UNIVERSITY OF ZIMBABWE

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

Assessment of the impact of landuse changes on the water quality of Incomati River, Southern Mozambique

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M.SC. THESIS IN IWRM

HARARE, JULY 2016

UNIVERSITY OF ZIMBABWE
FACULTY OF ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING

In collaboration with

Assessment of the impact of landuse changes on the water quality of Incomati River, Southern Mozambique

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

July 2016

DECLARATION

I, Esperança David Muchanga, declare that this research report is my own work. It is being submitted for the Master of Science Degree in Integrated Water Resources Management (IWRM) at the University of Zimbabwe. It has not been submitted before for any other degree for examination at any other University. The findings, interpretations and conclusions expressed in this study neither reflect the views of the University of Zimbabwe, Department of Civil Engineering nor those of the individual members of the MSc. Examination Committee, nor of their respective employers.

Signature: ____

Date: ______________________________

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LIST OF ABBREVIATIONS AND ACRONYMS

ARA-Sul	South Regional Water Administration of Mozambique
AUCRG	African Union Commission Research Grant
CNA	National Water Council
COD	Chemical Oxygen Demand
DNA	National Directorate of Water
DO	Dissolved Oxygen
FAO	(United Nations) Food and Agriculture Organization
GCPs	Ground Control Points
GPS	Global Positioning System
GWP	Global Water Partnership
ILWIS	Integrated Land and Water Information System
IWRM	Integrated Water Resource Management
LIRB	Lower Incomati River Basin
MAE	Ministry of state administration
MCD	Miami Conservation District
NASA	National Aeronautics and Space Administration
SPSS	Statistical Package for Social Sciences
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UGBI	Incomati River Basin Management Unity
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UN-WWDR	United Nations World Water Development Report
USGS	United States Geological Survey
WHO	World Health Organization
WWD	World Water Day
WWTP	Waste Water Treatment Plant

DEDICATION

This thesis is dedicated to my lovely son, Melven.

ACKNOWLEDGEMENTS

First of all I would like to thank God who created me. Thanks to the Heavenly Lady Santa Maria for keeping me all the way throughout the study. I also want to acknowledge and thank WaterNet for funding and making this research possible. Gratitude is also extended to my supervisors Mr. W. Gumindoga, Eng. Z. Hoko and Eng. E. Macuacua for their assistance and advice throughout the research period. Many thanks go to the rest of the lecturers at the University of Zimbabwe and University of Botswana; and my employer (Tongaat Hulett) for their support. I am also thankful for the encouragement of my family.

ABSTRACT

The growth of socio-economic activities such as irrigated agriculture and urbanization in the Lower Incomati River Basin in Mozambique is putting pressure on water quality in the catchment. The area between Xinavane and Marracuene is covered with high density of aquatic weeds and signals of eutrophication in the river and related lagoons. This could be caused by the excessive use of fertilizers, disposal of untreated wastewater from settlements and sugar industry. This study aims to assess the impact of landuse changes on water quality based on GIS and remote sensing techniques. The study used historical data on water quality from 2000 to 2015 and primary data collected in seven established sampling sites from January to March 2016. Images with less than 10 % cloud cover were downloaded from http://glovis.usgs.gov/, for 2000, 2005, 2010 and 2015, for the off rainy season (July-September). The images were classified in a GIS environment, based on the maximum likelihood classifier algorithm and future projections were done using the Markov Chain analysis through the *Terrset* software. Results show that EC, nitrates and turbidity are the most variant parameters; with EC varying from 191 to 924 µS/cm, nitrates from 0.08 to 88.63 mg/l and turbidity from 0.5 to 53.3 mg/l. The spatial variation in the water quality results revealed that the sampling site at the drainage of Três de Fevereiro Churamati (SS5) presented the highest parameter values and the sampling site control located in Chinhanguanine (SS1) had the lowest values. The land cover changed significantly from 2000 to 2015 with an increase in settlements by 185 % and irrigation by 162 %. There was a considerable decrease in forestland by 58 % during the same period. Between 2015 and 2030, there is a predicted increase in irrigation by 58 % and settlements by 61 % and a decrease in forestland by 98 %. The study revealed that there is significant relationship between water quality (nitrates) and forestland (-0.97), grassland (-0.95), settlements (0.98) and irrigation (0.65) between 2000 and 2015, showing that these changes in landuse could have caused a deterioration in water quality in the Lower Incomati River Basin. At the same rates of increase, in 2020 the concentrations of pH, nitrates and turbidity are expected to be 8.32, 20.9 mg/l and 11.0 mg/l, respectively; and for 2030 the concentrations of the same parameters are expected to be 8.43, 21.3 mg/l and 11.3 mg/l, respectively. The study concluded that there are significant relationships between landuse and water quality, and it is therefore recommended that there should be an improvement on the monitoring network by increasing the sampling frequency from quarterly to monthly, and by increasing the key parameters which are TSS, TDS and COD. Best practices in irrigated agriculture are encouraged and the implementation of proper environmental management plans for the urban area in order to improve water quality is also recommended.

KEY WORDS: Incomati River, GIS, remote sensing, Principal Component Analysis, Markov Chain, supervised classification, water pollution.

1. INTRODUCTION

1.1. Background

Water quality is now an issue of global concern (GWP, 2015). It is affected by a wide range of natural and human influences (UN-WWDR, 2015). According to the GWP (2015) water has to be seen in multiple perspectives; as an economic, social and environmental good. The population of the world is projected to reach 9.1 billion by the middle of 21th century, 34 percent higher than what it is in 2016 (GWP, 2012). In addition, the world's cultivated area has grown by 12 % over the last 50 years and irrigated area has doubled over the same period (FAO, 2011). As human populations grow, agricultural and industrial activities expand, and climate change threatens to cause major alterations to the hydrological cycle (UN-water, 2011). Nevertheless, global achievements in production in some regions have been associated with degradation of land and water resources, and the deterioration of related ecosystem goods and services (FAO, 2011).

According to the WWD (2010), two million tons of sewage, agricultural and industrial waste are discharged into the world's water system every day, the equivalent of the weight of the entire human population. Therefore, there has been widespread decline in biological health in inland waters and more than 50 % of native freshwater fish species are at risk of extinction (WWD, 2010). A comparison of agriculture, industry and commerce shows that agriculture is the leading source of nutrients containing nitrogen and phosphorus that can deplete oxygen levels and eliminate species, thus affecting ecosystem integrity (UN-water, 2011).

For Africa, the primary aim is to achieve resilient participation in the global economy while developing its resources without replicating the negative experiences on the development paths of other regions (UN-WWDR, 2015). Currently, only 5 % of Africa's potential water resources are developed and the average per capita storage is 200 m^3, compared to 6,000 m^3 in North America (UN-WWDR, 2015). Various surveys indicate that 20-50 % of wells contain nitrate levels greater than 50 mg/1, and in some cases as high as several hundred milligrams per litre (FAO, 1999).

Mozambique is one of the poorest countries in the world and in 2011, the country was ranked 184th out of 187 countries in the human development index of the United Nations (UNDP, 2014). Due to its location, the country is also vulnerable to disasters, the susceptibility of receiving polluted waters from upstream and the salinity from ocean salt intrusion (Vieira *et al.*, 2014). Therefore, much of the emphasis in water resource management decisions has revolved around ensuring that users have sufficient quantities of water with less effort on water quality (van Eekelen *et al.*, 2015). Although, as water demand increases, the available water per capita decreases, feedback loops become even tighter, and quality begins to deteriorate (Bauder *et al.*, 2008).

The Incomati is a river in Mozambique with high variability of streamflow and competing water demands from irrigated agriculture, energy, forestry and industries, which also compete with the environment and basic human water needs (van Eekelen *et al.*, 2015). These competing demands result in a stressed water resource system (Okello *et al.*, 2015). The impacts of these demands, relative to the natural flow regime and the quality of water, appear significant (Macuacua, 2011). Furthermore, efforts have been made to face these challenges such as the introduction of water sector reform programmes and river basin management based on IWRM principles (Chikozho, 2005).

Irrigated agriculture is an important landuse in the Incomati Basin and the main irrigated crop is sugarcane (van Eekelen *et al.*, 2015). However, water quality is often degraded by agricultural landuse (Ferrell, 2001). Intensive agriculture increases erosion and sediment load, and leaches nutrients and agricultural chemicals to rivers, streams, and groundwater (Foley *et al.*, 2005). Water quality in the catchment is suitable only for agriculture and for some areas it can be used for domestic and urban use after treatment (Vaz and van der Zaag, 2003).

Floods and drought are the hazards that mostly affect water quality in the catchment (Leestemaker and Tauacale, 2000). The most recent flood event was experienced in the year 2013, killing 7 people and affecting more than 10,000 people only at basin level. During these two events no cases of cholera or other water borne disease were reported (MPD, 2013). However, in the country, it is estimated that more than 60 % of paediatric cases are related to malaria which is mainly related to poor environmental sanitation (Wateraid, 2010). Therefore, some measures could be taken in order to minimize the impacts of agriculture on water quality, such as the adoption of wastewater treatment systems or constructed wetlands (Sultana *et al.*, 2015). But not all agricultural development projects in the basin meet these requirements (SWECO, 2003).

1.2. Problem statement

Irrigated agriculture, urbanisation and forestry along the Crocodile River (Incomati's tributary) are already affecting the stream flow regime, and water quality of this river (Okello *et al.*, 2015). In the Sabie River (Incomati's tributary), there are reports of water pollution events due to mining activities (Olivares and Pereira, 2013). Further downstream the basin, between Xinavane and Marracuene, there is a significant spread of aquatic weeds and visible signals of eutrophication (Loforte, 2014). This phenomena is caused by the excessive use of fertilizers, untreated sewage and industrial effluent coming from the sugar industry (Leestemaker and Tauacale, 2000). On the other hand, sand mining for construction purposes is causing sedimentation which may also impact the quality of water in the Incomati River (Loforte, 2014). However it is not known to what extent these activities are affecting water quality (SWECO, 2003).

Furthermore, the dominant economic activities contributing to water quality deterioration have not yet been established (Leestemaker and Tauacale, 2000). On the other hand, the prolonged drought spell that is occurring in this hydrologic year (2015-16) is affecting the basin in such a way that it calls for the attention of water managers, showing that it is time for recycling and reusing water in the basin and also introducing measures of pollution control. Therefore, this study was carried out to find out the actual contribution of agriculture and other economic activities on the water quality of the Lower Incomati River in Mozambique, based on GIS and Remote Sensing tools that can provide spatial and temporal information with high accuracy.

1.3. Justification

The excessive use of fertilizers for agricultural production results in nutrient enrichment of water bodies leading to gradual contamination of freshwaters (Khoa *et al.*, 2005). High nutrients levels increase the productivity of the water bodies, leading to algal blooms

(Leestemaker, 2014). Contaminated water will affect downstream uses, such as domestic, navigation, irrigation and the environment (Chu *et al*., 2013). Mozambique experiences reduced flows in the LIRB during the dry season and floods during the wet season caused by the increased flows (Leestemaker, 2014). The consequences of upstream management practise of Swaziland and South Africa disturb the environment and infrastructure downstream, and also salt intrusion occurs as result of reduced flow and water quality reduction (Leestemaker and Tauacale, 2000).

Although the rivers in Mozambique are mostly in a natural state, the opposite is observed upstream where there are large dams belt across the rivers and its flow is controlled by professionals in water resources management (Basson and Rossouw, 2003). This situation will create conditions for degradation of water quality downstream making water not suitable even for domestic use (Leestemaker, 2014). This is critical, mostly in a country with lack of infrastructure and thousands of people rely on the Incomati River as their source of domestic water (Leestemaker, 2014). In the LIRB there is a quarterly water quality monitoring routine done by ARA-sul (Southern Mozambique Water Authority). The current monitoring strategy has a challenge on the absence of an effective integrated water quality management system which incorporates monitoring of chemical, physical and biological parameters.

This study will contribute to establishment of key pollutant parameters to be analysed and the critical sampling sites. The study will also contribute with GIS and remote sensing based solutions to help monitoring of water quality in the Incomati River Basin by bringing the concepts of high temporal and spatial resolutions into the process. The findings will assist in the catchment management and creating strategies to minimize impacts of land use on water quality, thus reducing the risk of pollution. In addition, it will enhance knowledge on the status of water quality of the Lower Incomati River Basin and also boost the implementation of the principles of IWRM in the country.

1.4. Objectives

1.4.1. Main objective

The main objective of this study was to assess the effects of landuse changes on water quality from 2000 to 2015 in the Lower Incomati River Basin, Mozambique.

1.4.2. Specific objectives

The specific objectives were:

1) To analyze the historical, current and future water quality situation on the lower Incomati catchment, Mozambique;

2) To assess the historical, current and future changes in landuse using GIS and remote sensing techniques for the years 2000 – 2030;

3) To establish the relationship between current and future water quality parameters and landuse changes for the years 2000 – 2030.

2. LITERATURE REVIEW

2.1. Global and regional status of water quality

Water in many parts of the world is being affected by nutrient enrichment as a result of agricultural activities (Verhoeven *et al*., 2006). Globally, approximately 70 % of freshwater is used for agriculture, 20 % for industry and only 10 % for domestic needs (Zimmerman *et al*., 2008). The use of unsafe water results in 4 billion cases of diarrhoea each year, and causes 2.2 million deaths (WWD, 2010). In Sub-Saharan Africa there is still a challenge in achieving improved sanitation with only 31 % of the residents having access to improved sanitation (WWD, 2010).

Urbanization and the adherence of modern life that the richer communities adopt increase waste production that end up polluting water systems (Tarr and Tarr, 2002). Water pollution is also resulting from the increase of agriculture, mining and industrial activities (Tarr and Tarr, 2002). More than 40 % of the people living in Southern Africa have no access to safe water for basic needs (SADC, 1999). These figures are too high for a region with countries that are in development stage and the probability of increased pollution is still high. Therefore, some measures have to be put in place in order to reduce pollution and recover the polluted water bodies that exist.

2.2. Water quality status in Mozambique

Mozambique has limited access to water supplies and depends approximately on 50 % of its surface water from upstream catchments (USAID, 2007 and Loforte, 2014). Surface waters are being polluted and only 41 % of the population have access to save drinking water (Garcia *et al*., 2005). The country is experiencing freshwater problems related to continued deterioration of river systems, reduction in water quantity and quality, increasing impact from dams, increased siltation of rivers, alien invasive species (plants and fish) and decreasing access to safe potable water for rural communities (Mitchell *et al*., 2010).

Water quality degradation is due to use of buffer zones, agricultural drainage, acid drainage from mining rocks, inadequate sanitation and increase in salt intrusion mostly in the rivers Pungue, Incoomati, Umbeluzi, Limpopo and Maputo (Loforte, 2014). Therefore, this has led to developmental projects to take responsibility of implementing measures to ensure the prevention of water resources pollution.

