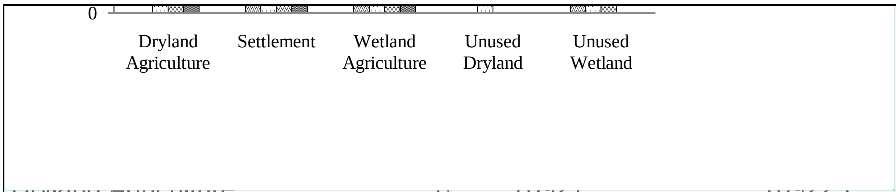
Settlement had the highest number of patches in the wetland and could be one of the major driving factors of drying up of the wetland. The other land uses have 1 or 2 patches however they may have larger perimeter (total edge) than the settlement class.

The MPS of wetland agriculture in Honeydew decreased sharply from 1972 to 2008 (Figure 9). This decrease was a reflection of the decrease in the wetland area. In contrast the MPS of dryland agriculture increased from 1972 to 2008 which reflected an increase in the area drying up in the wetland.

Settlement land use had the highest number of patches in the Honeydew wetland therefore was the main cause of fragmentation in this wetland. The number of patches of settlement land use increased from about 5 to 8 between the period 1972 and 2008 whilst the total edge during the same period increased from about 8000m^2 to 11000 m^2 (Figure 7).This indicated that the wetland experienced an increased exposure to the settlement which was likely to have increased the impact from human activity (Mapedza *et al*., 2003).







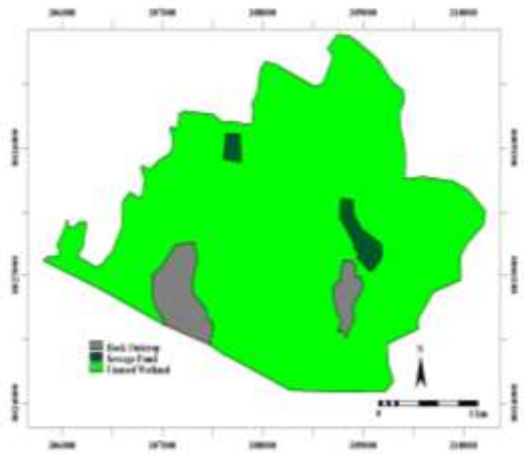
				51062.26
				2008
Dryland Agriculture	0	70921	109223	953093
Settlement	475300	820775	1098407	846149
Wetland Agriculture	1309434	892792	642747	180368
Unused Dryland	0	71815	0	0
Unused Wetland	251062	179577	179977	0
TLA	2035796			
	MPS			
Class	1972	1984	1995	2009
Dryland Agriculture	0	70921	109223	476547
Settlement	95060	273592	183068	105769

Figure 9: a) NP (Number of patches) b) MPS (Mean patch size) and c) Total Edge for each class area in Honeydew wetland.

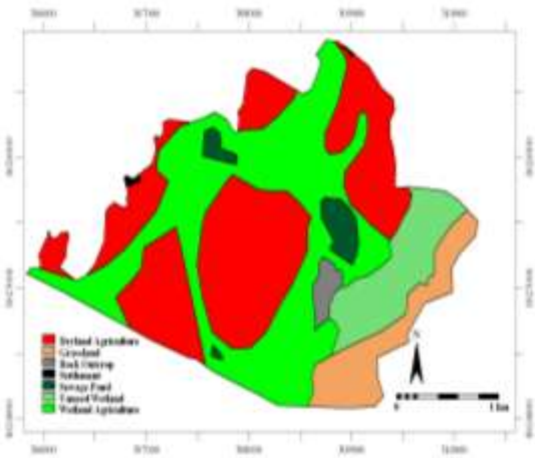
The patches used for wetland agriculture increased from one to two in 2008. The increase coincided with the time agricultural activity started at the southern section of the wetland. The observed change in the mean patch size of wetland agriculture was merely a reflecting the overall reduction in the area used for wetland agriculture.

b) Mabvuku Wetland

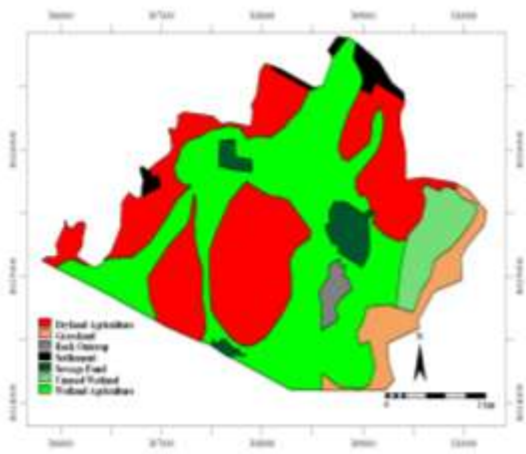
a) 1972



b) 1984



c) 1995



d) 2008

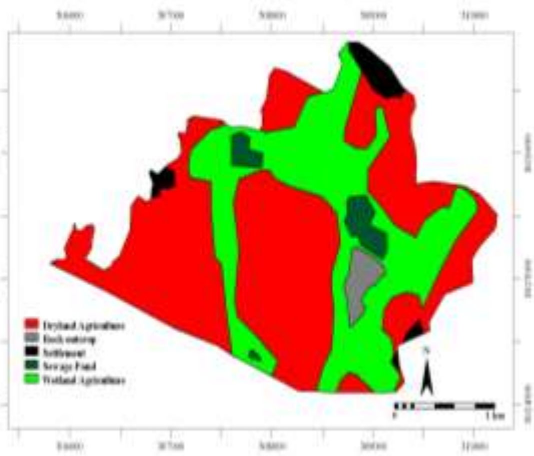


Figure 10: Maps of Mabvuku showing land use pattern in a) 1972, b) 1984, c) 1995 and d) 2008

The most striking change in the Mabvuku area was the increase in patches of land used for different purposes and the size of area under dryland agriculture (Figure 10). In 1972, there was no dryland agriculture in Mabvuku wetland. However, by 2008 dryland agriculture was carried out on more than half (58%) of the 1972 total wetland area. Wetland agriculture decreased by about 28% between 1995 and 2008 showing a decrease in wetland area. Dryland agriculture may have increased due to farming practises such as putting up drainage ridges as crops grown in the wetland do not favour standing water.

Settlement in the wetland increased as more Africans migrated into Harare, to provide for labour in the adjacent industrial area of Mabvuku (Zanamwe, 1997).

There was an increase in number of sewage ponds in the Mabvuku wetland between the periods 1972 and 1984 (Figure 10). From the aerial photographs, it was observed that one sewage pond complex was extended between 1984 and 1995. The decrease in sewage area between the period 1995 and 2008 from 4% to 3% respectively, may be because of reduced sewage inflow due to water cuts in Mabvuku residential area (Table 6).

Table 6: Mabvuku wetland class area, proportion area and % change between time intervals for each year.

Year	Class Area (m^2)	Proportion of Class Area (%)	Between Interval Class area change (%)
DrylandAgriculture			
1972	0	0%	
1984	2606640	39%	100%
1995	2472532	37%	-5%
2008	3825820	58%	35%
Grassland			
1972	0	0%	
1984	543504	8%	100%
1995	388716	6%	-40%
2008	0	0%	
Settlement			
1972	0	0%	
1984	11282	0.2%	100%
1995	139096	2%	92%
2008	172407	3%	19%
Sewage Pond			
1972	184020	3%	
1984	182382	3%	-1%
1995	231118	4%	21%
2008	184874	3%	-25%
Unused Wetland			
1972	6057098	91%	
1984	648956	10%	-833%
1995	368707	6%	-76%
2008	0	0%	
Wetland Agriculture			
1972	0	0%	
1984	2504641	38%	100%
1995	2866181	43%	13%
2008	2244022	34%	-28%

The dryland agriculture class had the highest number patches in the wetland (Figure 11a). In 1972, there were no patches of dryland agriculture but by 1984 there were 6 patches used for dryland agriculture. The number of patches reduced from 6 to 5 between 1984 and 1995 through merging of patches. This is evidenced by an increasing mean patch size of the dryland class area from about 500000m^2 in 1984 to about 900000m^2 in 2008 (Figure 11b). There was no wetland agriculture in 1972 but by 1984 it had developed.