2.3. Relevant water quality parameters for this study

2.3.1. Temperature

Temperature measurements of air and water at a field site are essential for water quality data collection (USGS, 2014). A thermometer is a device used to measure temperature, consisting of a temperature sensor and some type of calibrated scale or readout device. The U.S. Geological Survey (USGS) uses the Centigrade or Celsius (^{o}C) scale for measuring temperature, and the same scale is used in Mozambique (Wilde, 2006).

Water temperature is one of the most important parameters since it determines the biological processes in many aquatic systems (Paaijmans *et al*., 2008). It also affects the way people use water and the abilities of aquatic organisms to live, grow, and reproduce; and affecting also the self-purification phenomenon in water bodies and therefore the aesthetic (PASCO, 2010). Since the values of temperature could alter during the sample conservation process, this parameter was measured *on site* together with pH.

2.3.2. Turbidity

Turbidity is an expression of the optical properties of a liquid that causes light rays to be scattered and absorbed rather than transmitted in straight lines through a sample (USGS, 2006). It is usually measured in Nephelometric Turbidity Units (NTU) using an instrument referred to as a turbidy-meter (USGS, 2014). If the amount of total suspended solids in the water is high, high values of turbidity can be expected as well (Somvanshi *et al*., 2011). Turbidity makes water appears cloudy or muddy (USGS, 2014). It is commonly caused by dissolved or suspended matter such as clay or sand, organic matter plankton and organic acids (USGS, 2014).

Most agricultural waste discharges contribute to sustained turbidity (Worcester, 2011). This parameter can reduce the suitability of water for some beneficial uses such as domestic and recreational use, making it only suitable to agriculture and industry (Somvanshi *et al*., 2011). Water turbidity can affect the water temperature in such a way that when the suspended particles in a water body absorb sunlight, they are scattered back to the atmosphere and determine the loss of solar radiation (Paaijmans *et al*. 2008). In conclusion, the highest values of turbidity can be found in areas where there is agricultural and industrial drainage where the values of total suspended solids are usually high.

2.3.3. Total suspended solids

Suspended solids is a term used to refer to particles that usually range from 10 to 100 microns in diameter (PASCO, 2010). Suspended solids can impact the suitability of water bodies to recreational activities, and it can also contribute to water-borne diseases outbreaks (Wilson, 2013). Total suspended solids (TSS) can impact water quality by increasing productivity of water bodies and submersed plant communities (Bilotta and Brazier, 2008). It can be measured in the laboratory by filtration methods (Liebl and Lowndes, 2002).

The procedures in this method consists of filtering the sample through a membrane, and drying at a specified temperature of usually 105 °C, then a gravimetric estimation of the concentration is done (EPA, 2001). Water with a TSS concentration < 20 mg/l is consider to be clear, water with TSS concentrations between 40 mg/l and 80 mg/l appear cloudy and water with TSS concentrations > 150 mg/l generally appears dirty (EPA, 2001). In conclusion the measurement of total suspended solids is important as suspended solids are a good indicator of the pollution potential of effluents and any other water body.

2.3.4. Total dissolved solids

Total dissolved solids (TDS) is a term that refers to the inorganic salts and small amounts of organic matter present in water (WHO, 1996a). The presence of dissolved solids in water may affect the taste of water to humans. Usually the principal components of TDS are sodium, chloride, calcium, carbonate, potassium, sulphate, magnesium, and nitrate anions (PASCO, 2010).

The method used to determine TDS is usually through a specific EC measurement, and then the values are converted into TDS based on a factor that varies with the type of water. When the concentrations of TDS are high, a gravimetric method is used (WHO, 1996a). The gravimetric method is based on the procedure whereby a sample of water is boiled until all liquid evaporates leaving the solid residues on the bottom of the beaker, and then the mass of the residue is weighed using an analytical balance (PASCO, 2010). The conversion factors from EC to TDS are found in Table 2.1 and they vary from 0.4 to 0.96.

Table 2.1 Conversion factor (k values)

Type of water	Total dissolved solids (mg/l)	Conversion factor
Freshwater	0 – 2,200	0.7
Brackish water	2,200 – 8,300	0.6
Saline water	> 8,300	0.5

Source: (PASCO, 2010)

In conclusion, knowing the conversion factor for the waters intended to analyse, it can be easy to estimate the amount of total dissolved solids in natural waters, based on the electrical conductivity measurements that are easy to perform.

2.3.5. Electrical Conductivity

Electrical conductivity (EC) is a measure of the ability of water to pass an electrical current (Dalmas, 2000). In surface waters it is affected by the presence of inorganic dissolved solids such as sulphate, chloride, nitrate and phosphate anions or sodium, magnesium, calcium, iron, and aluminium cations (Dalmas, 2000). It is also affected by temperature: the warmer the water, the higher the conductivity, thus it is important because significant changes in conductivity can be an indicator that a discharge or some other source of pollution has entered the water (SAS, 2004).

Conductivity is also measured together with temperature using a conductivity meter (USGS, 2014). In surface waters it should be measured *in situ*, otherwise, determine conductivity in discrete samples collected from a sample splitter or compositing device (USGS, 2014). This is an important parameter to be studied in the LIRB. EC helps in assessing the total dissolved solids and gives a picture of how the study area is prone to salinity. This parameter was measured *on site* together with temperature, total dissolved solids and salinity.

2.3.6. pH

The Power of Hydrogen (pH) is a measure of the relative amount of hydrogen and hydroxide ions in an aqueous solution (Emerson, 2010). According to USGS (2014), pH is a primary factor governing the chemistry of natural water systems and it directly affects physiological functions of plants and animals and it is, therefore, an important indicator of the health of a water system. In an aqueous solution, pH can be measured in a variety of ways. The most common way is to use a pH-sensitive glass electrode, a reference electrode and a pH-meter (Kohlmann, 2003). Since alterations of nutrients can increase the fluctuations of pH in surface waters (MCD, 2011), studying this parameter will define the characteristic of the water and help understanding the reactions on other parameters.

2.3.7. Salinity

According to Podmore (2009) the term salinity refers to the accumulation of salts normally dominated by sodium chloride in water to levels that impact on human and natural resources. Salinity in agriculture occurs mostly in irrigated land due to increased rates of leakage and groundwater recharge causing rise of the watertable and bringing salts into the root zone of plants, affecting in that way the growth of plants and also the soil structure (Dunlop *et al.*, 2005). During the evaporation process or when water is taken up by plants, the salt remains behind in the soil causing agricultural, environmental and social impacts (Fipps, 2003).

Salinity is also one of the most important water quality parameters influencing biodiversity in water bodies especially in estuaries (Abowei, 2010). Some areas that are already affected by salinity suffer from the disturbance of the ecosystem, thus considerable loss of habitat is observed, loss of biodiversity, loss of native vegetation and water resource value (Dunlop *et al.*, 2005). Salinity is also an important parameters that determines what animals and plants can live in or around a water body; and it has strong effects in agriculture and industry (PASCO, 2010). In conclusion, runoff from saline soils and small floods can cause salinity of water bodies. Some irrigation methods such as inundation and furrows can induce the salinity process. This parameter is also related to EC and it is very important to consider when analyzing water quality.

2.3.8. Nutrients

Nutrients are chemicals needed by living organisms to live and grow (MCD, 2011). All living organisms require nutrients to sustain their growth and development (EPA, 2013). Nitrogen and phosphorus are primary nutrients for algal and macrophyte production and are essential to the functioning of healthy aquatic ecosystems (Conley *et al*., 2009). Although nutrients are essential to the functioning of aquatic ecosystems, they can exert negative effects when they are overabundant (Hussain and Bhattarai, 2003). Excessive concentrations of nutrients in the water environment alter trophic dynamics by increasing algal and macrophyte production, increasing turbidity (through algal production), decreasing dissolved oxygen (DO) concentrations, and increasing fluctuations in daily DO and pH (MCD, 2011).

a) Nitrogen

Nitrogen is found in several different forms in terrestrial and aquatic ecosystems which can be ammonia (NH_3), nitrates (NO_3) and nitrites (NO_2) (Walworth, 2013). Nitrates are essential plant nutrients, but in excess amounts they can cause significant water quality problems (Hussain and Bhattarai, 2003). Together with phosphorus, nitrates in excessive amounts can accelerate eutrophication, causing dramatic increases in aquatic plant growth and changes in the types of plants and animals (Conley *et al*., 2009). The sources of nitrates include wastewater treatment plants, runoff from agriculture and animal manure storage areas, and industrial discharges that contain corrosion inhibitors (MCD, 2011).

b) Phosphorus

Phosphorus plays an important role in eutrophication of surface waters (MCD, 2011). High Phosphorus concentrations in rivers have been linked to increasing rates of plant growth, changes in species composition and proliferation of planktonic which is related to water pollution (Conley *et al*., 2009). Phosphorus exists in different forms in natural waters, in both particulate and dissolved phases, and in organic and inorganic forms; but mostly it is found in form of phosphates (PO_4) that can be orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate (Jarvie *et al*., 2002). In conclusion, phosphorus and nitrogen in form of ammonia, nitrates and nitrites, are the most important parameters when studying nutrients in surface waters. Other authors also assessed similar parameters (Kibena, 2012; Mueller-Warrant *et al*., 2012 and Chu *et al*., 2013) when studying the relationship between landuse change and water quality.

2.4. Effects of land use changes on water quality

There is need to understand the consequences of human activities, such as land transformations, on watershed ecosystem services (Uriarte *et al.*, 2011). This is a difficult task because different indicators of water quality are expected to vary in their sensitivity to land use and land cover change (Uriarte *et al.*, 2011). Changes in land use associated with development have contributed to the degradation of surface water quality in many parts of the world (Ferrell, 2001).

Johnes (1996) used the Windrush and Slapton models to evaluate the impact of land use change on the nitrogen and phosphorus load delivered to surface waters in the catchment of the Windrush River, a tributary of the River Thames in United Kingdom. Both models proved to be sensitive to the impact of temporal changes in land use and management on water quality and were, therefore, used to evaluate the potential impact of proposed pollution control strategies.

With the same objective, Sliva and Williams (2001) used secondary databases, GIS and multivariate analysis tools to determine whether there was a correlation between water quality and landscape characteristics within three watersheds. The study was carried out in the southern Ontario watershed, in Canada. The authors found out that there was a clear trend of increased chemical fluxes with increasing urban land use intensity within a watershed.

Tong and Chen (2002) modelled the relationship between landuse and surface water quality using GIS and remote sensing tools in the state of Ohio. The study used Spearman's correlation rank to analyse the relationship between landuse types and water quality variables. The study revealed that the land use was related to many water quality parameters, such as total phosphorus, total nitrogen and faecal coliforms. The study also found out that agricultural and impermeable urban lands produced a much higher level of nitrogen and phosphorus than other land surfaces.

In conclusion, the changes in landuse such as urbanization, industrialization and the constant increase of irrigated agriculture have been impacting the quality of water worldwide. Although these changes in landuse are necessary, there is need to study their impacts before new developments in order to prevent extreme and irreversible situations.

2.4.1. Previous studies on landuse change effects on water resources in the LIRB

A number of studies (Macuacua, 2011; Okello *et al*., 2015; van Eekelen *et al*., 2015) have been conducted in the Incomati catchment in an attempt to assess the contribution of land use changes and agricultural water abstraction on stream flow changes in the basin. In this investigations, Macuacua (2011) found that landuse in the basin has been changing at a significant rate with emphasis on a decrease in forestland of 46 %, water bodies of 37 %, and grassland of 32 %, and an increase in settlements and irrigation of 285 % and 310 %, respectively. There has been also a change in the Incomati river inflows into Mozambique through the border station of Ressano Garcia.

Okello *et al*. (2015) shows that areas under irrigated agriculture and commercial forestry have increased four times over a period of 40 years. Landuse and flow regulation are also larger drivers of temporal changes in streamflow. Van Eekelen *et al*. (2015) demonstrated that data from remote sensing on evaporation, rainfall and land use can be used to determine spatially distributed water withdrawals facilitating the development of a transparent monitoring system based on independently gathered measurements that all parties trusts.

A similar study was conducted in the Incomati River Basin by Sunday *et al*. (2014) aiming on forecasting streamflow for operational water management. Results of this study show that there is some scope for streamflow forecasting that can support water management decision making in the basin. It also shows that the rainfall and streamflow of previous months can be used to predict the streamflow in the following month or season with reasonable to good results.

From these studies it can be concluded that landuse and human activities taking place in the Incomati River Basin are impacting the streamflow. The studies also reveal that remotely sensed data can provide trustable information that can support decision making in the basin. However, there are gaps in research related to water quality status, major polluting activities and pollutants. Therefore, this study addresses the existing gap in terms of water quality in the catchment. As such, historical data on water quality was used and also water samples were collected and studied different parameters according to the landuse and also the water use downstream.

The water parameters studied are essential in relation to human activities that may affect the environment. In this study the following parameters were analysed: temperature, turbidity, total suspended solids, total dissolved solids, pH, electrical conductivity, salinity, alkalinity, COD, total coliforms, faecal coliforms and nutrients (ammonia, nitrates, nitrites and phosphorus). The measurement of these parameters tells the current status of water quality and helps performing pollution control programmes.

2.5. Effects of agricultural production on water quality

Agricultural practices, including tillage, fertilization, and residue management, can affect surface runoff, soil erosion and nutrient cycling; in turn, these processes may adversely affect quality of water resources (Mueller-Warrant *et al*., 2012). Improper agricultural methods may elevate concentrations of nutrients, faecal coliforms, and sediment loads (Johannsen and Armitage, 2010). Increased nutrient loading from animal waste can lead to eutrophication of water bodies which may eventually damage aquatic ecosystems (Parris, 2012).

In the United States of America (USA), for example, it is estimated that over 50 % of the total length of rivers had high concentrations of phosphate and 25 % of the total length of rivers had high nitrate. In addition, it has been estimated that 40 % of phosphates and 61 % of nitrates in waters derive from agricultural inputs (Johannsen and Armitage, 2010). According to Spack (2006) animal waste may also introduce toxic faecal coliforms which threaten public health. Grazing and other agricultural practices may intensify erosion processes raising sediment input to nearby water sources. Increased sediment loads make drinking water treatment more difficult while also effecting fish and macro-invertebrates (Sapek, 1997).

Although the important roles of wetlands in stabilizing the environment and ecosystem are now known worldwide, in Sub-Saharan Africa wetlands are being exploited for poverty alleviation and livelihood security (Verhoeven *et al*., 2006). This is a measure for productivity enhancement that will give rise to serious ecological problems (Barbier, 2015). The inland wetlands in Malawi, Zimbabwe and Zambia are cultivated in about 10 % of its area. Mozambique has five wetlands ecosystems (lacustrine, palustrine, riverine, estuarine and marine) that are being used for small-scale agriculture (Inocencio *et al*., 2003). The destruction of wetlands has led to several initiatives to protect and restore them (Mccartney, 2014). The Ramsar Convention on Wetlands is the most significant initiative; established in

1971 in Iran, aiming to conserve wetland ecosystems, in particular for their importance as a habitat for birds, for their value to wildlife and also for the benefits they provide for humans, particularly people living in poverty (Mccartney, 2014).