Settlement class patches increased from 1972 to 2008. Number of patches of sewage pond class also increased in the same period as settlement land use was increasing. There was no unused wetland and grassland patches in 2008 showing that the whole Mabvuku wetland was under use. All land was then being utilised mostly for subsistence agricultural purposes.

The MPS and total edge (Figure 11a and b) for unused wetland class decreased sharply between 1972 and 1995. In 1972, unused wetland was a dominant land class implying that the wetland was not being affected through anthropogenic activities. Wetland agriculture MPS and Total edge on the other hand increased sharply approximately from 0m^2 to 2244000m^2 and 0m to 22865m in 1972 to 2008 respectively.

c) Monavale Wetland

The Monavale Wetland had changed from a mostly natural wetland to a state where agricultural and settlement land use were dominant (Figure 12).

There was a sudden conversion of all the unprotected wetland area to wetland agricultural use between 1995 and 2008 (Table 7). The area involved was 43 % of the whole wetland. Kamusoko and Aniya, 2007 also observed that there was significant spatial expansion in agricultural land use in Bindura District of Zimbabwe between 1970 and 2006. Prevailing socio economic situation in Zimbabwe may have led people to cultivate in the wetland as a livelihood strategy.

By 1984, a portion of the wetland which was approximately 6% of the total wetland area was excised and protected by local residence. Any land use that was deemed to compromise the wetland's integrity was prohibited. The size of the protected area did not change throughout the study period. To compliment this protection a shade for a wetland ranger was developed in the wetland although it covers an insignificant area.

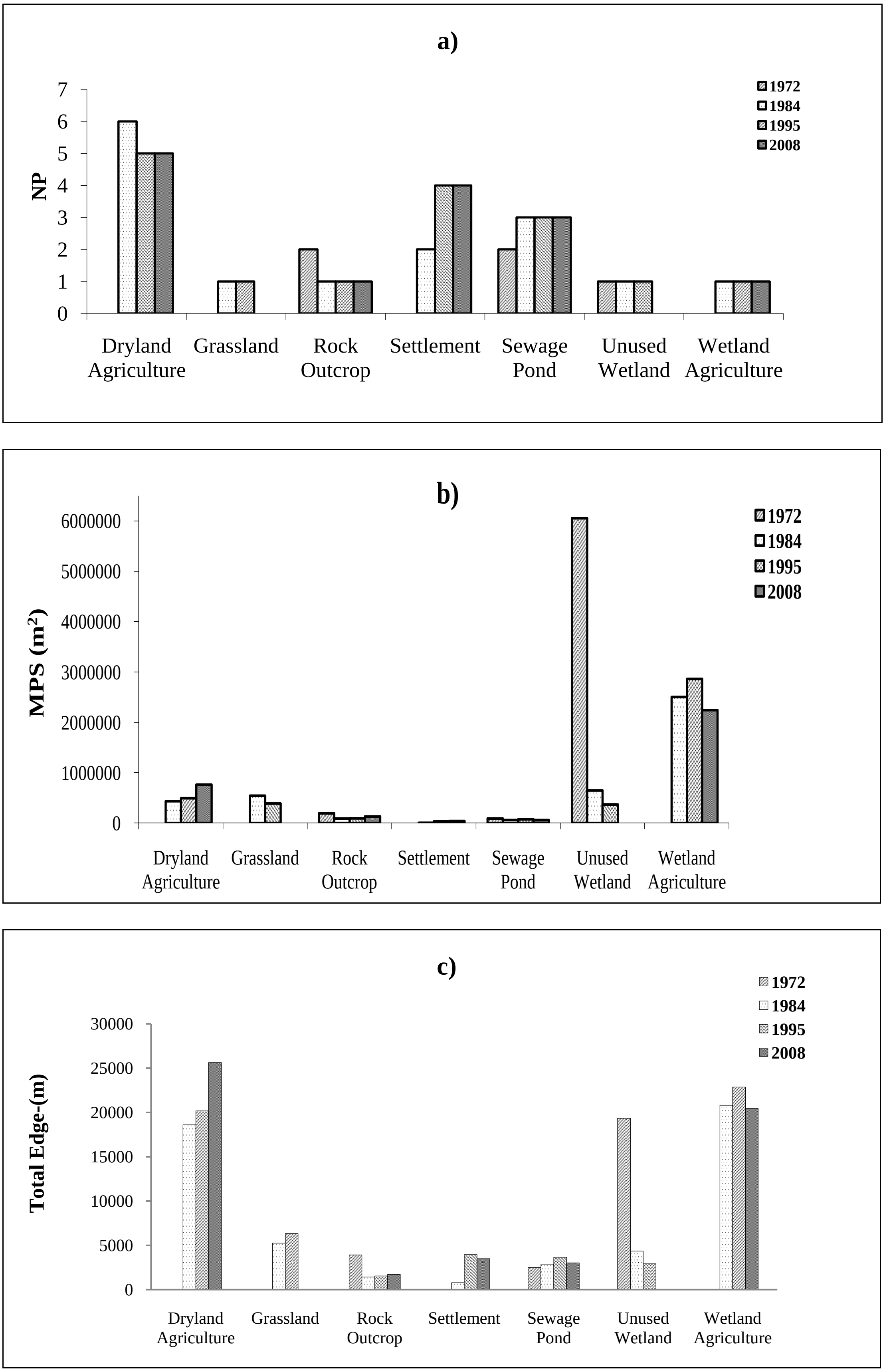
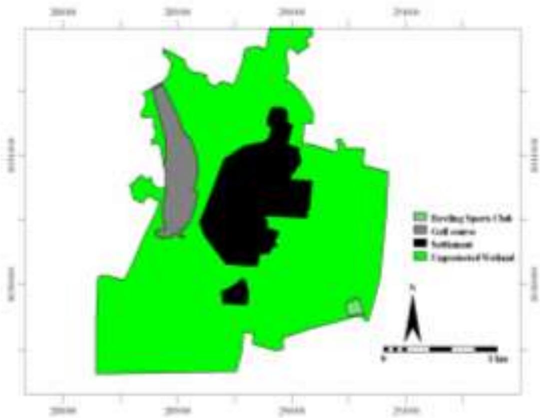
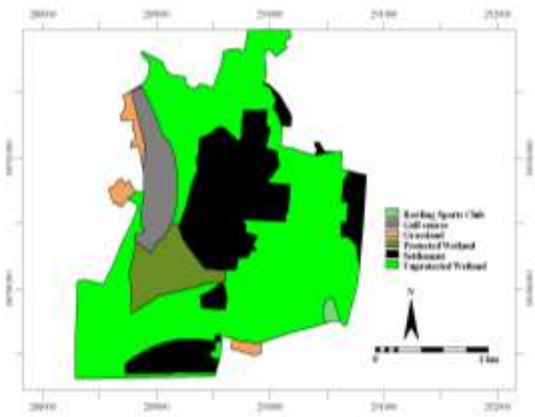


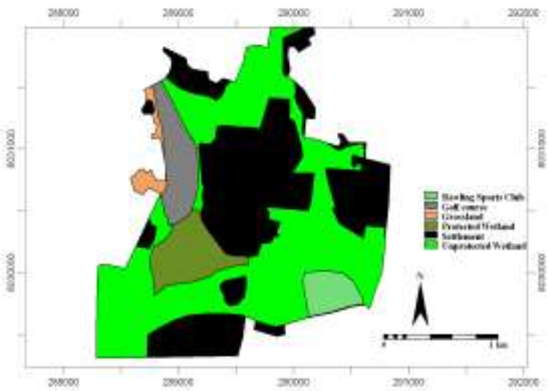
Figure 11: a) NP (Number of patches) b) MPS (Mean patch size) and c) Total Edge for each class in Mabvuku wetland.

a) 1972 **b) 1984**





c) 1995 **d) 2008**



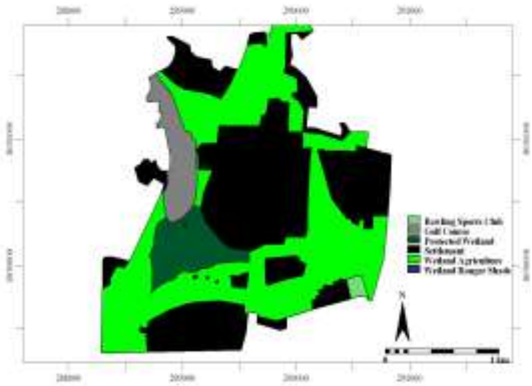


Figure 12: Maps of Monavale wetland showing land use pattern in a) 1974, b) 1984, c) 1995 and d) 2008

The area taken by settlement land use increased gradually during the study period from 16% to 44% of the total wetland area (Table 7). Construction of houses led to a direct reduction of the wetland area. Settlement in urban areas is generally associated with drainage systems which subsequently lead to drying off of the wetland.

The number of patches for all land uses except settlement and grasslands varied from zero to 1 (Figure 13). Most patchy land use was the settlement land use which had 15 patches in 2008. Figure 11a showed that from 1972 to 2008 the number of patches in the settlement land use class increased steadily from 3 to 15. Settlement therefore was one land use that contributed to fragmentation of Monavale wetland. Kamusoko and Aniya, 2007 also found that settlement in Bindura District, Zimbabwe significantly expanded in spatial terms between the 1970 and 2006.

Table 7: Monavale wetland class area, proportion of 1972 area and % change between time intervals for each year.

Year	Class Area (m^2)	Proportion of Class Area	Between Interval Class area change
Bawling Sports Club			
1972	15571	0.4%	Baseline
1984	18952	0.4%	18%
1995	141083	0.4%	87%
2008	23855	0.5%	-491%
Golf course			
1972	261306	6%	Baseline
1984	279438	6%	6%
1995	253173	6%	-10%
2008	242649	6%	-4%
Grassland			
1972	0	0%	Baseline
1984	94870	2%	100%
1995	64362	1%	-47%
2008	0	0%	0%
Protected Wetland			
1972	0	0%	Baseline
1984	275323	6%	100%
1995	281264	6%	2%
2008	282613	6%	0%
Settlement			
1972	694683	16%	Baseline
1984	1072314.203	25%	35%
1995	1613467.954	37%	34%
2008	1922197	44%	16%
Unprotected Wetland			
1972	3383220.33	78%	Baseline
1984	2611289.721	60%	-30%
1995	2014994.922	46%	-30%
2008	0	0%	0%
Wetland Agriculture			
1972	0	0%	Baseline
1984	0	0%	0%
1995	0	0%	0%
2008	1879565	43%	
Wetland Ranger Shade			
1972	0	0%	Baseline
1984	0	0%	0%
1995	0	0%	0%
2008	724	0.02%	

The MPS and total edge for wetland agriculture suddenly increased in 2008 reflecting the sudden change to this land use (Figure 13c & d). The settlement total edge more than tripled from 1972 to 2008. Although settlement land use had the highest number of patches its MPS was about 400 000m^2 which was far less than the MPS for wetland agriculture. This was because the wetland agriculture land use occupied a single large patch. In future this high level of utilization for agriculture and settlement may exacerbate drying up of the wetland.

4.4 Socio economic factors and fragmentation.

One common observation in this study was that agriculture use in all the wetlands increased during the study period. What was observed in this study is not unique to this part of the world. In many parts of Africa, agricultural use of wetlands has increased as more and more people have been forced to seek new livelihood strategies, as a result of environmental degradation of other farmlands and population pressure (van Koppen *et al*., 2007).

Protection of wetlands in Zimbabwe is under the Environmental Management Act 20-27. The Act states that, "no person shall except in accordance with the express written authorisation of the Agency given in consultation with the Board and the Minister responsible- reclaim, drain, disturb(drilling, tunnelling in a manner with adverse effect impact on animal or plant there in) or introduce any exotic animal or plant species". Although government policies in Zimbabwe recognise the significance of local wetland management practises, and the wider value of wetlands, implementation problems have resulted in the intensification of wetland agriculture in an attempt to create more economically productive land (Matiza and Crafter, 1994).

Zimbabwean economy and socio economic development is land based agriculture still constitute major economic activities (Mannion, 2002; Lambin *et al.*, 2003). Consequently, the landscape is fragmented due to such factors.

People's long association with wetlands means that indigenous systems of wetland management and utilisation are found throughout the developing world (Dixon and Wood, 2007). In urban areas of Harare there seems not be any indigenous system for management, as evidenced by the fact that the subsistence farmers may not even know the farmer next to them. There is no communication amongst the farmers anyone can come in and clear their portion of land and grow crops. For these urban wetlands it is difficult to manage as some users are not easily identifiable like in rural areas. For instance in the Mabvuku wetland some users come as far as Epworth whilst in Monavale some users come as far as Warren Park. Such wetlands do not have a discrete community therefore this institutional arrangement has to be changed.

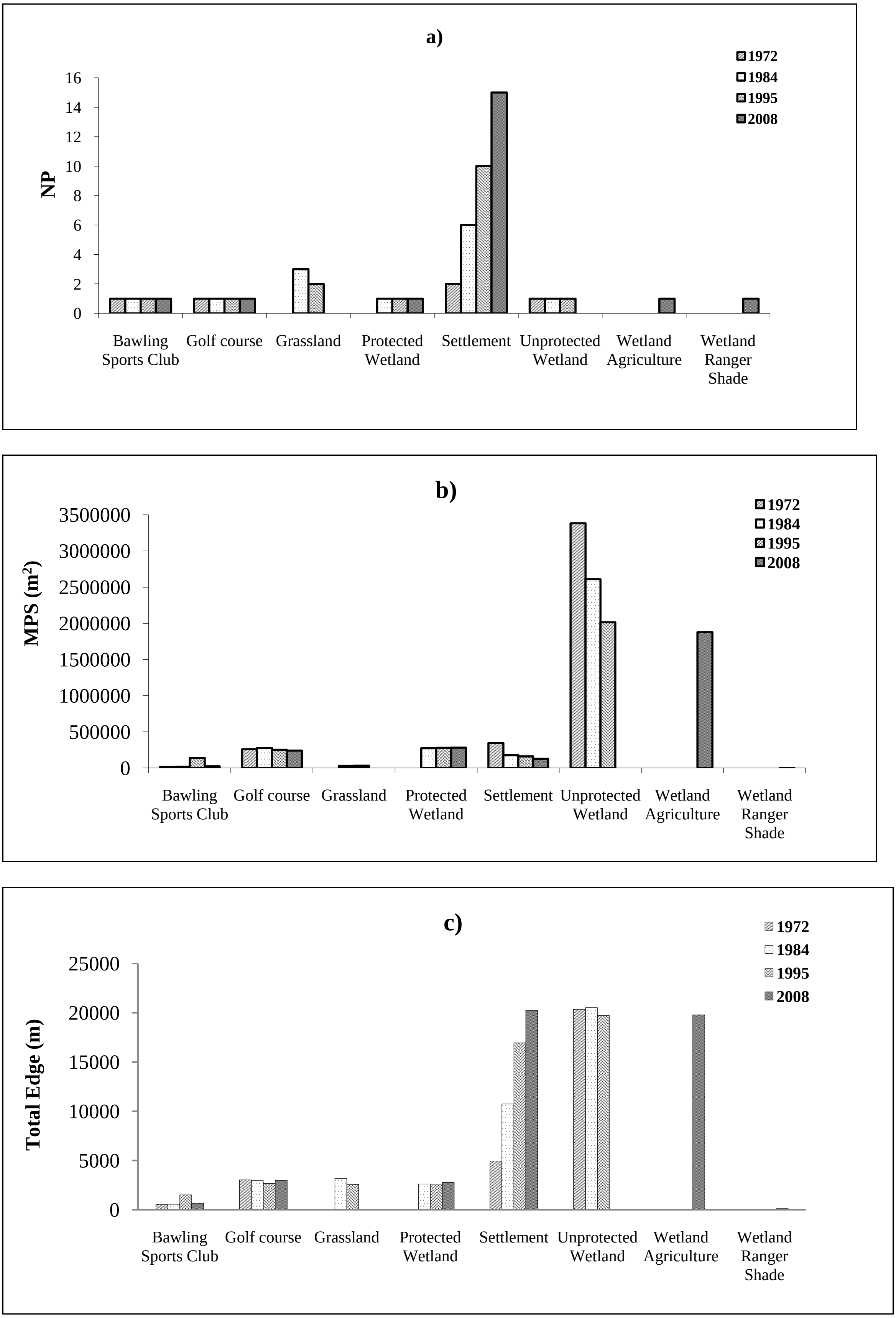


Figure 13: a) NP (Number of patches) b) MPS (Mean patch size) and c) Total Edge for each class in Monavale wetland.