In conclusion, wetlands are difficult to value, but it can be estimated from the goods and services that we benefit from them. Southern African countries should adopt the good example of the Okavango Delta, one of the largest wetland in the words that is famous for wildlife tourism.

2.6. Statistical analysis used on landuse change and water quality relationship

It is very important to understand the relationship between landuse and surface water quality for effective water resources management. There are a number of studies that used remote sensing to assess the relationship between landuse changes and the water quality, most of them conducted statistical analysis such as Pearson's correlation coefficient and Spearmen's correlation rank, to find out the relationship between the two variables.

Chu *et al*. (2013) used multiple linear regression also based on the Statistical Package for Social Sciences (SPSS) and showed that water quality is related to land cover in various spatial scales and landuse change has a significant influence on both suspended solid and nitrate-nitrogen loadings. With the same objective, Ding *et al*. (2015) used the Spearman rank correlation based on SPSS package and concluded that urban landuse was positively related to increase in concentration of nutrients in the rivers, while forest landuse was negatively related to increase in concentration of nutrients in the rivers.

Tong and Chen (2002), when modelling the relationship between landuse and surface water quality in the East Fork Little Miami River Basin of USA, used non-parametric statistical tests based on Spearman's correlation rank analysis to explore the relationship between landuse and water quality in the State of Ohio. The study revealed that landuse was related to many water quality parameters, such as total phosphorus, total nitrogen and faecal coliforms.

Msipa (2009) investigated the impacts of land uses changes and assessed the water quality of wetlands in urban communities in Harare, the capital city of Zimbabwe. The study applied linear regression analysis and found that agricultural and settlement landuses were the major causes of wetland fragmentation in urban areas of Harare.

In conclusion, these studies confirmed that a combination of remote sensing images and measured water quality parameters in investigations can provide an overview of the relationship between land use and water quality based on statistical techniques such as the SPSS package. The statistical analysis of the relationships between variables can be analysed using correlation and regression. Correlation includes Spearman rank order correlation coefficient and Pearson's correlation coefficient.

a) Spearman's Rank Order Correlation Coefficient (r_s)

When data meet all of the assumptions for Pearson's r except that one or both of the variables are measured on an ordinal scale rather than on an interval or ratio scale, one can use Spearman's Rank Order Correlation Coefficient. Sometimes this coefficient is referred to as "Spearman's Rho" and the symbol for it is r_s (Pirie, 2006).

b) Pearson's correlation

According to Larsen (2008), often several quantitative variables are measured on each member of a sample. If a pair of such variables is considered, it is frequently of interest to establish if there is a relationship between the two, to see if they are correlated. One can categorise the type of correlation by considering as one variable increases what happens to the other variable. For example, if the other variable has a tendency to also increase, the correlation is positive; if the other variable has a tendency to decrease, the correlation is negative; and if the other variable does not tend to either increase or decrease there is no correlation (Huang *et al*., 2013).

A scatter plot is used in determining whether or not two variables are related. The sign of the correlation coefficient determines whether the correlation is positive or negative. The magnitude of the correlation coefficient determines the strength of the correlation. Although there are no hard and fast rules for describing correlational strength these guidelines can be used: $0 < r < 0.3$ weak correlation, $0.3 < r < 0.7$ moderate correlation and $r > 0.7$ strong correlation (Larsen, 2008).

Based on Pearson`s correlation, Huang *et al*. (2013) determined the correlation coefficient that was then used in an econometric model to determine the relationship between landuse and water quality. The model was based on the research of four lakes watersheds in Hanyang District in China. The relationship was determined through the equation:

WQV = ($\beta 1$ * land1 + $\beta 2$ * land2 + $\cdots$ βi * land$i$+ α); .... Equation (2.1)

Where, WQV represents the water quality variables in the catchment, β is the correlation between land use area (%) and water quality variables, and α is a constant. If $\beta i > 0$, then the land use type i has a positive effect on the indicator of water quality. When $\beta i < 0$, it means that land use type i has a negative effect on the water quality indicator.

2.7. Earth observation techniques in water quality assessment

2.7.1. Use of GIS and Remote Sensing to assess water quality

Staudenrausch *et al*. (2000) studied the application of remote sensing and GIS for Integrated Water Resources Management (IWRM) in southern Africa. The study covered five River Basins; Mupfuri in Zimbabwe; Limpopo in Mozambique, South Africa, Zimbabwe and Botswana; Mbuluzi in Swaziland; and Mkomazi and Umzimvubu in South Africa. The study found out that using GIS and remote sensing together with a hydrological model are suitable tools in water resources planning.

LeMarie *et al*. (2006) used remote sensing techniques to monitor environmental indicators in the Incomati estuary in Mozambique. Remote sensing techniques were used to identify and quantify mangrove forests in two selected areas of the estuary. The results show that mangrove forests are relevant indicators of the state of the estuary and they proved that remotely sensed images may provide important data for an environmental monitoring system.

Usali and Ismail (2010) studied the application of GIS and remote sensing in monitoring water quality parameter such as suspended solids, turbidity, phytoplankton, and dissolved organic matter. From the study they concluded that remote sensing and GIS technologies coupled with computer modelling are useful tools in providing solutions for water resources management and planning. These tools can also be used by the government for formulating policies related to water quality issues.

The study conducted by Hellegers *et al.* (2012) in the Incomati River Basin, presented an interactive web-based assessment tool that creates key water-related indicators to support stakeholders' in making decisions in landuse planning. The study was aimed at assessing the impacts of converting landuse on the water resources, to prioritize areas for conversion and to determine required changes in landuse to fulfil tripartite agreements of water allocation. The study revealed a tool that generates spatial distribution of information about changes in water productivity, consumption, and availability.

A recent study conducted by Xiao *et al*. (2015), used multispectral remote sensing images for rapid river water quality assessment in the Han River, in China. The study was based on measured water quality data and synchronous spatial high and medium-resolution remote sensing data. The study found that neural network retrieval model of water quality index that is established based on multispectral data of satellite has higher accuracy and that its assessment results are of high credibility and strong applicability which can reflect changes in water quality.

Recently, Dlamini *et al*. (2016) studied the feasibility of integrating remote sensing and in-situ measurements in monitoring water quality status of Lake Chivero in Zimbabwe. The study investigated the likelihood of integrating the cheap and readily-available broadband multispectral Moderate Resolution Imaging Spectroradiometer (MODIS) data and in-situ measurements in quantifying and monitoring water quality status of an inland lake within Upper Manyame Catchment. They concluded that it is important to use free and readily available satellite datasets in quantifying and monitoring water quality across inland lakes, mostly in areas like Sub-Saharan Africa where there is scarcity of data.

Overall, it can be concluded from the studies that GIS and remote sensing provide useful tools of how water quality monitoring and management can be operationalized. Such tools include images that can be used for environmental assessment and decision support systems that can be derived from multispectral data.

2.7.2. Methods of quantifying landuse changes

Much of the information on land cover and land use that can be derived using remote sensing can only with great difficulty or cost, be obtained using in situ methods. One of the most important characteristics of remote sensing and GIS is that it can provide detailed, quantitative land surface information at large spatial coverage and at frequent temporal intervals (Prenzel, 2004). However, changes in land use and land cover can be detected at the local, regional, continental and global scales by sensors on earth-orbiting satellites (NASA, 2000).

Use of satellites and sensors

Satellite technologies allow to accurately quantifying change at the global scale. Satellites such as Landsat bring the big picture and with observations of Earth from space, enables researchers to easily grasp how events in one place are affected by or affect life in other places (NASA, 2000). Sensors on satellites give the global and regional perspectives, such as the sources of pollution, how cities are growing, or how coast lines are changing in response to hurricanes and sea level rise (Lu and Weng, 2007). Sensors on the National Aeronautics and Space Administration (NASA) satellites collect data about the atmosphere, oceans, ice, biosphere and land used to make daily global maps of the planet (NASA, 2000). The Landsat series of satellites enables researchers to see changes in the land surface over time.

2.7.3. Image classification and its algorithms

The techniques for image classification are well described in Table 2.2.

Table 2.2 Image classification methods

Categories	Characteristics	Algorithms
Supervised classification approaches	Land cover classes are defined. Sufficient reference data are available and used as training samples.	Maximum likelihood, minimum distance, artificial neural network, decision tree classifier.
Unsupervised classification approaches	Clustering-based algorithms are used to partition the spectral image into a number of spectral classes based on the statistical information inherent in the image	Maximum likelihood, linear discriminant analysis.

Source: (Lu and Weng, 2007)

Landsat imagery

Image classification is an important part of the remote sensing (Thakur *et al*., 2012). The main purpose of satellite imagery classification is the recognition of objects on the Earth's surface and their presentation in the form of thematic maps (Kokalj and Oštir, 2007). The image classification can be supervised or unsupervised. Unsupervised classification is computer-controlled whilst in supervised classification one has much closer control over the classification process (Thakur *et al.*, 2012). The most used for landuse change determination is the supervised classification. Landsat imagery has been effectively used to classify homogeneous landscapes with its moderate spatial resolution of 30 m (Yüksel *et al.*, 2008).

ASTER

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument is a joint Japan-United States imager deployed on NASA's Terra platform (Wynn *et al.*, 2003). Unlike Landsat, this sensor is a stereoscopic instrument which allows for dynamic monitoring of Earth surface events with its short revisit time (Yüksel *et al.*, 2008). It can be used to assess events such as active volcanism, floods, urban growth and forest change (Kaab *et al.*, 2002). The altitude of ASTER is 438 miles; the revisit period of 16 days, each acquisition is approximately 60 km x 60 km and a spatial resolution of 15 m (Yüksel *et al.*, 2008).

MODIS

Moderate Resolution Imaging Spectroradiometer (MODIS) is an instrument designed to provide enhanced monitoring for ocean, land and atmosphere researches (Justice *et al.*, 1998). MODIS is an important sensor on the NASA's Terra and Aqua satellites (Vermote *et al.*, 2011). The land imaging component of the MODIS sensor combines characteristics of AVHRR and Landsat sensors to provide improved monitoring of surface of the Earth's (Petus, 2013). MODIS data available are derived from the sensor on the Terra platform (Justice *et al.*, 1998). The scene size for MODIS is 10 km x 10 km, altitude of 705 km and revisit time of 16 days and a resolution of 250 m (Notarnicola *et al.*, 2013).

2.7.4. Prediction of future landuse

There are various techniques that can be used to project the future landuse/land cover in a catchment, but the most them are based on the Markov Chain method. This method is based on the assumption that what has been happening in the catchment in the past, will continue happening in the future (Tsarouchi *et al.*, 2014). Some softwares that are used are: ERDAS used by (Huang *et al.*, 2005), *IDRISI selva* used by (Mishra *et al.*, 2014 and Kumar *et al.*, 2015) and TerrSet used by (Kumar *et al.*, 2015).

TerrSet Geospatial Monitoring and Modelling System: TerrSet is software that incorporates the *IDRISI GIS* and Image Processing tools, and offers a collection of vertical applications focused on monitoring and modelling the earth system for sustainable development (Eastmen, 2015). The collection includes tools such as:

i. *The Land Change Modeller (LCM)* for analyzing land cover change and projecting future changes. It also includes tools for the assessment of climate change mitigation strategies through REDD (Reducing Emissions from Deforestation and forest Degradation).
ii. *The Habitat and Biodiversity Modeller (HBM)* for habitat assessment, landscape pattern analysis and biodiversity modelling.
iii. *The Ecosystem Services Modeller (ESM)* for assessing the value of various ecosystem services such as water purification, crop pollination, wind and wave energy, and others.
iv. *The Earth Trends Modeller (ETM)* for the analysis of time series of earth observation imagery.
v. *The Climate Change Adaptation Modeller (CCAM)* for modelling future climate and assessing its impacts on sea level rise, crop suitability and species distributions.
vi. *The IDRISI GIS Analysis tools* for GIS analysis, primarily oriented to raster data.
vii. *The IDRISI Image Processing System* for the restoration, enhancement, transformation and classification of remotely sensed images.

The relationship between *TerrSet* and *IDRISI* is therefore quite close. *IDRISI* provides two of the major components of the system (GIS Analysis and Image Processing) as well as the foundation for all components. All components use the *IDRISI API* and the *IDRISI* data file structures. While *IDRISI* was once a standalone product, it is now incorporated within the *TerrSet* system (Eastmen, 2015).

The change prediction process in Land Change Modeller (LCM)

According to Eastmen (2015) Land change prediction in LCM is a process empirically driven that moves in three steps:

i) *Change Analysis,* where change is assessed between time 1 and time 2 between the two land cover maps;

ii) *Transition Potential Modelling,* where the potential of land to transition is identified. At this step, transition potential maps that are in essence maps of suitability for each transition are created.

iii) *Change Prediction***,** where using the historical rates of change and the transition potential model, LCM predicts a future scenario for a specified future date.

It is based on the historical change from land cover map of time 1 to land cover map of time 2 to project future scenarios.

A study by Mishra *et al*. (2014) predicted and analyzed the future growth of Muzaffarpur City and its surrounding, in Bihar-India using the Landsat images of 1988 and 2010. This data was used for change prediction maps for the years 2025 and 2035. The study used Land Change Modeller (LCM) to analyze the landuse changes. The prediction of landuse changes was done in the *IDRISI Selva* version.

A similar study which used LCM was carried out by Kumar *et al*. (2015). The objective of the study was to predict and analyse the future growth of the Vijayawada city of Andhra Pradesh in India. The study used Landsat images of 1973, 2001and 2014. The prediction of 2030 and 2040 images were done using LCM of TerrSet software.

2.7.5. Use of remote sensing to predict future landuse changes

Studies have successfully predicted future changes in landuse based on remote sensing and the Markov model. Veldkamp and Lambin (2001) conducted a study aiming at predicting future landuse changes in Wageningen, in the Netherlands, and concluded that models of predicting landuse change can be used as decision support systems and scenarios of land-use change can help to investigate possible futures under a set of simple conditions.

Reveshty (2011) used GIS and multi-temporal satellite imagery to predict landuse changes to urban area in Zanjan, in Iran. The research employed supervised classification to detect land use changes which occurred in the study area and Markov Chain was used for forecasting landuse change until 2020. The study revealed that dry farming land and settlements were the critical regions in terms of land use changes. About 44 % of the total area changed the landuse from cropped areas and bareland to settlements.

In India, a study was carried out by Mishra *et al*. (2014) to predict landuse changes based on Land Change Modeller by the use of remote sensing techniques. The study demonstrated the efficiency of remote sensing data in the studies of land use and land cover changes and the possibility of planning for the future based on past information.

Recently, Tsarouchi *et al*. (2014) also predicted landuse changes by investigating the historical rate of change and creating future scenario projections using Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper images. The study was carried out in the Upper Gages Basin, in India. Results of this study show the capability of Landsat data in providing accurate land cover maps. The study projected future expansion of forest, urban, grass and shrubland; with a decline in cropped areas and bareland.