4.5 Water quality comparison

4.5.1 Water quality within wetland's land uses.

a) Honeydew wetland

Samples taken in April showed that subsistence agriculture had higher TDS, conductivity, ORP and phosphates levels than commercial agriculture land use (Table 8). Higher ORP levels in subsistence agriculture may be attributed to the higher organic content of the soils compared to soils under commercial agriculture. Subsistence agriculture in this wetland is a recent land use having cropped up between 1995 and 2008 therefore the soils may still be more fertile. However, commercial agriculture water had higher TN levels of 4.54mg/l compared to 2.2mg/l in water from the subsistence agriculture area. Results for June samples were similar to samples taken in April with TDS, conductivity, ORP, TP levels higher in subsistence agriculture than in commercial agriculture except for TN. However, these differences were not significant (Table 8).

Table 8: Honeydew wetland mean and standard deviation (in brackets) of water quality parameters (Commercial agriculture n=5, Subsistence agriculture n=3).

Condition	TDS mg/l	Conductivity µs/cm	Salinity	PH	ORP mV	Phosphates mg/l	Nitrogen mg/l
April							
Commercial Agriculture	672(123)	692(168)	0.1(0.1)	7.5(0.9)	-14(13)	0.6(0.3)	4.5(6.1)
Subsistence Agriculture	703(706)	722(62)	0.1(0.1)	6.7(0.4)	-21(7)	0.9(0.7)	2.2(1.9)
Kruskal-Wallis Test (p)	0.655	0.881	0.491	0.180	0.177	0.764	0.655
June							
Commercial Agriculture	674(102)	725(110)	0.1(0.1)	6.8(0.3)	-20(18)	0.3(0.1)	2.9(1.5)
Subsistence Agriculture	714(136)	766(147)	0.1(0.1)	6.8(0.5)	-25(23)	0.3(0.1)	2.9(3.2)
Kruskal-Wallis Test (p)	0.456	0.456	0.528	1.000	0.881	0.230	0.453

b) Mabvuku wetland

Samples taken at the sewage ponds had a highest mean of 880mg/l, 917.5μs/cm and 0.25 for TDS, conductivity and salinity respectively compared to points downstream and upstream of sewage ponds for samples collected in both April and June (Figure 14). Figure 14 showed how the sewage pond samples clearly stood out from the rest in April. TN levels at the sewage ponds also were higher in both sampling months than downstream sewage and upstream sewage land use. Studies by Phiri, 1998, showed that organic content from leaking or spilling sewage could elevate conductivity in urban areas. Moyo, 1997 also found that TP levels in water increase as discharge of sewage increases. ORP levels at sewage ponds, downstream sewage ponds and upstream sewage ponds for June were generally higher than in April.

Table 9: Mabvuku wetland mean and standard deviation (in brackets) of water quality parameters (Downstream sewage n= 3; Sewage n = 2; Upstream sewage n =2).

Condition	TDS mg/l	Conductivity µs/cm	Salinity	PH	ORP mV	Phosphates mg/l	Nitrogen mg/l
April							
Upstream sewage	62 (58)	66 (63)	0.0(0.0)	6.2(0.6)	-46(32)	0.6(0.4)	0.5 (10.2)
Sewage	880 (283)	918 (361)	0.3 (0.2)	6.6(0.0)	-18 (14)	0.9 (0.4)	8.9(10.8)
Downstream sewage	78 (58)	84 (63)	0.0 (0.0)	5.8 (0.6)	-62 (31)	1.0 (0.4)	6.5 (10.2)
Kruskal-Wallis Test (p)	0.018	0.018	0.030	0.907	0.118	0.327	0.118
June							
Downstream sewage	168(121)	180(130)	0.0(0.0)	5.8(0.25)	-81(6)	3.8(3.7)	3.3(1.4)
Sewage	152(62)	162(64)	0.0(0.0)	5.9(0.0)	-81(17)	1.9(0.1)	4.4(1.0)
Upstream sewage	116(42)	124(44)	0.0(0.0)	5.6(0.2)	-78(2)	3.4(3.8)	1.7(1.1)
Kruskal-Wallis Test (p)	0.738	0.738	1.000	0.247	0.915	0.779	0.137

There was significant difference in TDS (p=0.018), conductivity (p=0.018) and salinity (p=0.03) within the Mabvuku wetland for samples taken in April using Kruskal Wallis test (Table 9). There was no significant difference in all the parameters measured in June for Mabvuku wetland.

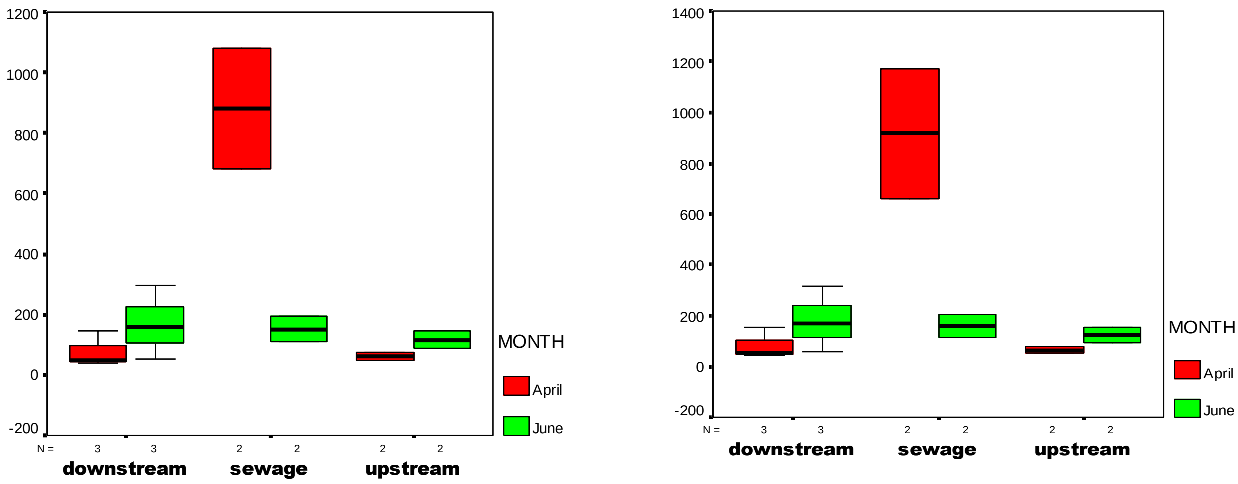


Figure 14: TDS (mg/l) and conductivity (μs/cm) in the Mabvuku wetland.

Sewage ponds built in this wetland had an effect on water quality which may have affected the general ecosystem health. Ntengwe, (2006) cites some sources contributing to elevated conductivity as being natural sources as geology and anthropogenic sources such as sewage effluent discharges, urban and industrial runoff. Building sewage ponds in the wetland may be a strategy to reduce pollution as wetlands can purify the effluent. The fact that the downstream sites showed less effect of the sewage ponds may attest the importance of the wetland in absorbing the pollutants. However, this is only possible up to a certain levels of effluent discharge. The wetland can be designed and managed for more efficient use in sewage processing.

c) Monavale wetland

Protected area had lower TDS and conductivity levels compared to subsistence agriculture in both sampled months (Table 10). ORP and TP levels were higher in protected area than in subsistence agriculture in both sampled months. More organic matter content is found in the protected area than in subsistence agriculture.