Another study in India, carried out by Kumar *et al*. (2015) predicted future land use and land cover changes of Vijayawada City using GIS and remote sensing. The projection of future scenarios was based on the LCM of *IDRISI Selva* software. Results from this study show a rapid and enormous conversion of vegetative and open land into built up area in 50.21 %. The authors concluded that this conversion of vegetation into settlements may have serious impacts on the environmental.

In conclusion all the studies show that results derived from such kind of investigation provide the necessary support base to maintain a regional landuse planning and can be used for developing future water resource management strategies.

3. STUDY AREA

3.1. Geographical location and Geology of Lower Incomati River Basin

The Lower Incomati River Basin (LIRB) presented in Figure 3.1, is a catchment located in the Southern part of Mozambique and it covers an area of about 15,500 Km^2. The Incomati River rises in the mountains in South Africa, 2,000 meters above the sea levels and discharges in Maputo Bay in the ocean (Vaz and van der Zaag, 2003). The basin covers the districts of Moamba, Magude, Manhiça and Marracuene (AUCRG, 2012). The geology of the basin is characterized by granitic, sedimentary and dolomitic rocks (Vaz and van der Zaag, 2003). There is also occurrence of some minerals such as coal, asbestos and gold (Vaz and van der Zaag, 2003).

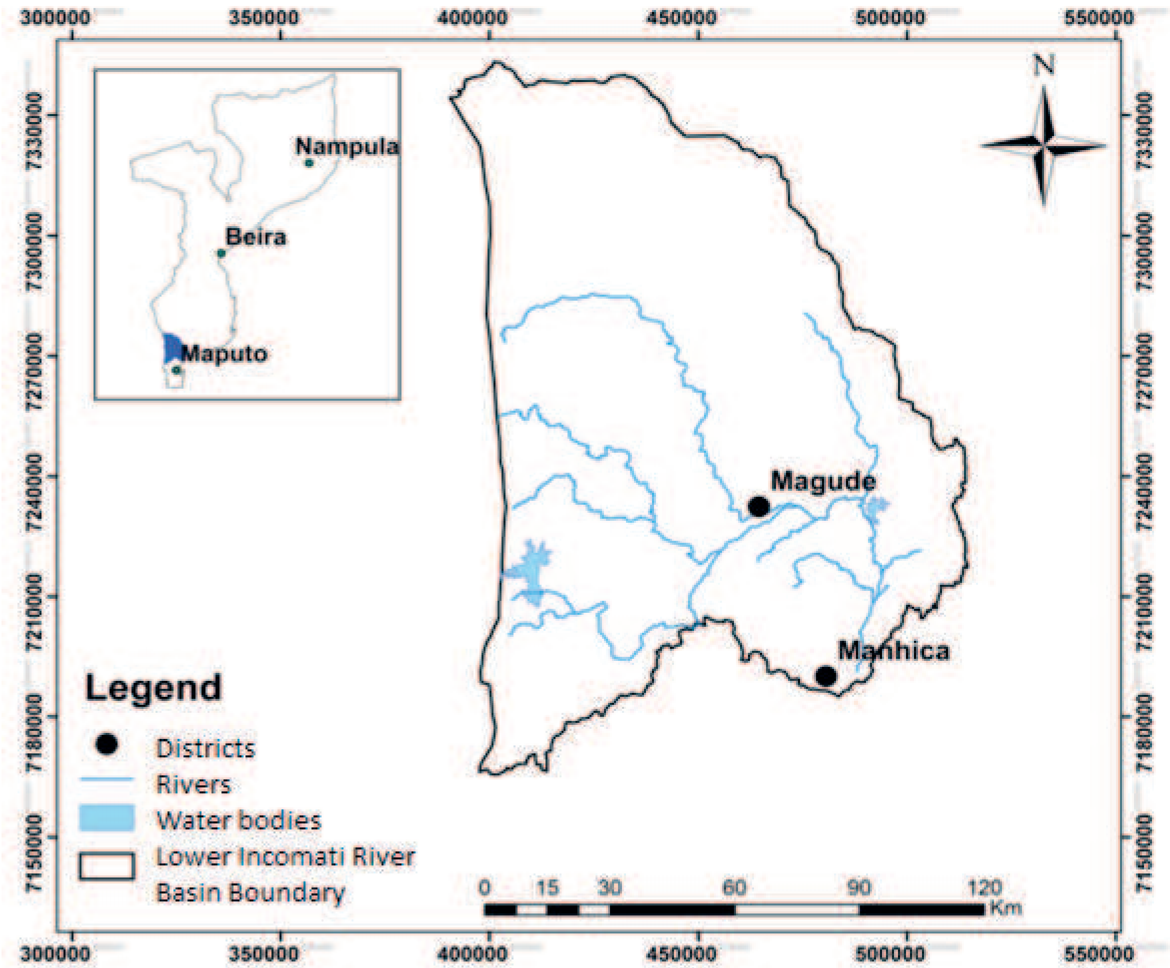

Figure 3.1 The Lower Incomati River Basin with its tributaries and lakes

3.1.1. Population of the Lower Incomati River Basin

The population in the LIRB is about 352,405 inhabitants according to the Census of 2007 with a density of 17 people/km^2 (Leestemaker, 2014). The most populated district is Manhiça with 45 % followed by Marracuene with 24 %, then Moamba with 16 % and finally Magude with 15 % of the total population as shown in Table 3.1. In terms of gender in the catchment, female are the majority (53 %) and the remaining 47 % are male (AUCRG, 2012).

Table 3.1 Population distribution in the LIRB

District	Female	Male	Total	Total (%)
Maracuene	44,126	40,849	84,975	24 %
Manhiça	85,921	71,721	157,642	45 %
Moamba	29,229	27,330	56,559	16 %
Magude	29,068	24,161	53,229	15 %
Total			**352,405**	**100 %**

Source: (AUCRG, 2012)

3.1.2. Economic development

Although Mozambique has been performing well on human development index, the poverty incidence is still a problem in the basin (UNDP, 2014). According to AUCRG (2012), the economic development of the basin falls under the context of the development of the country. Table 3.2 shows an increase of poverty incidence in all districts from 1997 to 2007. Magude District presents the highest percentage poverty incidence followed by Manhiça, Moamba and Marracuene. It can therefore be concluded that the majority of people living in LIRB are poor based on the high poverty incidence in all the districts which is above 50 %.

Table 3.2 Poverty incidence in the LIRB

	Poverty incidence (%)	
District	**1997**	**2007**
Maracuene	57	68
Manhiça	63	78
Moamba	62	74
Magude	59	80

Source: (AUCRG, 2012)

3.1.3. Climate

The catchment has three different climate types, dry climate in Moamba, dry subtropical in Magude and humid tropical climate in Marracuene and Manhiça (AUCRG, 2012). Generally the climate in the catchment is hot humid on the littoral and dry as one approaches the inland (MAE, 2005). It has got two seasons: the summer which is characterized of high precipitation from October to Mach and dry season from April to September. The mean annual precipitation is 740 mm/year. The mean annual potential evaporation is 1,900 mm/year. Therefore, there is a deficit between the annual potential evaporation and precipitation as demonstrated in Figure 3.2. This makes irrigation a very important component of crop production (Vaz and van der Zaag, 2003).

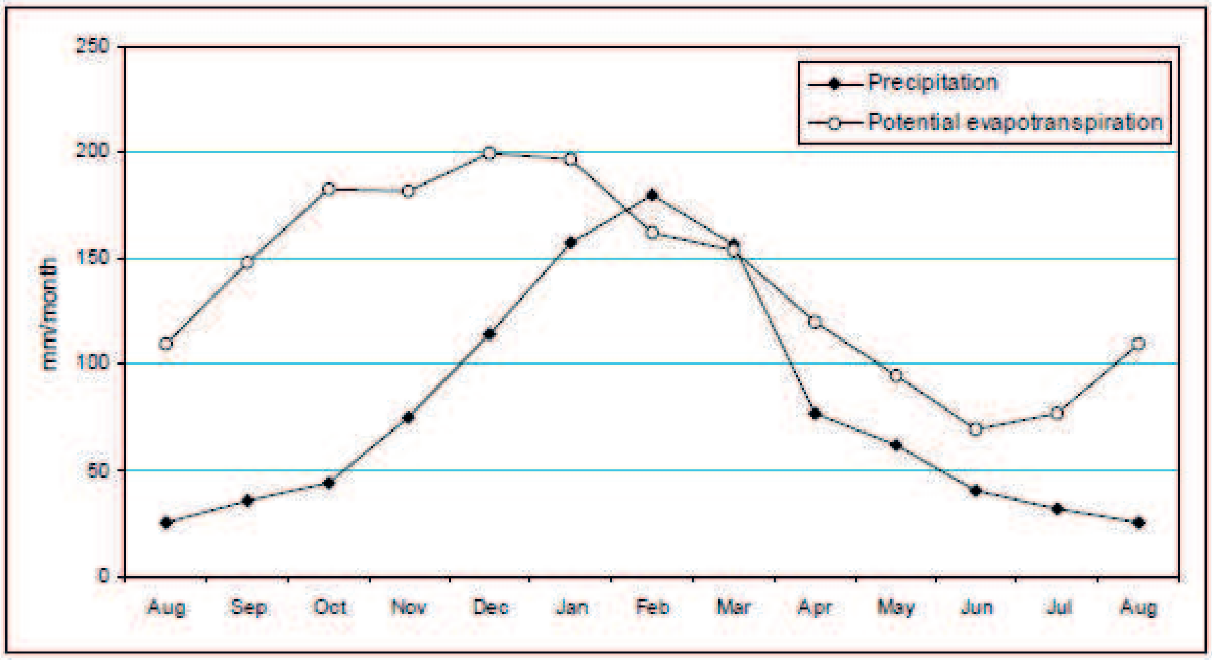

Figure 3.2 Average precipitation and potential evaporation

Source: (Vaz and van der Zaag, 2003)

3.1.4. Hydrology, infrastructure and water use

The major tributaries of LIRB are Sábie, Massintonto, Mazimechopes and Uanetze, all contributing 171 Mm^3/year equivalent to 5 % contribution to the total basin runoff (Vaz and van der Zaag, 2003). The variations of the average annual flow are presented in Figure 3.3, which shows a declining trend from 1952 to 2008. Occurrence of floods in the Lower Incomati River Basin is at irregular intervals which impacts on agriculture, infrastructure and life. The most devastating flood in the basin occurred in the year 2000 (UNEP, 2009). There are hydraulic infrastructures in all districts but the major one is Corumana Dam with a storage capacity of 879 Mm^3 located in Moamba District (AUCRG, 2012).

According to AUCRG (2012) the main water users are irrigation consuming 150 million m^3/year, followed by industry with 11 million m^3/year, then municipality and domestic 4 million m^3/year, and exotic tree plantation 2 million m^3/year. Nevertheless, water use has been increasing in the last decade and water scarcity is becoming severe (Vaz and van der Zaag, 2003). This scenario might be related to the establishment of new agricultural development such as COFAMOSA association with about 29,000 ha in Moamba District, the Indian farm with 7,000 ha and also the expansion of Xinavane Sugar Company by 3,000 ha in Magude District (AUCRG, 2012).

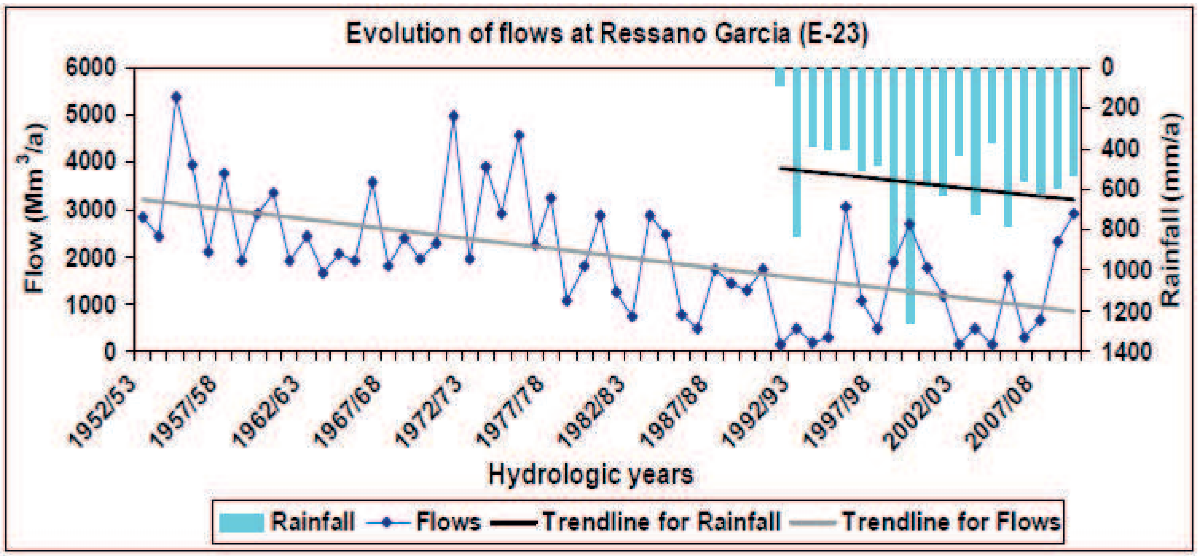

Figure 3.3 Average annual flows at Ressano Garcia (E-23)

Source: (Macuacua, 2011)

3.1.5. Temperature

The temperature in the LIRB varies from one district to another because of the geographical location of the districts (Marracuene, Manhiça, Moamba and Magude) (Vaz and van der Zaag, 2003). The annual average temperature downstream in Marracuene and Manhiça districts is 20 ºC with amplitude variation of 10 ºC, in Magude region the temperatures range from 22 to 24 ºC, then upstream in Moamba region the temperatures range from 23 ºC to 24 ºC (AUCRG, 2012).

3.1.6. Soils and biodiversity

According to AUCRG (2012) the basin soils vary from heavy texture clay soils to medium and sand soils. The predominant vegetation of the Lower Incomati River Basin is shrub savannah generally it is made up of *Colophospermum mopane* type of vegetation (Vaz and van der Zaag, 2003). In addition, the Lower Incomati River Basin provides habitats for a variety of animal species which include over 500 bird species (AUCRG, 2012). Some of the animal species include the Wattled Crane, Blue Swallow, Blackrumped Buttonquail, Egyptian Vulture, Hippotragus equines (roan antelope), Yellowbilled Oxpecker, and Lycaon pictus (wild dog) (Vaz and van der Zaag, 2003). There are also numerous rare reptiles, amphibians, and butterflies occurring in the Lower Incomati River Basin (Vaz and van der Zaag, 2003).

3.1.7. Ecological conditions of the Lower Incomati River Basin

The ecological conditions of the LIRB in Mozambique are under threat from soil erosion stimulated mostly by floods and soil extraction for construction purpose mainly in Moamba District (Loforte, 2014). About 150 ton/km^2 of soil is eroded annually in the catchment hence impacting on the water flow downstream due to deposition (Vaz and van der Zaag, 2003). The occurrence of aquatic plants in the river, shown in Figure 3.4 is also an ecological threat of the LIRB in Mozambique (Loforte, 2014). This affects negatively socio-economic activities such as water abstraction for irrigation and domestic use, navigation, fishing, recreation. Saline contamination is another ecological problem in the basin and it is affecting the downstream areas in Manhiça and Marracuene districts (AUCRG, 2012). In Corumana Dam there are reports of occurrence of green blooms that produce toxic substances affecting the growth of fish due to reduction of oxygen in the water and increasing the cost of treatment for drinking purposes (AUCRG, 2012).

Figure 3.4 Occurrence of aquatic plants in LIRB

3.1.8. Institutional arrangement for water resources management

The first document developed in Mozambique after independence related to water resources management is the *Ministerial Diploma Nº 25/87* that resulted in the formation of the National Directorate for Water (DNA) (AUCRG, 2012). After the formation DNA, the Mozambican Government set Water Tariffs, which regulated the extraction of large amounts of water from the dams (NEPAD, 2013). The first national Water Law, which replaced the Portuguese Water Law, was approved in 1991 (Law Nº 25/91) (UNICEF, 2011). This Law established the property right regime of the water resources in the country by stating that superficial and underground water are owned by the State. The 1991 Water Law created the National Water Council (CNA) through the Decree Nº 25/91 and five Regional Water Administration Agencies (ARAs) through the Act Nº 26/91 (FAO, 2005).

The CNA is an inter-ministerial organ composed of members from various government ministries, which is responsible for advising the government on issues related to water management and policy including the implementation of the 1991 water law (NEPAD, 2013). The five Regional ARAs are ARA-Sul, ARA-Zambeze, ARA-Centro, ARA-Centro Norte and ARA-Norte; the five ARAs report to DNA but they have financial and administrative autonomy (WaterAid, 2010). The Lower Incomati River Basin falls under the ARA-Sul management (FAO, 2005).

ARA-Sul is represented by the Lower Incomati River Basin Management Unity called UGBI. It plays the role of implementation of general system of water use, tariff collections and ensuring that existing water resources meet demand (NEPAD, 2013). There is a committee in the LIRB through which the involvement of stakeholders in the water resources management is done at the basin level (AUCRG, 2012). The basin committee is chaired by the UGBI director and it is composed of stakeholders that include representatives of the private sector, Xinavane and Maragra sugar companies, water user associations, religious institutions, farmer, small growers associations and guests from other economic and political sectors (AUCRG, 2012).

Water resources management in Mozambique is satisfactory, and follows the IWRM Principles (NEPAD, 2013). A good example of that includes the development of legal frameworks (1991 Water Law and the 1995 Water Policy) (Munguambe *et al*., 2010). These legal frameworks created institutions at all levels and decentralisation of the water resources management (Ibraimo, 1999). According to NEPAD (2013) even though the implementation of IWRM has been successful, there are still challenges relate to:

i) Inadequate criteria of water allocation that consider efficiency and economic benefits;
ii) Lack of revenues from water users to for financing the effective work of IWRM;
iii) Restricted emphasis on groundwater;
iv) Resilience of the sector to climate change and extreme events;
v) And limited cross-sectorial coordination of pollution control.

4. MATERIALS AND METHODS

4.1. Study area

4.1.1. Selection of study site

The Lower Incomati River Basin is a transboundary river basin shared between three countries (Mozambique, South Africa and Swaziland). The portion of the basin in Mozambique is affected by activities from upstream countries (Vaz and van der Zaag, 2003). There are two sugar industry companies within the LIRB, making the basin important to the development of the country (Buur *et al*., 2012). The sugar production has negative impacts on the water quality in the catchment due to fertilisers runoff as a result of excess amount of water from the fields (Leestemaker and Tauacale, 2000). The basin is one of the major sources for various water uses (domestic, municipal use, agricultural and industrial use) in southern Mozambique (Vaz and van der Zaag, 2003). The LIRB has important features such as the Incomati estuary and wetlands that needs to be protected. The estuary and the wetland provide home to a large variety of animals and plant species, some already endangered (AUCRG, 2012).

4.1.2. Selection of sampling sites

Sampling sites were selected basing on the possible pollution type from particular land use, and the accessibility site. According to USGS (2014) the study area should have sites located upstream and downstream of polluting activity, and also there should be a control sampling site (see Table 4.1). These sites were located in the middle of the catchment where the biggest irrigation and other polluting activities are taking place. Other activities taking place apart from agriculture include sand mining, industry and urbanization.

Table 4.1 Sampling site locations, coordinates and their characteristics

Site No	Easting's (m)	Northing's (m)	Characteristics of the site
SS1	436517	7200448	Sampling site control located before any influence of the activities taking place in the estates
SS2	465159	7231641	Located soon after agricultural activities with less influence from drainage (ARA-sul sampling site)
SS3	473808	7228474	Located before Aguiar drainage to assess the contribution in the Tsatsimbe Lagoon
SS4	471172	7230305	Located after Aguiar drainage to assess the contribution in the Tsatsimbe Lagoon
SS5	479851	7222033	Located after Tres de Fevereiro drainage to assess the contribution in the Tsatsimbe Lagoon
SS6	488525	7223447	Vamagogo drainage point (ARA-sul sampling site)
SS7	489132	7218984	Taninga agricultural drainage point from sugarcane plantations located after agricultural activities

4.1.3. ARA-Sul sampling sites

At the catchment level, three sites were selected (E-23, E-43 and E-28) and these are presented in Figure 4.1. These sampling sites are quarterly monitored by the water authority. The site E-23 is located at Ressano Garcia near the border with South Africa. This site was chosen because it gives an indication of the status of the water entering into the country. The site E-43 is located in Magude District, and it represents the sampling site (SS2) of the infield measurements. It was selected to cater for the water quality situation within the sugar cane plantations. Finally the site E-28 is located downstream at Manhiça, almost 48 km to the river mouth; it was selected to help in assessing the influence of agricultural drainage.

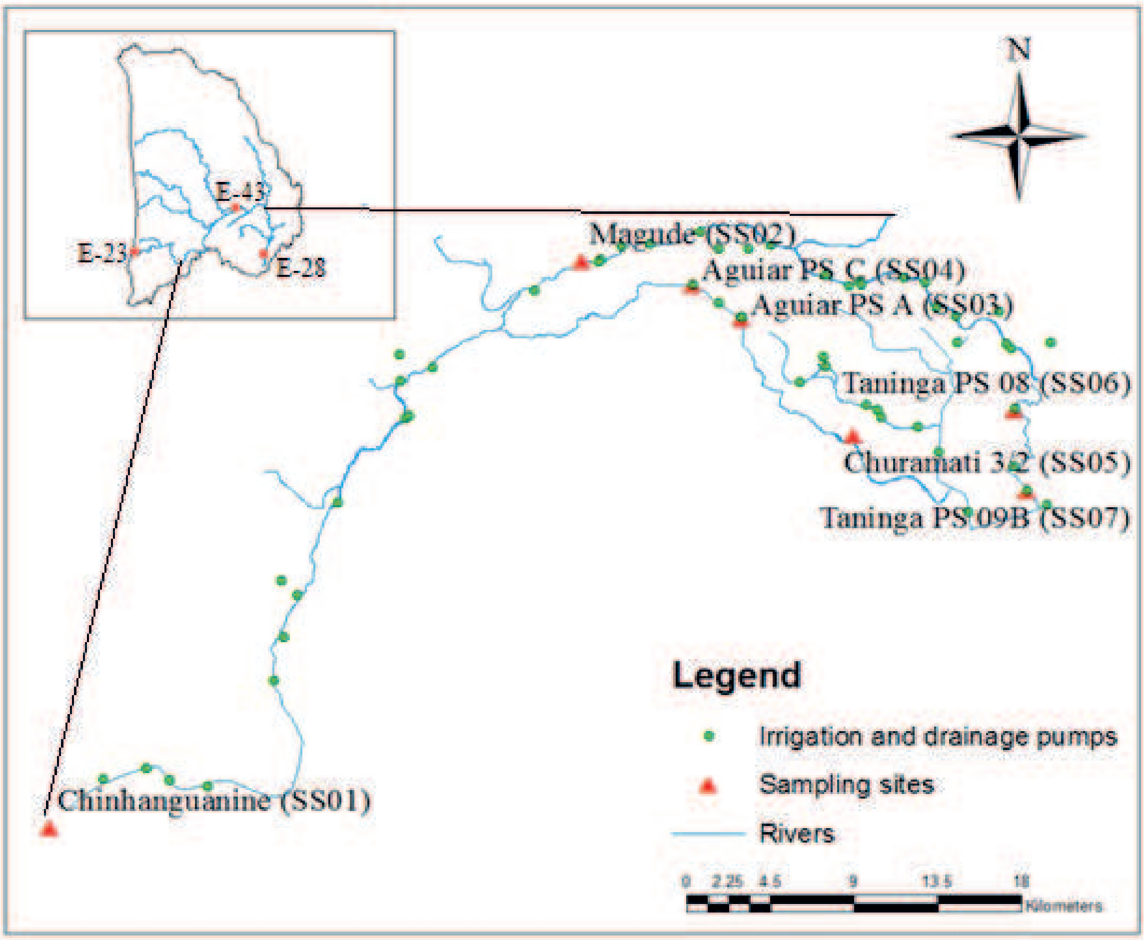

Figure 4.1 Location of sampling sites showing the ARA-sul sites and the sites study design

4.1.4. Selection of water quality parameters

The study parameters selected were related to the activities in the study area. The main land uses in the study area are agriculture, industry and urban settlements. The major pollutants from these sources are bacteria, nutrients, pesticides, herbicides, industrial organic micro pollutants, trace elements, oils and greases (Chapman, 1996). This study also took into consideration the interest of downstream water uses such, drinking, irrigation, fisheries and the environment (aquatic wildlife). The pollutants that can limit the use of water downstream are, suspended solids, organic matter, nitrates, trace elements and salts (Chapman, 1996). Therefore, the study measured the following parameters: temperature, turbidity, total suspended solids, total dissolved solids, pH, electrical conductivity, salinity, alkalinity, COD, total coliforms, faecal coliforms and nutrients (ammonia, nitrates, nitrites and phosphorus).

The parameters monitored by ARA-sul are: temperature turbidity, dissolved oxygen, colour, total dissolved solids, pH, electrical conductivity, alkalinity, faecal coliforms, total coliforms nitrites, nitrates, ammonia, total phosphorus, potassium, calcium, magnesium, sulphate, sodium, carbonates, chloride, and total hardness. However, amongst all these parameters, the ones with complete data from 2000 to 2015 and from the three sampling sites: turbidity, pH, EC, ammonia, nitrates and nitrites are the ones which were used to assess the historical changes on water quality.

4.1.5. Methods of sampling and frequency

The grab's sampling method was used for sampling as recommended by (USGS, 2014). According to EPA (2013) this method consists of a single discrete sample and can be applied for flowing waters for wide rivers and where the water flow is not turbulent. Samples were collected twice a month from January to March of 2016.

4.2. Data collection methods

4.2.1. Sampling of water

The study had separated parameters for *on-site* measurements and laboratory analysis. As shown in Table 4.2, parameters such as temperature, conductivity, TDS, salinity and pH were measured *on-site* as recommended by USGS (2014) using *Lovibond* brand meters. For parameters like turbidity, alkalinity, nutrients, and total suspended solids, samples were collected in one and half litres bottle and sent to the laboratory. Samples for faecal coliforms and COD where taken carefully in sterilized bottles acquired from the laboratory. All the samples were placed in a cooling box with ice immediately after collection and kept under 4 ^{o}C as recommended by standards guidelines (USGS, 2014).

4.2.2. Water quality testing

Samples were collected in the afternoon; just a day before analysis and conserved in a refrigerator allocated for the purpose (see Figure 4.2). In the morning of the following day, the samples were taken in a cooling box to the lab (National Laboratory for Food and Water Hygiene) for analysis. The methods or instruments used in the lab as well as in the field were conducted according to standard methods (APHA, 2001) as shown in Table 4.2 in relation to each parameter. The samples were tested within 24 hours (USGS, 2006). All the samples of water were collected from January to March 2016.

Figure 4.2 Instrument used for infield measurements (left) and samples preservation (right)

Table 4.2 Methods of water testing

Parameter	Units	Instrument/method	APHA Method No.
Temperature	(^{0}C)	Conductivity meter (*lovibond SD 300 pH*)	2550
TSS	(mg/l)	Gravimetric (LNHAA)	2540 B
Turbidity	(NTU)	Turbidimeter (LNHAA)	2132 B
Ammonia	(mg/l)	Spectrophotometric (LNHAA)	4500-SO_4^{-2} E
Nitrates	(mg/l)	Spectrophotometric /Molecular absorption (LNHAA)	4500-NO^{3-} B
Nitrites	(mg/L)	Spectrophotometric with sulfanilic acid (LNHAA)	4500-NO^{2-} B
T. phosphorus	(mg/l)	Tin chloride (LNHAA)	4500-PE
pH	(-)	pH meter (*lovibond SD 300 pH*)	4500-H^+
Conductivity	(µS/cm)	Conductivity meter (*lovibond SD 320 Con*)	2550
TDS	(mg/l)	Gravimetric (*lovibond SD 320 Con*)	-
Alkalinity	(mg/l)	Volumetry (LNHAA)	-
Salinity	(SAL)	(*lovibond SD 320 Con*)	-
COD	(mg/l)	Volumetric (LNHAA)	5220 C
F. coliforms	(ufc/100ml)	Membrane filtration (LNHAA)	9222 D

Source: (APHA, 2001)

4.2.3. Landsat image description

For landuse classification, Landsat images were downloaded from the website of the United State Geological Survey (USGS): http://**glovis**.usgs.gov. These images have high spatial (30

m) and temporal (15 – 16 days) resolutions. The study area was covered by four image scenes path/raw 167/77, 167/78, 168/77 and 168/78; and the images were less than 10 % cloud cover.

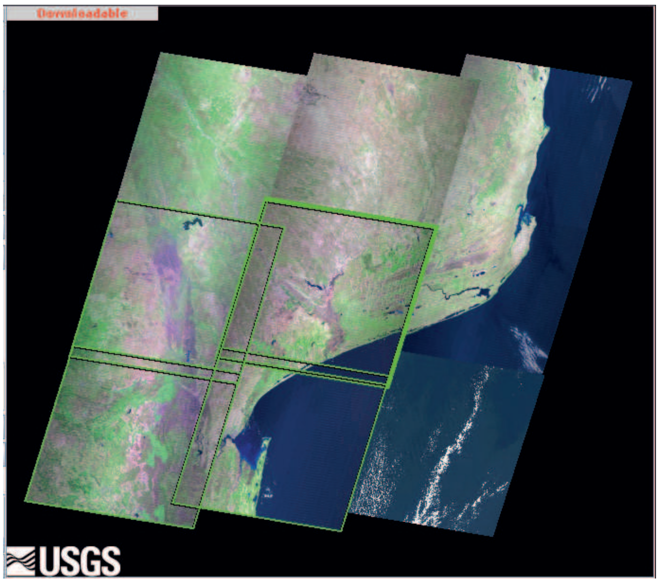

Figure 4.3 Sample of the scenes downloaded from the website http://glovis.usgs.gov

The images were downloaded for the years 2000, 2005, 2010 and 2015 for the dry season (between July and September). Table 4.3 shows information per image path and row where the image is found, the date, Landsat type and the bands used.