There was significant difference in total nitrogen (p=0.024) in water samples taken in April from the protected sites and subsistence agriculture sites in the Monavale wetland. The protected site had more phosphorus levels as these accumulate naturally in the conserved site whilst the phosphates levels in the subsistence agriculture may be depleting due to crop uptake.

There was significant difference in pH (p=0.035) and oxidation reduction potential (ORP) p=0.025 between the protected site and subsistence agriculture for the June samples from Monavale wetland (Figure 15).

Table 10: Monavale wetland mean and standard deviation (in brackets) of water quality parameters (Protected site n=5; subsistence agriculture n=3).

Condition	**TDS mg/l**	**Conductivity µs/cm**	**Salinity**	**PH**	**ORP mV**	**Phosphates mg/l**	**Nitrogen mg/l**
April							
Protected site	385(406)	414(436)	0.1(0.1)	6.1(0.5)	-42(27)	0.5(0.2)	1.4(1.4)
Subsistence Agriculture	459(47)	491(53)	0.0(0.0)	6.4(0.3)	-28(15)	0.1(0.2)	0.0(0.0)
Kruskal-Wallis Test (p)	0.180	0.180	0.439	0.456	0.655	0.053	0.024
June							
Protected site	485(55)	516.4(63.5)	0.0(0.0)	6.4(0.2)	-27(11)	0.8(0.9)	1.0(1.8)
Subsistence Agriculture	469(98)	505(106)	0.0(0.0)	6.9(0.3)	-10(3.1)	0.5(0.2)	1.9(1.0)
Kruskal-Wallis Test (p)	0.456	0.655	1.000	0.035	0.025	0.546	0.177

The protected site had a higher ORP value compared to the subsistence agriculture. This may be due to the differences in organic matter content of soils in the two types of land uses. Points with higher ORP values indicate that there is more organic matter in them (Younger, 2007). Therefore in the subsistence agriculture section there was less organic matter content compared to the protected site which left ‘undisturbed’ accumulated organic matter.

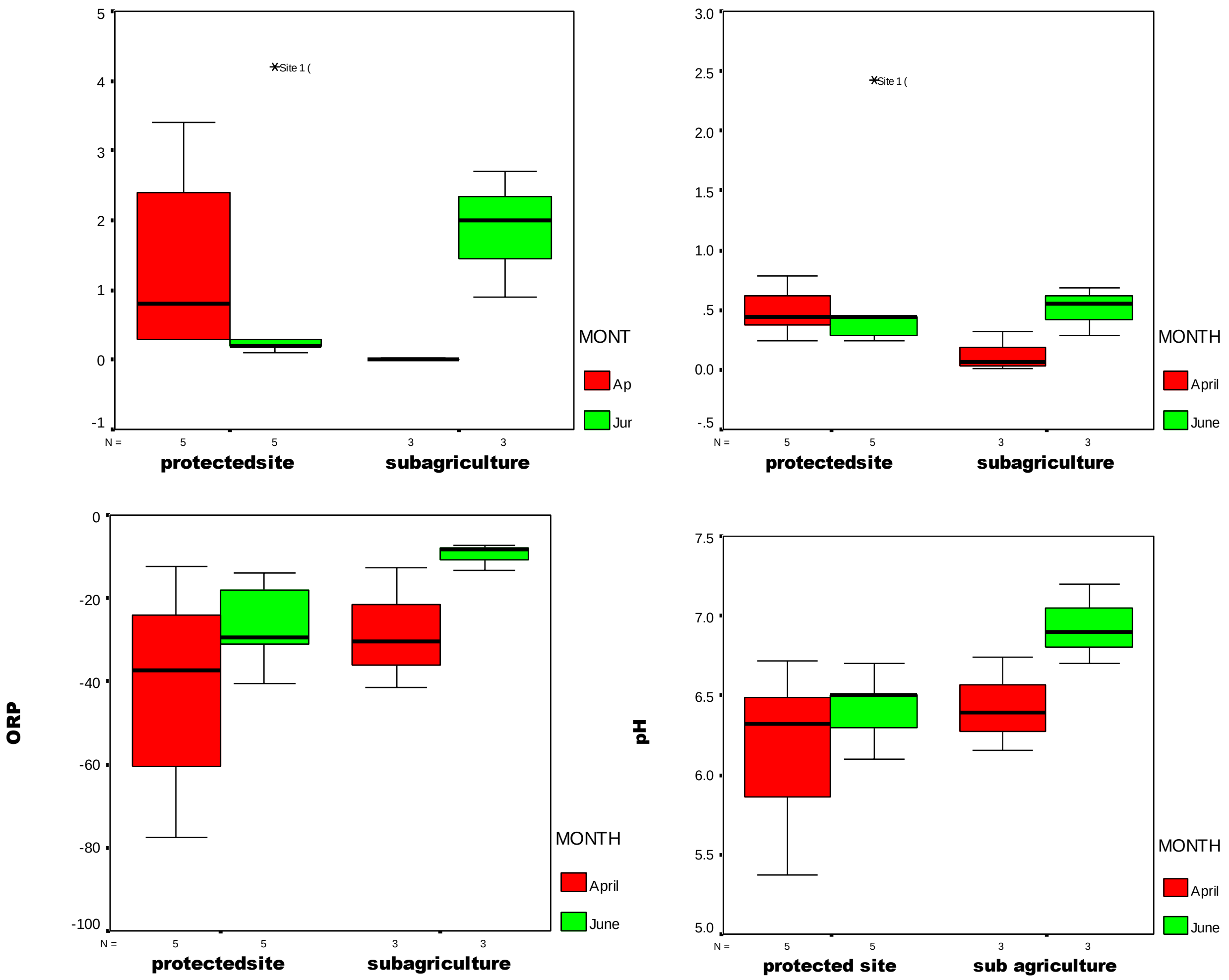


Figure 15: Total nitrogen (mg/l), Total phosphorus (mg/l), ORP (-mV) and pH in Monavale wetland.

4.5.2 Wetland water quality comparisons

There was significant difference in TDS (p=0.025), conductivity (p=0.026), salinity (p=0.04), pH (p=0.009), and phosphates (p=0.034) between the three wetlands for the April samples (Figure 16 & Table 11). More pronounced differences in these water parameters were observed in June. Unlike in the April comparison, there was a significant difference between wetlands in ORP (p= 0.001). In both sampling dates there was no significant difference in TN.

Honeydew wetland had higher TDS and conductivity levels compared to the other two wetlands, Monavale and Mabvuku (Figure 16). This may be a result of the clay soils in this wetland. Mabvuku had the least TDS and conductivity as the water may have been filtered in the sandy soils characterising the wetland.

Higher salinity levels were also recorded in Honeydew wetland compared to the other two wetlands (Table 11). This may be due to use of fertilizers and irrigation. This finding was similar to those by Murty, 1998 who found that there were higher salinity levels in irrigated agriculture than other land uses in India. Salt build up in the root profiles could occur over a period of time. This is because during crop growth water evaporates leaving the salts in the root zone. High water tables at some locations could bring the salts to the surface. In some locations groundwater contains large amounts of salts and use of such waters for irrigation accelerates the salt up in the soil profiles. Salts could also be brought in through sub-surface inflows (Murty, 1998).

Honeydew and Mabvuku wetlands had higher phosphates levels compared to Monavale wetland for April water samples (Figure 16). In Honeydew fertilisers are applied both in the commercial and subsistence agricultural land use. In Mabvuku, the sewage ponds contained effluent high in phosphates. Furthermore, industrial area upstream of Mabvuku may also be source of pollution in this wetland through runoff. Phosphates in June where found to be highest in Mabvuku wetland compared to Monavale and Honeydew wetland (Figure 16). TP levels for Mabvuku may relatively be higher especially for the June samples this may be due to sewage ponds seepage into groundwater. Harrison (1990), remarks that phosphates are very high in waste waters. According to Nhapi, *et. al.* (2002), urban and rural agriculture cause severe stress on water quality due to nutrient enrichment.