Table 4.3 Landsat image path and raw, type, date, cloud cover and bands used

Image path/raw	Landsat Mission	Image date	Cloud cover	Spectral bands used
167/77	LS 4-5 MSS	19 September 2000	1 %	3,4 and 5
197/78	LS 4-5 MSS	01 September 2000	10 %	3,4 and 5
168/77	LS 4-5 MSS	10 September 2000	0 %	3,4 and 5
168/78	LS 4-5 MSS	10 September 2000	6 %	3,4 and 5
167/77	LS 4-5 TM	23 July 2005	0 %	3,4 and 5
197/78	LS 4-5 TM	23 July 2005	0 %	3,4 and 5
168/77	LS 4-5 TM	30 July 2005	0 %	3,4 and 5
168/78	LS 4-5 TM	30 July 2005	0 %	3,4 and 5
167/77	LS 4-5 TM	07 September 2010	0 %	3,4 and 5
197/78	LS 4-5 TM	07 September 2010	3 %	3,4 and 5
168/77	LS 4-5 TM	14 September 2010	0 %	3,4 and 5
168/78	LS 4-5 TM	14 September 2010	0 %	3,4 and 5
167/77	LS 8 OLI	01 September 2015	0 %	3,4 and 5
197/78	LS 8 OLI	01 September 2015	1 %	3,4 and 5
168/77	LS 8 OLI	27 August 2015	1 %	3,4 and 5
168/78	LS 8 OLI	27 August 2015	1 %	3,4 and 5

4.2.4. Image processing and classification

The mapping process of land use change over time began with mapping the 2015 Landsat imagery, then 2010, followed by 2005 and finally the 2000 Landsat imagery. The Landsat images were used due to their relatively good spatial and temporal resolution (30 m and 15 days respectively) and because they are freely available on internet. Supervised digital image processing was then performed using the *ILWIS 3.31 Academic* software analysis. Six landuse classes were defined and separated using the maximum likelihood classifier algorithm. The number and type of landuse classes are normally determined by the author; but the usual classes are bareland, forest, grassland and shrubland, irrigation, settlements and water. These classes ware also defined and applied by (Chu *et al*., 2013; Wagner *et al*., 2013 and Han *et al*., 2015).

4.2.5. Future landuse projection

To generate future landuse scenarios, the Markov Chain analysis was applied as suggested by many authors (Huang *et al*., 2005; Iacono and Levinson, 2009; Reveshty, 2011; and Han *et al*., 2015). The method is based on the assumption that the driving forces that resulted in changes in the past will continue to do so in the future (Tsarouchi *et al*., 2014). Implementation of the equation was done through the *Terrset 18.9* software. For this study, images for 2000 and 2015 were used as earlier and later land cover images respectively. The images were used to develop different scenarios of the future landuse/cover status for the years 2020 and 2030, since the number of years of predicted landuse change (15) cannot be more than the years used to predict.

Other authors also follow the same thought, for example Huang *et al*. (2005) used maps for 1984 and 2005 to predict landuse changes in 2020; Kumar (2016) used maps for 1977 and 2015 to predict for 2053; and Reveshty (2011) used maps for 1984 and 2011 to predict for 2020. Subsequently, ten transition potential groups were derived from the two maps and grouped into four transition sub-models that were then used to map the changes. From the changes derived between the two land cover maps, the future changes were predicted based on the change demand modelling method, Markov Chain. The Markov transition matrix *(P)* is calculated using Equation 4.1.

$$P = (p_{ij}) = \begin{vmatrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ P_{n1} & P_{n2} & \cdots & P_{nn} \end{vmatrix}, \quad \sum_{j=1}^{n} p_{ij} = 1$$

.... Equation (4.1)

Where: i,j = landuse class of the first and second time period

P_{ij} = probability from landuse class i to landuse class j.

The Markov Chain was implemented under the land change modeller (LCM) module of *TerrSet 18.9* software. The steps on the methodology to obtain the future landuse maps are shown in Figure 4.4.

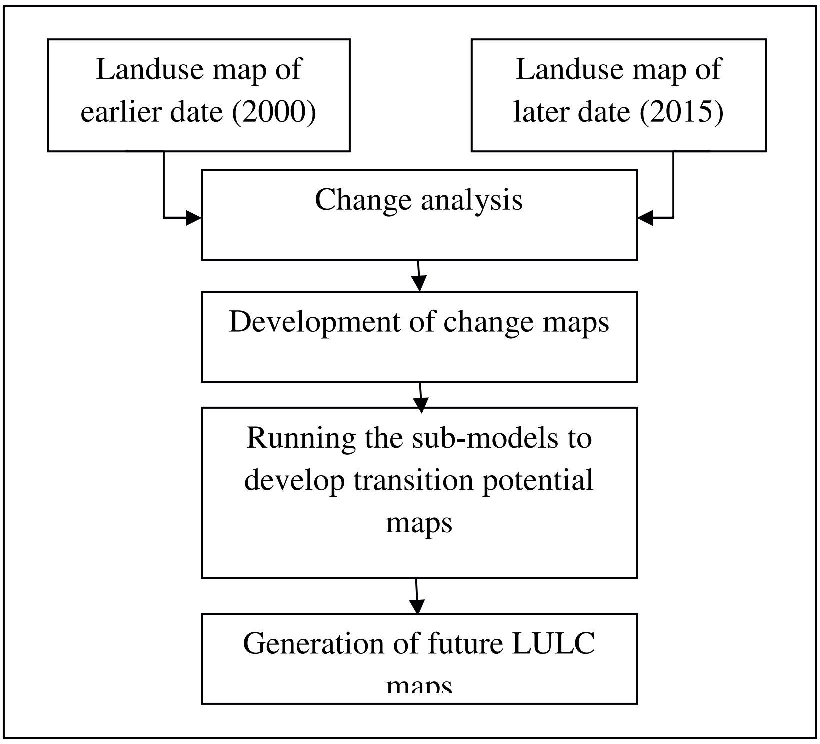

Figure 4.4 Process of future landuse map prediction

4.2.6. Assessment of accuracy

The accuracy for landuse classification process was done in *ILWIS 3.31 Academic* software, using a confusion matrix. The method is based on a comparison of the classification results and the ground information. The accuracy assessment for future prediction of landuse in *Terrset* software was done on the validation panel, based on the predicted map for 2015 and the classified map for the same year. The map for 2015 was predicted based on the earlier map for 2000 and later map for 2010.

4.3. Methods of data analysis and interpretation

4.3.1. Interpretation of water quality data

Historical data obtained from the water authority were sorted using a Microsoft office 8.0 excel worksheet. The data were then tested for normality in IBM SPSS software version 23 (Statistical Packaged for the Social Sciences). When the p-value was less than 0.05 the data was not normally distributed, if greater than 0.05 it was normally. The descriptive analysis was run to determine the maximum, minimum, mean, standard deviation, standard error and coefficient of variance. Again in excel graphs were drawn to show the temporal and spatial variation of water quality in the catchment.

Cluster analysis was performed to verify the similarities of the sampling sites; the sites were grouped into clusters according to their similarity based on the Agglomerative hierarchical clustering (AHC) method. Also key parameters contributing to pollution in the catchment were identified from the descriptive statistics. Then to check the trend on the historical data, Mann-Kendall trend test was performed using XLSTAT software. All the results were then compared to the Ico-Maputo standards. These standards were adopted for the monitoring of the Incomati River, established on Inco-Maputo agreements, between Mozambique, Swaziland and South Africa, in 2002. The standards encompass the intended uses in the catchment which are domestic, irrigation, industry and environment. The standards also consider the drinking purpose since in upstream areas people still drink the water without treatment.

4.3.2. Interpretation of land cover data

To interpret the landuse change data, statistical analysis were also used. Firstly, the area occupied by each landuse class was determined based on the ILWIS map histogram data for each year, from there, percentages for each landuse was determined and the percentage change from 2000 to 2015.

4.3.3. Relationship between changes in landuse and the quality of water

Based on the historical water quality and the historical change in landuse, six water quality and six landuse variables were used to determine the relationship between changes in landuse and water quality. The water quality variables used were pH, EC, ammonia, nitrates, nitrites and turbidity. The land use variables were bareland, forestland, grassland and shrubland, irrigation, settlements and water, chosen according to the landuse classes. Bivariate correlation and multiple regression analysis were performed to determine the correlation coefficients at 0.05 significance level, r-squared and constants using the SPSS software. Then, an econometric model recommended by Huang *et al*. (2013) was used to establish the relationship between the two variables.

5. RESULTS AND DISCUSSION

5.1. Water quality analysis

To assess the water quality situation in the catchment, the section was divided into two aspects, current and temporal variation.

5.1.1. Current variation of water quality

To assess the current variation of water quality, primary water quality data was used based on field and laboratory analysis. The data was collected in six campaigns from 7 sites, namely SS1, SS2, SS3, SS4, SS5, SS6 and SS7. Fifteen parameters ware analyzed and descriptive statistics were used to identify the most important for this study. Ammonia, nitrates and nitrites are not included in Table 5.1 because these parameters show constant results (ammonia <0.04, nitrates <0.5 and nitrites <0.03), which cannot be analysed statistically. These values of ammonia, nitrates and nitrites are within the recommended standards for Inco-Maputo. The standards state a maximum of 1 mg/l, 50 mg/l and 1 mg/l, respectively.

Table 5.1 Descriptive statistics for current water quality analysis

Parameter	Minimum	Maximum	Mean	Std. deviation
Temperature	28.4	30.8	29.3	±0.7
Turbidity	10.5	78.8	46.8	±24.4
TSS*	202	518	316	±109
TDS*	299	3,115	1,052	±979
pH	7.2	8,0	7.5	±0.4
EC*	479	4,783	1,628	±1,497
Salinity	0.1	0.9	0.4	±0.3
Alkalinity	50	186	120	±52
COD*	320	11,200	5,362	±4,137
Total Phosphorus	0.2	0.9	0.4	±0.2
Total coliforms	57	100	87	±19
Faecal coliforms	47	100	82	±25

*Key water quality parameters

From Table 5.1, it can be seen that TSS, TDS, EC, and COD are the key pollutant parameters since they are the most variant. The parameters show a standard deviation of 109, 979, 1,497, and 4,137, respectively.

a) Classification of sites

The sampling sites were classified according to their similarities and the results are shown in Figure 5.1. The dendogram suggests four classes for the seven sampling sites namely, class 1 for SS1, class 2 for SS2, class 3 for SS3, SS4, SS5 and SS7, and class 4 for SS6.

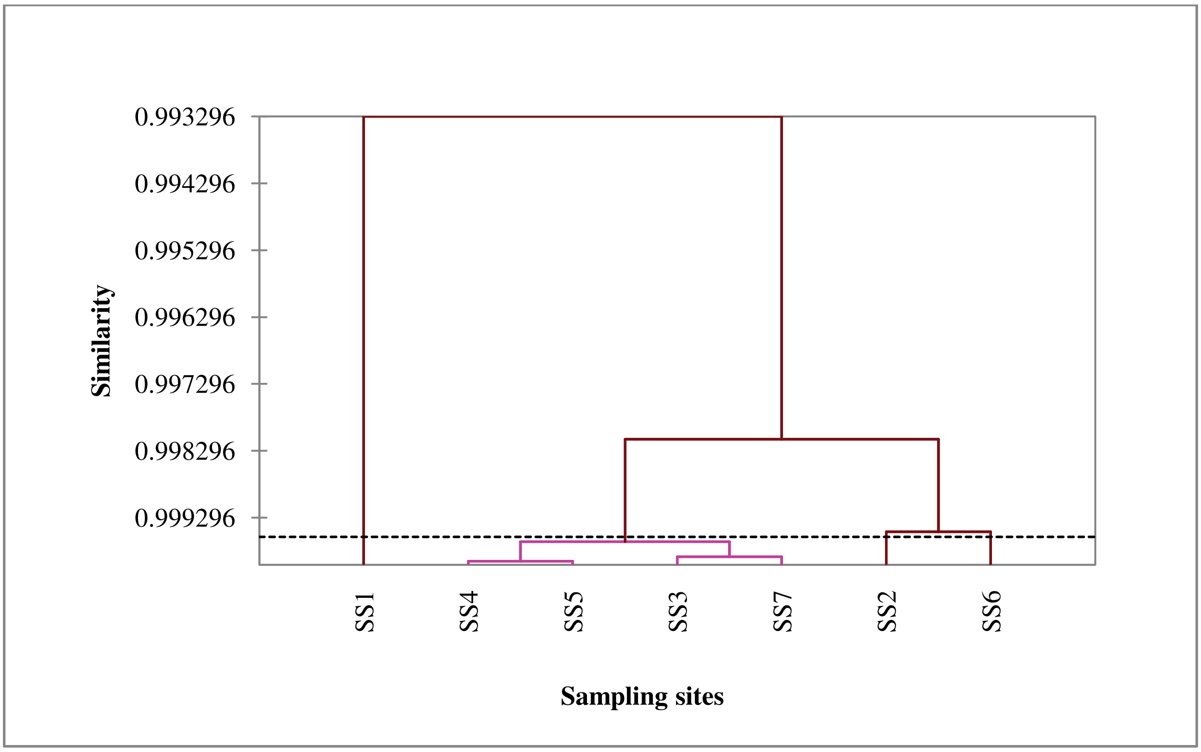

Figure 5.1 Classification of sampling sites

Figure 5.1 shows that the sampling site control (SS1) was well located, since it does not have similarities with any other site. The sampling sites SS3, SS4 and SS5 that are located in Tsatsimbe lagoon are found in the sane class (class3).

b) Total Suspended Solids

In terms of TSS, the results show a slight decrease from upstream to downstream. The highest values were found at an upstream sampling site (SS1) that reached 518 mg/l and the lowest at a downstream sampling site (SS4) of 202 mg/l. This can be explained by the fact that the waters are shallow and usually polluted by cattle and laundry activities (see Figure 5.2). Contrary at SS4, there are deep, stagnant waters that allow suspended particles to settle down.

Figure 5.2 Sampling sites SS1 (left) and SS4 (right)

According to WHO (2003c), concentrations of TSS in rivers can increase with its turbulence and by the resuspension of particles deposited in the river bed. Figure 5.3, shows the variation of total suspended solids in the study area. Similar results were found by Pullanikkatil *et al.* (2015) when investigating the impacts of landuse change on water quality in the Likangala catchment in Malawi. This study found out that suspended solids were more concentrated in busy areas with high turbulence such as the rice farms, downstream of hospitals, busy market area and close to wastewater treatment works.

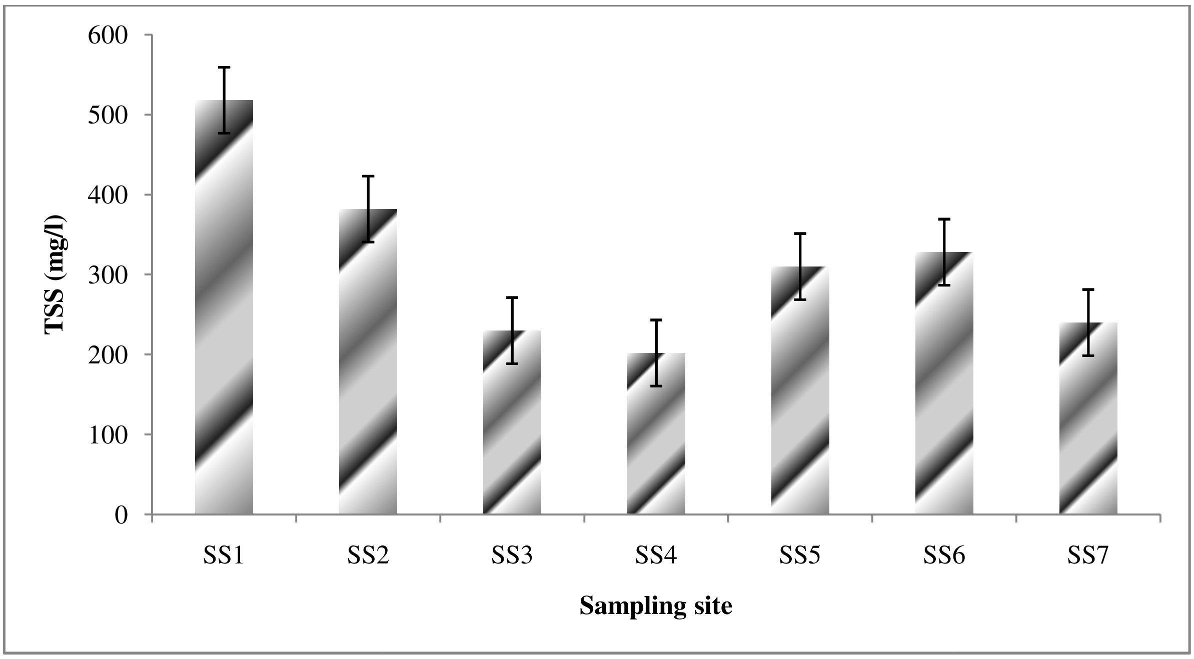

Figure 5.3 Concentrations of TSS for January to March 2016 for Incomati River

The Inco-Maputo standards have no guidelines for total suspended solids. However, from the results, it can be concluded that total suspended solids in the study area are within acceptable conditions for drinking purpose since the limit should be 1,500 mg/l (WHO, 2003b). High concentrations of suspended solids can cause problems for aquatic life and river health, and can also cause blockage in irrigation systems, mostly the nozzles of sprinkles (FAO, 2000). A study conducted in Limpopo River Basin in Mozambique revealed similar results. The mean value for total dissolved solids was found to be 389 mg/l. The aim of the study was to evaluate the water quality condition and propose a downstream water quality network to support activities in the basin. The overall conclusion was that water was deteriorated and not meeting the guidelines for most of the sites (Chilundo *et al*., 2008).

c) Total dissolved solids and electrical conductivity

The highest values of TDS and EC obtained, as shown in Figure 5.4, was for sampling site five (SS5) that reached an average of 3,115 mg/l and 4,786 µS/cm, respectively. This site happens to be a drainage point at the Tsatsimbe Lagoon in Três de Fevereiro cropped area, within the sugarcane plantations of Xinavane. This area is known for its high concentrations of salt as a result of poor drainage and frequent floods in the rainy season (Loforte, 2014). Since EC is the measure of the capacity of water to move electrical current, it should be directly related to salts dissolved in water. This fact explains the values of TDS and EC found at sampling site (SS5) (Iyasele and David, 2015).

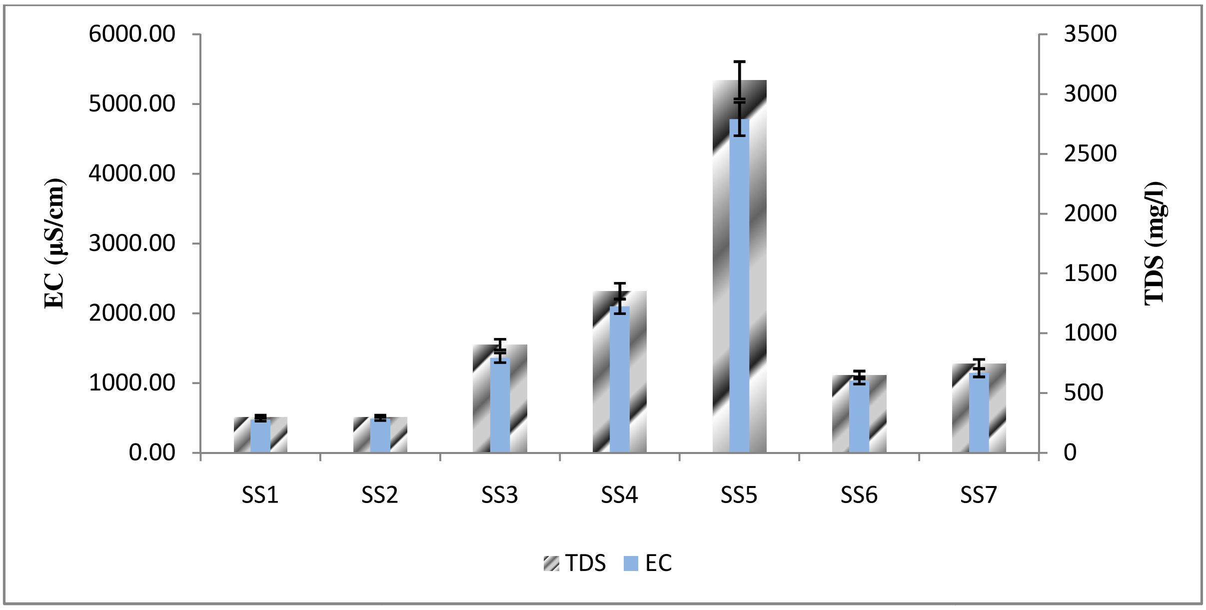

Figure 5.4 Concentrations of EC and TDS for January to March 2016 for Incomati River

The lowest values obtained are at sampling site (SS1) which happens to be the sampling site control located upstream of the polluting activities. The lowest EC value is 479 µS/cm and the lowest TDS value is 299 mg/l. The graph shows an increase from upstream to downstream, showing some influence of activities taking place in between. The relationship between EC and TDS was established and the *k* value determined is equal to 0.65 ≈ 0.7, the adequate conversion factor for fresh water (PASCO, 2010). The results showed that *TDS=0.65*EC*, implying that, it is possible to predict the value of one parameter based on values of another. Figure 5.5 shows graphical representation of the EC vs TDS relationship.

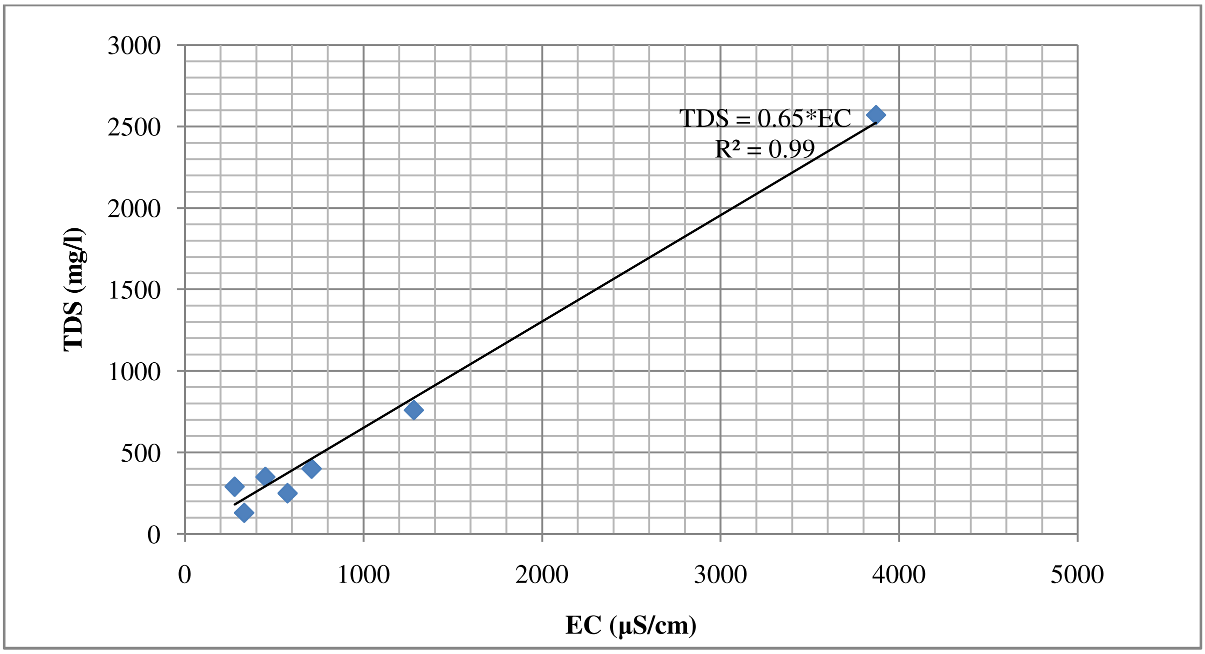

Figure 5.5 Representation of the k-value showing the relationship between TDS and EC

From the values of the two mentioned parameters, it can be concluded that water quality is suitable for irrigation since the salt concentrations are within 200 to 4,000 mg/l of TDS as recommended by FAO (2000), except for sampling site (SS5) where EC is above 4,000 mg/l. From the drinking perspective, water from sampling sites (SS1) and (SS2) is acceptable since the TDS concentrations are below 1,000 mg/l (WHO, 2003b), although it is not acceptable compared to NGRDC (2001) which states a maximum of 500 mg/l. It is always important to treat the water before drinking, even though in the communities around these sampling sites (SS1) and (SS2), the water is not treated before drinking. However the EC values are far above the limit established for Inco-Maputo of 1,500 mg/l for sites SS3, SS4 and SS5. These three sites are located in Tsatsimbe Lagoon. Again this fact can be related to the salinity in this lagoon resulting from excessive use of fertilizers from agricultural activities taking place in the area (Loforte, 2014). A study conducted in Khorezm, province of Uzbekistan in central Asia, proved that unsustainable management of irrigation systems resulted in various ecological problems, for instance high levels of soil salinity. The soil salinity leaching from agricultural production contributes to the water salinity in Amudarya River (Ho, 2004).

d) Chemical oxygen demand

The current variation of chemical oxygen demand (COD) for the study area is presented in Figure 5.6. These results are for January to March 2016.

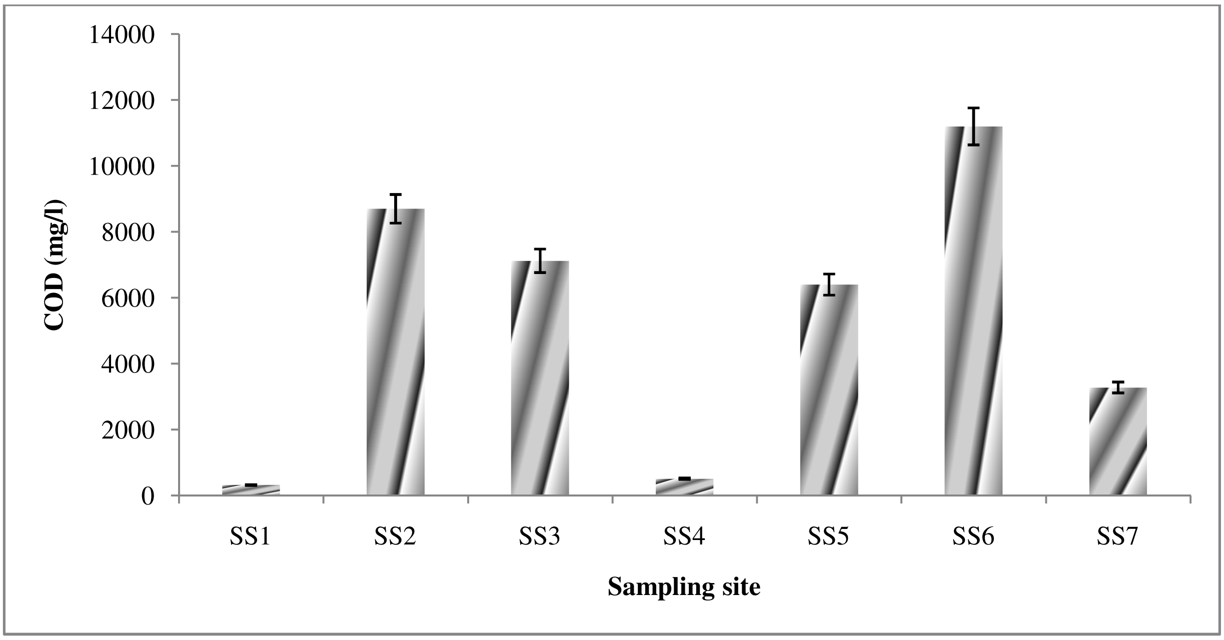

Figure 5.6 Concentrations of COD for January to March 2016 for Incomati River

Figure 5.6 shows that the COD values range from 320 mg/l to 11,200 mg/l, at SS1 and SS6 respectively. At SS1, the water is used for drinking purposes; although the sampling site SS6 is one of the main agriculture discharge points. The river at SS6 is covered by aquatic plants (algae, reeds, etc). Hydro biota excretion, atmospheric deposition, surface runoff, industrial, municipal and agricultural inputs can lead to the occurrence of organic matter in water lowering the dissolved oxygen concentrations and increasing COD (Gwaski *et al.*, 2013). These values can be explained by the fact that in these sites with high COD values, the water surface is covered by aquatic plants showing effects of eutrophication.

Kibena (2012) also found similar results when studying water quality in the Upper Manyame Catchment in Zimbabwe. Concentrations of COD were high in areas that receive human waste from settlements and wastewater from industries. Although the similarity in terms of location of highest values, the values found in the present study are too high as compared to the ones found by Mero (2011) where COD concentrations were ranging from 2,399 mg/l to 3,784 mg/l in the wastewater from textile and tannery. It shows that water in the LIRB is demanding for oxygen more than the demand of oxygen for wastewater. This is critical in a basin where the water is used for multiple purposes (irrigation, industry, fishing and domestic in some points). This lack of oxygen can be linked to eutrophication since the sites with high demand for oxygen are the ones basically covered by aquatic plants.

e) Load of exceedance

The load of exceedance was compiled and the results are presented in table 5.2. Only the parameters with guidelines are presented.