Table 11: Wetland comparisons mean and standard deviation (in brackets) (Honeydew n=8; Mabvuku n=7; Monavale n=8).

Wetland	TDS	Conductivity	Salinity	PH	ORP	Phosphates	Nitrogen
	Mg/l	μs/cm			mV	mg/l	mg/l
April							
Honeydew	683(101)	703(132)	0.1(0.1)	7.2(0.8)	-16(11)	0.7(0.4)	3.7(4.9)
Mabvuku	302(413)	317(438)	0.1(0.1)	6.1(0.5)	-45(28)	0.9(0.3)	5.5(8.2)
Monavale	413(311)	443(333)	0.1(0.1)	6.3(0.5)	-37(23)	0.3(0.3)	0.9(1.3)
Kruskal-Wallis Test (p)	0.025	0.026	0.040	0.009	0.065	0.034	0.108
June							
Honeydew	689(108)	741(116)	0.1(0.1)	6.8(0.4)	-22(19)	0.3(0.0)	2.9(2.0)
Mabvuku	148(80)	159(85)	0.0(0.0)	5.7(0.2)	-80(8)	3.1(2.8)	3.1(1.5)
Monavale	479(67)	512(75)	0.0(0.0)	6.6(0.3)	-20(12)	0.7(0.7)	1.3(1.5)
Kruskal-Wallis Test (p)	0.000	0.000	0.001	0.001	0.001	0.001	0.074

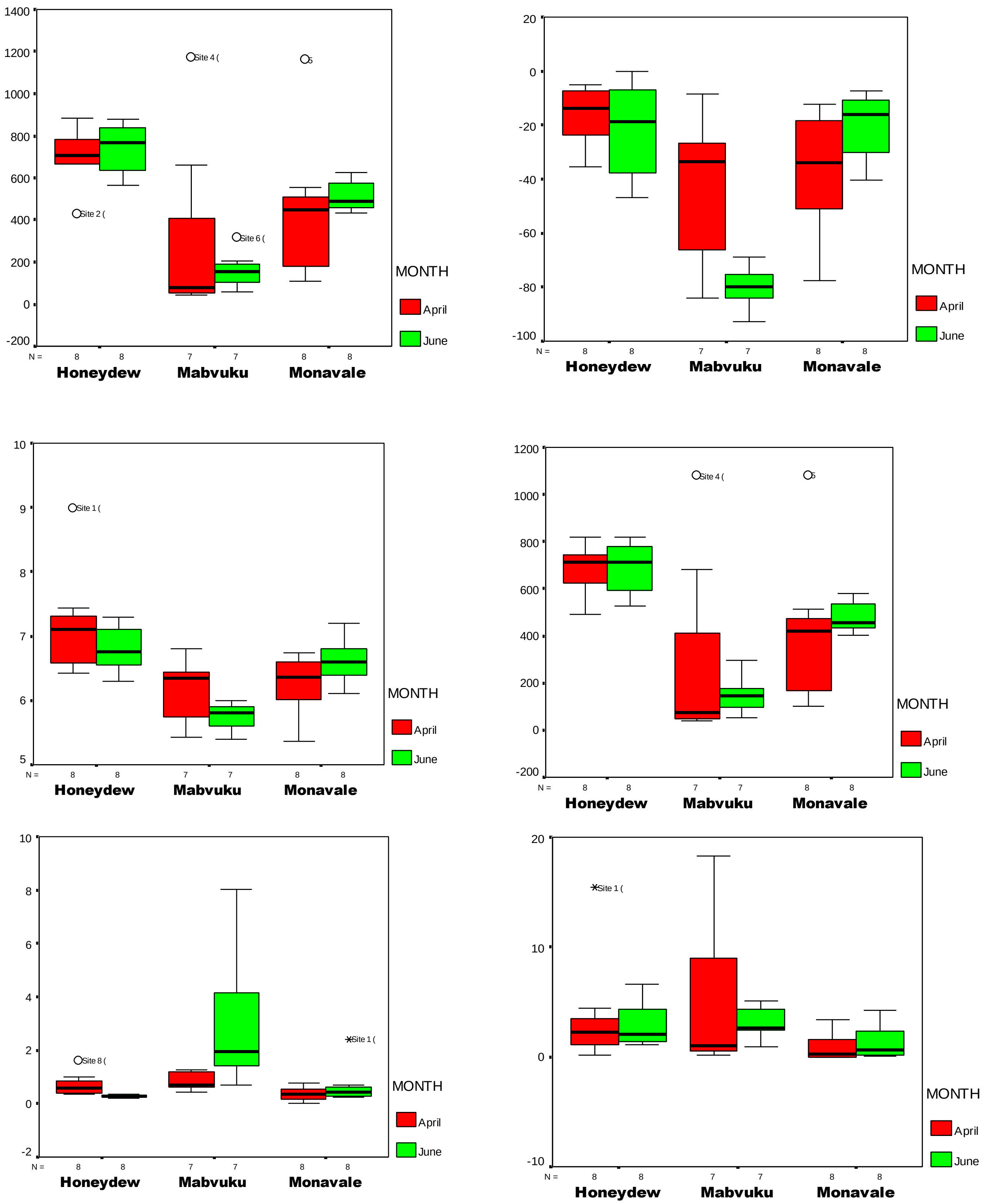


Figure 16: Conductivity, ORP, pH, TDS, Total phosphorus and Total nitrogen for April and June samples in all wetlands.

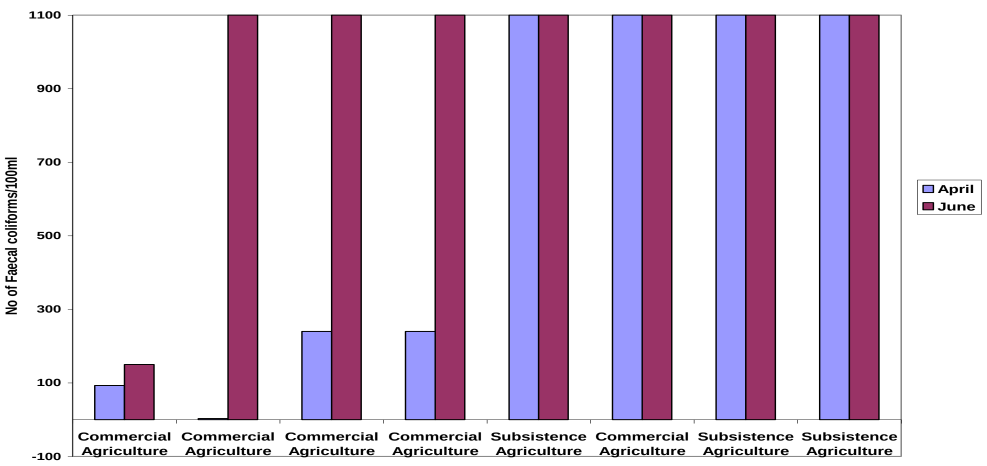
4.5.3 Faecal coliform count

There was generally high level of faecal contamination of water from all wetlands. Half the water samples taken in April were in the very high risk category (>1000) for drinking water (WHO, 1997). Low risk (1 -10) to intermediate risk (10-100) coliform counts were obtained from two sampling points upstream of sewage works, and the deep well in Mabvuku, 2 upstream sampling points at Honeydew and 2 points in the protected section of Monavale wetland (Figure 17). Only one sample in the protected section of the Monavale wetland was in the very high risk category. Whilst all the three water samples from the subsistence agriculture section of Monavale were in the very high risk category. In Mabvuku, wetland the upstream points had faecal coliform counts not detrimental to human health compared to the downstream sites 2, 3, 4 and 6 which all had an MPN count of 1100+. This indicated that sewage was an important source of water contamination.

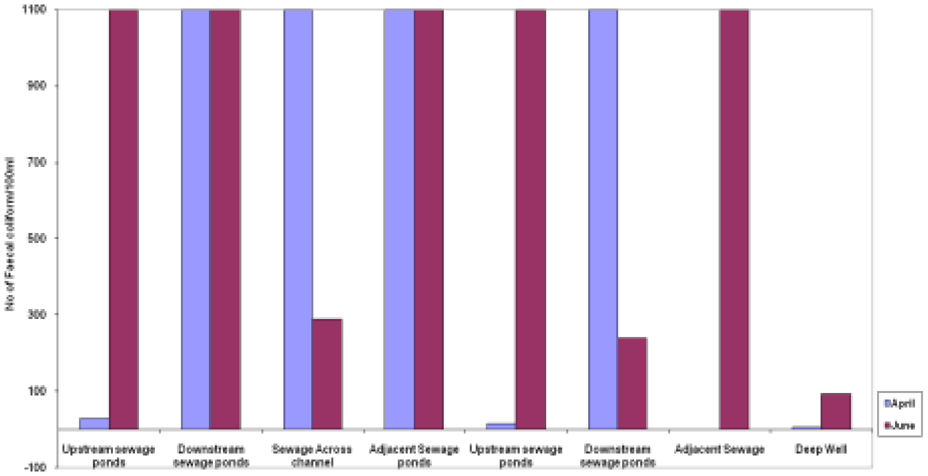
In June, there were 3 samples in the intermediate risk class; 2 samples from Monavale wetland in the protected site and 1 sample from the deep well in Mabvuku. High risk levels of faecal coliforms were found in point 3 and 8 of Monavale, point 3 and 6 of Mabvuku and point 1 of Honeydew. Very high risk levels of faecal coliform where recorded at all sampling points of Honeydew except at point 1. All samples except 3 and 6 had very high risk faecal coliform levels in Mabvuku. Again, one sampling point (4) in the protected site of Monavale had very high risk levels of faecal coliform. This site was near an established path used by people to pass through the wetland. Generally the protected area had the lowest faecal coliform counts. Sampling points 6 and 7 of Monavale had very high risk faecal coliforms and these were in subsistence agriculture area. The faecal coliform levels were mostly beyond the maximum allowable levels in the subsistence agriculture land use in Honeydew. There was a gradient of increasing faecal coliform levels from the upstream (section 48c of the farm) going down to the subsistence agriculture land area in April. This could be due to unavailability of toilets or runoff in the part of the wetlands used for commercial and subsistence agriculture. Therefore, human contact appears to be associated with faecal coliform contamination and the matter need to be addressed.

Water with MPN of 1100+ is considered to be of very high risk to human health, according to WHO standards. Contaminated water contains many pathogens (SCA, 2002) and at high levels of MPN there is also higher risk from other types of pathogens in the water. A study by Barson and Dalu, (2008) in Mabvuku showed that raw sewage discharge caused microbial pathogens and protozoan microorganism contamination of river water. The faecal coliform levels in the downstream sites in Mabvuku wetland may have reached detrimental levels because of seepage and flow from the sewage ponds. In addition, in the absence of toilets in the wetland, people may have relieved themselves in the wetland. The upstream site in June had high coliform counts showing that there were other upstream sources of contamination. This calls for further investigation on the pollution sources in this area.

a) Honeydew Wetland



b) Mabvuku Wetland



c) Monavale wetland

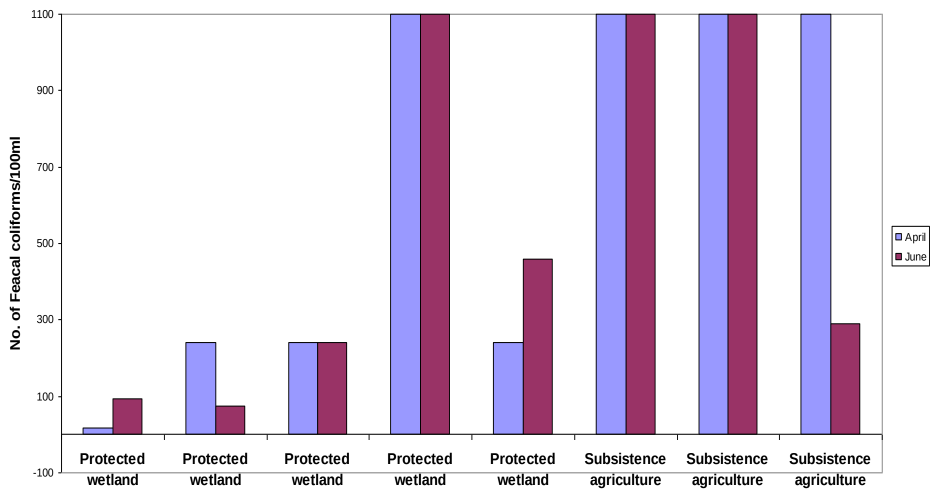


Figure 17: Feacal coliform per 100ml in a) Honeydew, b) Mabvuku and c) Monavale sampled sites (Sampling points arranged in ascending order).

Feacal coliforms are not considered a critical water parameter in determining the suitability for agricultural use (Fipps, 2003; Ayers and Westcot, 1994). However, water taken up by plants should have a faecal coliform count less than 1000/100ml according to WHO guidelines especially for crops taken raw/uncooked (Tyrrel, 1999). Therefore, vegetable gardens and sugarcane grown near sewage ponds in the Mabvuku wetland are a cause of concern. During the study it was observed that water from shallow wells was used for watering vegetables. Contaminated crops were likely to be marketed to unsuspecting consumers. The provision of a deep well was certainly beneficial to the Mabvuku residence in that this deep well had coliform counts of low to intermediate risk.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

- The study revealed that the Harare urban wetlands were disappearing, degraded and fragmented mainly because of agriculture and settlement within the wetlands. Commercial agriculture had the biggest impact on the wetland's rate of drying off. Honeydew had the highest rate of shrinking in size of 88%, between the period 1972 and 2008.
- Settlement and agriculture use of the wetland increased until all the wetland was under use in 2008 except in Monavale. Part of this wetland was protected thus highlighting the importance of wetland protection.
- Agricultural and/or settlement land uses were the major causes of wetland fragmentation in urban areas of Harare.
- Wetland conservation had an added beneficial of improving water quality. Most sites in the protected area of Monavale had low faecal coliform counts, a condition attributed to low human contact.

5.2 Recommendations

It is recommended that:

- Considering that eradicating the subsistence agriculture in urban wetlands may be an impossible task, local authorities should collaborate to organise the urban communities carrying out agricultural activities in the wetlands. Hence wetland agriculture will be monitored to protect wetlands from unplanned settlement and haphazard agriculture. The organised farming may also significantly improve people's livelihoods.
- Within the wetland plans some areas may be conserved to maintain wetland functions for example purifying runoff into the main river systems (Marimba River in Monavale, Chavaruva stream in Honeydew discharging into Mukuvisi River) to Lake Chivero.
- Local authorities and water management utilities need to monitor groundwater abstraction for irrigation purposes and associated agricultural activities as these lead to drying up of wetlands
- To reduce coliform bacteria pollution structural improvements and proper maintenance of the systems by local authorities is vital.

- The Monavale wetland committee should not allow people to pass through it as it results in higher faecal coliforms as they ‘relieve’ themselves in the grassland. Furthermore the paths created by people as they walk through lead to compaction and consequently drying up of the wetland.
- Growing of crops near sewage ponds in Mabvuku should be stopped by the local authorities to prevent contamination. The sewage pond area should be fenced off to bar access.

5.3 Limitations of the study

Aerial photographs were used so exact repeatability of the land use maps digitised by the researcher is not possible. The limited sampling frequency for water quality determination and small number of sampling sites was a constraint in coming up with more solid conclusions.

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APPENDICES

Appendix 1 Honeydew water quality results of groundwater samples collected on 20 April 2009

Parameter	**Point 1** (Commercial Agriculture)	**Point 2** (Commercial Agriculture)	**Point 3** (Commercial Agriculture)	**Point 4** (Commercial Agriculture)	**Point 5** (Subsistence Agriculture)	**Point 6** (Commercial Agriculture)	**Point 7** (Subsistence Agriculture)	**Point 8** (Subsistence Agriculture)
TDS (mg/l)	821	491	705	626	753	716	733	622
Conductivity (µs/cm)	882	429	711	666	706	772	790	669
Temperature (^{o}C)	26.8	16.7	16.9	17.2	18.1	15.6	19.9	17
Salinity	0.2	0	0.1	0.1	0.2	0.1	0.1	0.1
pH	8.994	6.7	7.165	7.055	7.194	7.43	6.472	6.42
ORP (mV)	-5.1	-9.8	-13.6	-5.1	-14	-35.5	-28.4	-19.1
TP (mg/L)	0.36	0.99	0.42	0.7	0.34	0.46	0.7	1.62
TN (mg/L)	15.4	0.2	2.5	2	4.4	2.6	1.5	0.8

Appendix 2 Monavale wetland water quality results of groundwater samples collected on 21 April 2009

Parameter	**Point 1** (Protected Site)	**Point 2** (Protected Site)	**Point 3** (Protected site)	**Point 4** (Protected site near river Marimba)	**Point 5** (Protected site near river Marimba)	**Point 6** (Subsistence Agriculture)	**Point 7** (Subsistence Agriculture)	**Point 8** (Subsistence Agriculture)
TDS (mg/l)	184	101	151	410	1081	434	430	514
Conductivity (μs/cm)	196	109	163	440	1160	458	464	552
Temperature (^{o}C)	17.5	15.7	17.9	16.5	18.3	16.5	17.9	16.7
Salinity	0	0	0	0	0.4	0	0	0
pH	5.86	5.37	6.32	6.485	6.714	6.738	6.156	6.396
ORP (mV)	-60.4	-77.5	-37.4	-24.2	-12.2	-12.6	-41.6	-30.3
TP (mg/L)	0.38	0.62	0.24	0.79	0.44	0.32	0.06	0.01
TN (mg/L)	3.4	2.4	0.3	0.3	0.8	0.01	0.02	0.01

Appendix 3 Mabvuku wetland water quality results of groundwater samples collected on 22 April 2009

Parameter	**Point 1** (Upstream sewage ponds 2)	**Point 2** (After confluence)	**Point 3** (Below sewage ponds 2 across river channel)	**Point 4** (Right below sewage ponds 2)	**Point 5 (**Above sewage ponds 2)	**Point 6** (Below sewage ponds 1)	**Point 7 (**Above sewage ponds 1)	**Point 8 (**Deep well)
TDS (mg/l)	50	48	41	1080	73	145	680	missing
Conductivity (μs/cm)	52.9	51.3	43	1173	78.2	156.6	662	missing
Temperature (^{O}C)	16.9	18.8	18.6	17.6	18	16.1	15.1	missing
Salinity	0	0	0	0.4	0	0	0.1	missing
pH	6.42	5.42	5.604	6.809	5.89	6.468	6.345	missing
ORP (mV)	-33.4	-84.1	-74.6	-8.5	-57.6	-25.7	-27.8	missing
TP (mg/L)	0.68	1.27	0.62	0.59	0.44	1.26	1.1	0.25
TN (mg/L)	0.4	1	0.2	1.3	0.6	18.3	16.6	2.5

Appendix 4 Honeydew water quality results of groundwater samples collected on 10 June 2009

Parameter	Point 1 (Commercial Agriculture)	Point 2 (Commercial Agriculture)	Point 3 (Commercial Agriculture)	Point 4 (Commercial Agriculture)	Point 5 (Subsistence Agriculture)	Point 6 (Commercial Agriculture)	Point 7 (Subsistence Agriculture)	Point 8 (Subsistence Agriculture)
TDS (mg/l)	528	693	627	795	821	729	759	561
Conductivity (µs/cm)	567	748	673	854	880	784	818	601
Temperature (^{o}C)	18.7	18.2	18.4	17.6	17.8	17.8	17.6	16.4
Salinity	0	0.1	0.1	0.2	0.2	0.1	0.2	0
pH	6.3	7	6.8	7.2	7.3	6.7	6.7	6.4
ORP (mV)	-46.7	-8.3	-8.9	-5.5	-5.3	-28.8	-28.6	-46.5
TP (mg/L)	0.33	0.25	0.35	0.29	0.23	0.26	0.33	0.22
TN (mg/L)	1.6	1.9	2.3	5.4	1.1	3.2	1.1	6.6

Appendix 5 Monavale Wetland water quality results of groundwater samples collected 10 June 2009

Parameter	**Point 1** (Protected Site)	**Point 2** (Protected Site)	**Point 3** (Protected site)	**Point 4** (Protected site near river Marimba)	**Point 5** (Protected site near river Marimba)	**Point 6** (Subsistence Agriculture)	**Point 7** (Subsistence Agriculture)	**Point 8** (Subsistence Agriculture)
TDS (mg/l)	443	442	496	468	575	581	423	402
Conductivity (μs/cm)	477	454	530	503	618	627	458	431
Temperature (^{o}C)	16.8	17.6	19.1	18.7	18.1	18.5	19	19.3
Salinity	0	0	0	0	0	0	0	0
pH	6.1	6.3	6.5	6.5	6.7	6.7	6.9	7.2
ORP (mV)	-18.1	-40.5	-29.4	-30.9	-13.9	-13.2	-8.2	-7.4
TP (mg/L)	2.42	0.29	0.44	0.44	0.24	0.29	0.68	0.55
TN (mg/L)	4.2	0.3	0.1	0.2	0.2	0.9	2	2.7

Appendix 6 Mabvuku Wetland Water Quality Results of groundwater samples collected on 9 June 2009

Parameter	**Point 1** (Upstream sewage)	**Point 2** (After confluence)	**Point 3** (Below sewage ponds 2 across river channel)	**Point 4** (Right below sewage ponds 2)	**Point 5** (Above sewage ponds 2)	**Point 6** (Below sewage ponds 1)	**Point 7** (Above sewage ponds 1)	**Point 8** (Deep well)
TDS (mg/l)	86	52	157	108	145	294	195	45
Conductivity (µs/cm)	92.7	56.3	168.9	116.4	154.5	316	207	47.8
Temperature (^{O}C)	16.4	16.2	15.9	16.2	16.1	15.7	16.8	19.2
Salinity	0	0	0	0	0	0	0	0
pH	5.4	5.5	5.8	5.9	5.7	6	5.9	5.2
ORP (mV)	-79.8	-86.1	-74.1	-92.9	-76.4	-81.7	-68.9	-90.8
TP (mg/L)	6.02	8.02	2.32	1.84	0.71	1.02	1.94	0.25
TN (mg/L)	2.4	4.9	2.6	3.7	0.9	2.4	5.1	1.4

Appendix 7 Faecal Coliform count in 100ml of water

Wetland and Sampling Points	Land Use	MPN (per 100mls sample)	
		April	**June**
Honeydew			
Point 1	Commercial Agriculture	93	150
Point 2	Commercial Agriculture	3	1100+
Point 3	Commercial Agriculture	240	1100+
Point 4	Commercial Agriculture	240	1100+
Point 5	Commercial Agriculture	1100+	1100+
Point 6	Commercial Agriculture	1100+	1100+
Point 7	Subsistence Agriculture	1100+	1100+
Point 8	Subsistence Agriculture	1100+	1100+
Mabvuku			
Point 1	Upstream sewage ponds	29	1100+
Point 2	Downstream sewage ponds	1100+	1100+
Point 3	Sewage Across channel	1100+	290
Point 4	Adjacent Sewage ponds	1100+	1100
Point 5	Upstream sewage ponds	16	1100
Point 6	Downstream sewage ponds	1100+	240
Point 7	Adjacent Sewage		1100+
Point 8	Deep Well	6	93
Monavale			
Point 1	Protected wetland	16	93
Point 2	Protected wetland	240	75
Point 3	Protected wetland	240	240
Point 4	Protected wetland	1100+	1100+
Point 5	Protected wetland	240	460
Point 6	Subsistence agriculture	1100+	1100+
Point 7	Subsistence agriculture	1100+	1100+
Point 8	Subsistence agriculture	1100+	290