Table 5.2 Percentage of exceedance for the parameters

Sampling site	Turbidity	pH	EC	Nitrates	Ammonia	Total coliforms	Faecal coliforms
SS1	78	7.84	479	<0.4	<0.03	>100	>100
SS2	37	8.02	489	<0.4	<0.03	>100	100
SS3	44	7.35	1363	<0.4	<0.03	64	47
SS4	11	7.71	2099	<0.4	<0.03	57	49
SS5	34	7.17	4783	<0.4	<0.03	85	78
SS6	79	7.16	1038	<0.4	<0.03	>100	>100
SS7	46	7.21	1146	<0.4	<0.03	>100	>100
IMS	5	6.5-8.5	150	50	1	10000	2000
% sampling limit	100	0	100	0	0	0	0

The table shows that turbidity and EC exceeded the standard in 100 % during the sampling campaigns and for all the sampling sites. pH, nitrates and ammonia did not exceed standards. Faecal and total coliforms were within the recommended standards for sites SS3, SS4 and SS5. For other sites, faecal and total coliforms were found to be greater than 100, which makes difficult to say if it was within or above the standards. This is critical mostly for site SS1 and SS2 were water is used for domestic purposes including drinking without any treatment.

5.1.2. Temporal variation of water quality

To assess the temporal variation of water quality, historical water quality data was used for three sampling sites at the basin level (E-23, E-43 and E-28). The data was analyzed for the period 2000 to 2015 for the six selected parameters (turbidity, pH, EC, ammonia, nitrates and nitrites,). As previously mentioned, these parameters are the ones frequently monitored by ARA-sul, hence are the ones with available data. The results of historical variation were also compared to the Mozambican standards. These standards were adopted for the monitoring of the Incomati River, established on Inco-Maputo agreements (Mozambique, Swaziland and South Africa) in 2002.

Average values of turbidity, pH, EC, ammonia, nitrates and nitrites, are presented in Table 5.3. The table shows that the parameter with high variation in the catchment is EC, the average concentration of which reached 435 µS/cm and standard deviation of ±152 µS/cm, followed by nitrates with standard deviation of ±25.57 mg/l and then turbidity with standard deviation of ±9.46 mg/l.

Table 5.3 Descriptive statistics of water quality for 2000 to 2015 for Incomati River

Variable	Maximum	Minimum	Mean	Standard deviation	Error
Turbidity (NTU) *	53.33	0.5	8.38	±9.46	1.37
pH	8.42	6.89	7.55	±0.35	0.05
EC (µs/cm) *	924	191	435	±152	22
Ammonia (mg N / l)	13.08	0.04	0.89	±2.18	0.31
Nitrates (mg N / l) *	88.63	0.08	20.42	±25.57	3.69
Nitrites (mg N / l)	0.68	0.03	0.10	±0.14	0.02

*Key water quality parameters
n = 48

a) Turbidity

The results of variations of turbidity in the LIRB are presented in Figure 5.7. This is the parameter that exceeded the standards of <5 NTU, throughout the period from 2000 to 2015. From Figure 5.7, it can be noticed that the maximum value of turbidity was reached in 2005 (53 NTU) for the sampling site E-23. The minimum value of turbidity was found in site E-43 for the year 2015 (0.5 NTU). These values can be related to the fact that runoff received in Mozambique from South Africa via site E-23 is already in high concentrations of turbidity. In addition to the socio-economic activities that are taking place in the catchment, the values increase to the point that the natural purification of the river cannot be efficient enough.

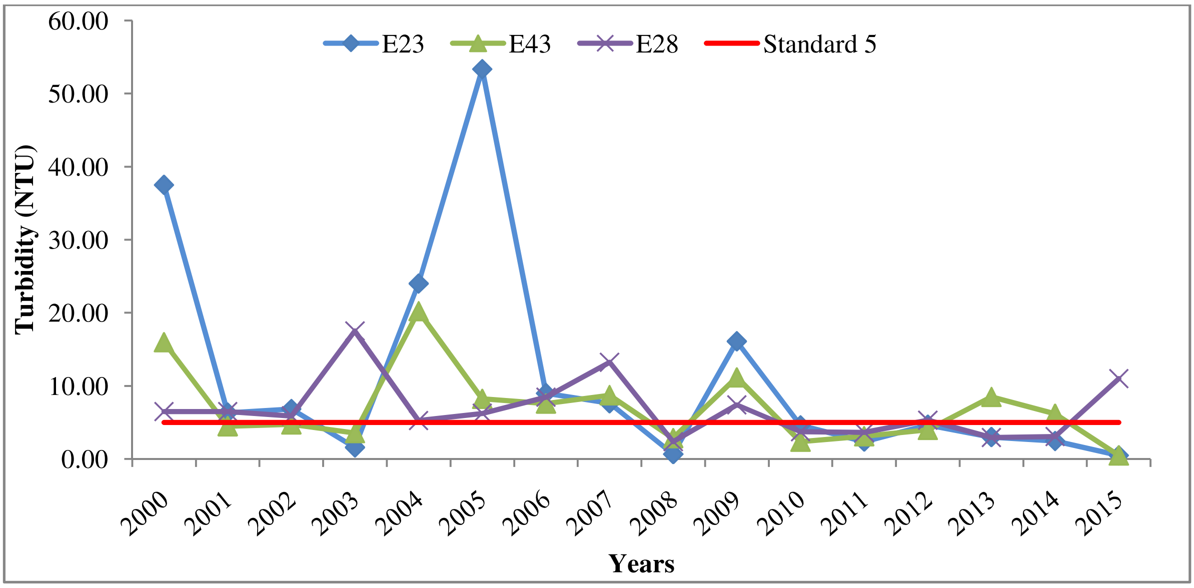

Figure 5.7 Temporal variation of turbidity for 2000 to 2015 for Incomati River

Figure 5.7 also shows that within the country there are some influences in the water quality since for some years (e.g. 2010, 2011, 2012 and 2015) there is an increase in turbidity from site E-43 to E-28. The figure also reveals that for the years 2013, 2014 and 2015, the limits are exceeded within the country since the runoff received had lower concentrations and it increased within the Mozambican portion of the basin. This can again be related to the anthropogenic activities taking place in the basin. NGRDC (2001) revealed that turbidity of 10 NTU or less represent very clear water, 50 NTU represent cloudy waters and turbidity >100 NTU represents very cloudy to muddy.

In general, turbidity values are not acceptable and might be affecting some fish species in case of exposure under prolonged conditions of >25 NTU (Sedaghat and Hoseini, 2012). Pullanikkatil *et al.* (2015) also found similar results when studying impacts of landuse on water quality in the Likangala catchment, in southern Malawi. The results of this study reveal that turbidity values where found high downstream of farms and settlements. For this study turbidity values exceeded WHO standards for all the sites.

A study by Ngoye and Machiwa (2004) carried out in Ruvu River in Tanzania, found out that turbidity ranged from 3.0 ± 0.6 to 840 ± 69.3 NTU, reaching higher values downstream towards the river mouth. The highest values for this study were found in agricultural areas and the lowest values in forestland. The values were considered out of the WHO standards of 5 NTU and Tanzanian standards of 30 NTU.

In conclusion, turbidity in the LIRB does not meet standard set by Inco-Maputo as well as that of WHO. The high concentrations of turbidity are linked to human activities since variations occur in areas close to human activities.

b) Electrical conductivity

The results for EC are presented in Figure 5.8. The highest value was found downstream at site E-28, the highest values is 924 µs/cm. The lowest value was found upstream at site E-23, the lowest value is 191 µs/cm. These values are within the standards, although the sampling site E-28 has high concentrations of EC as compared to the other two. This might be due to the fact that the site is located downstream of the catchment, about 48 km from the ocean and it is sometimes affected by salt intrusion (LeMarie *et al*., 2006).

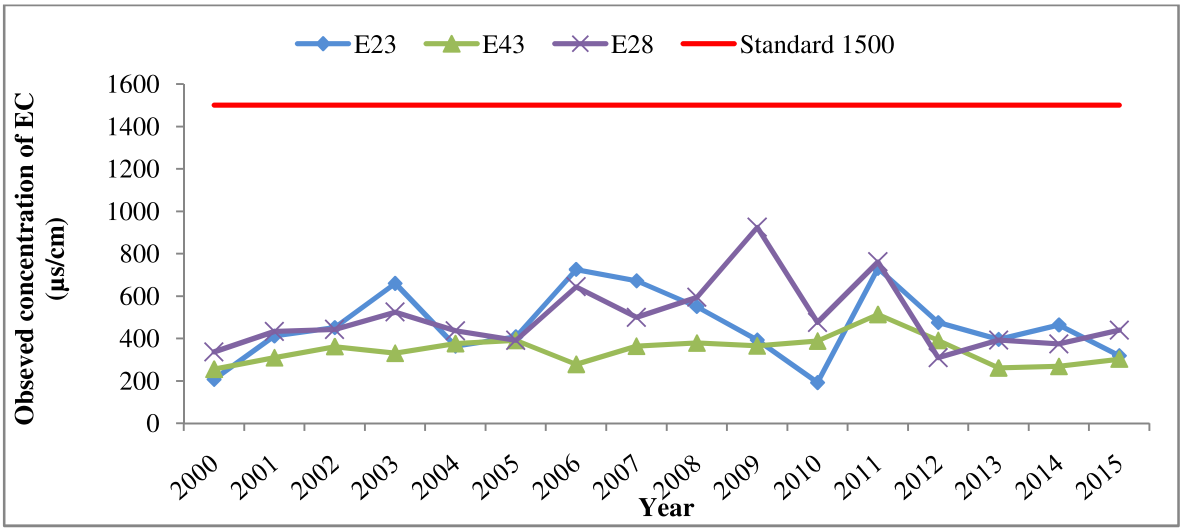

Figure 5.8 Temporal variation of EC for 2000 to 2015 for Incomati River

This fact was expected since concentrations of salts usually increase from upstream to downstream. A study conducted in Korea by Bae (2013) also revealed that concentrations of most pollutants were high downstream as compared to those upstream. On the other hand, the high concentrations at sampling site E-28 might be due to the fact that it is located after the sugarcane plantations that discharge its effluent into the Incomati River. As mentioned by Eekelen *et al*. (2015), water users often withdraw and consume water then return it into the environment in degraded quality. This fact is causing environmental problems such as the growth of aquatic plants in the river and lagoons, thus the increase in COD, previously discussed in this chapter.

Results from a study conducted in Ngerengere Catchment, in Tanzania by Mero (2011) revealed that concentrations of EC ranged from 32 to 5,930 µs/cm and the highest value was found at a site located at an outlet of industrial wastewater pipe. A study carried out in Elephants and Nuanedzi catchment in Southern Mozambique, by Chilundo *et al*. (2008) revealed that EC values vary from 200 to 2,400 µs/cm. This parameter was considered by the author to be out of standards and he also pointed human activities as the main determinant of spatial and temporal variability of water quality throughout the basin.

c) pH

During the past fifteen years, pH values for the three sampling sites varied from 6.89 to 8.42 which were within the recommended standards of (6.5-8.5). The highest values were found in sampling site E-43 located within the sugar cane plantations. The results of temporal variations of pH in the LIRB are presented in Figure 5.9. The figure shows the variation from 2000 to 2015 for three sampling sites (E-23, E-43 and E-28).

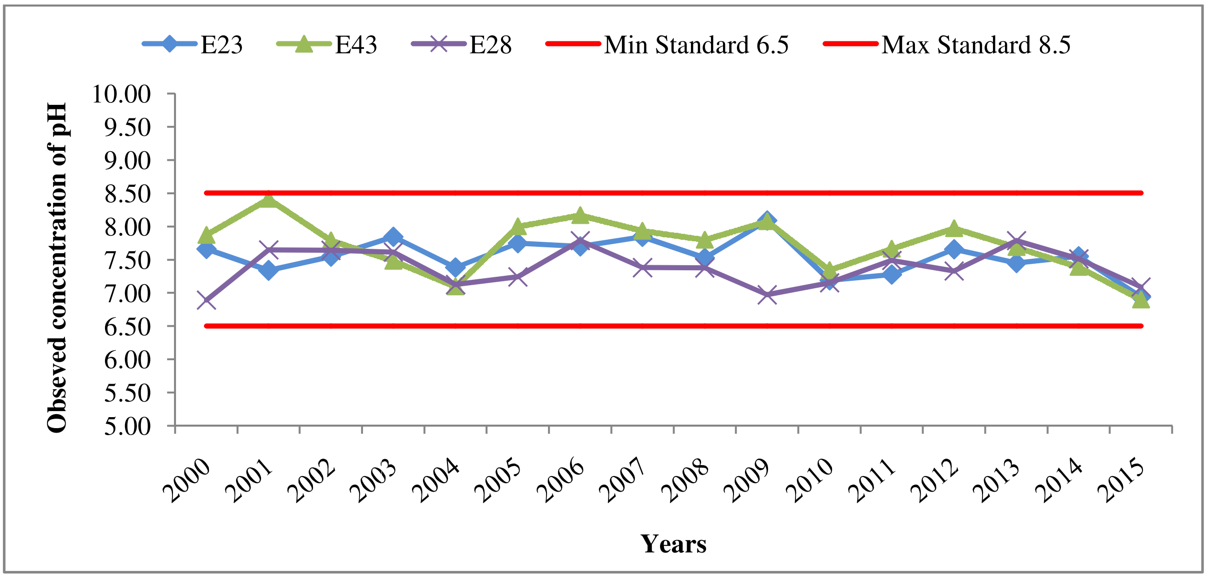

Figure 5.9 Temporal variation of pH for 2000 to 2015 for Incomati River

According to FAO (2000), the pH of water is also an indicator of its quality and it should be usually ranging from 6.5 to 8.4. For drinking water the ideal should be less than 8, before disinfection with chlorine (WHO, 2003b). When pH values are above 8.5, they reduce the availability of other micronutrients such as iron and phosphorus that are important for plant growth (FAO, 2000). Also uncontrolled pH of water entering a distribution system may create corrosion of pipes in household water systems, resulting in contamination of drinking water, therefore affecting negatively its appearance, taste and odour (WHO, 2003b).

A similar study was conducted in Tanzania by Ngoye and Machiwa (2004) with the objective of assessing the impacts of landuse patterns in the Ruvu River Basin on water quality. The study found out that pH values ranged between 6.95 ± 0.09 and 8.07 ± 0.23 and the values were within Tanzania Temporary Standards (TTS) for drinking water quality. Another study carried out by Sajidu *et al*. (2007) in Malawi aiming at evaluating the water quality in streams and wastewater treatment plants in the Blantyre City, found that pH values were within range of the WHO standards, except the site for the final effluent of Limbe wastewater treatment plant, which measured pH of 9.38. The study revealed that the high values observed in that site were result of production of hydroxyl ions (OH^-) during photosynthesis. In conclusion, for the case of the LIRB, runoff received in Mozambique from South Africa through site E-23 is acceptable. Within the country it also varies within recommended standards for Inco-Maputo agreements and WHO guidelines.

d) Ammonia

The results of ammonia are presented in Figure 5.10. The figure represents the variation of ammonia from 2000 to 2015 in the lower Incomati River Basin. The limit standard is 1 mg/l.

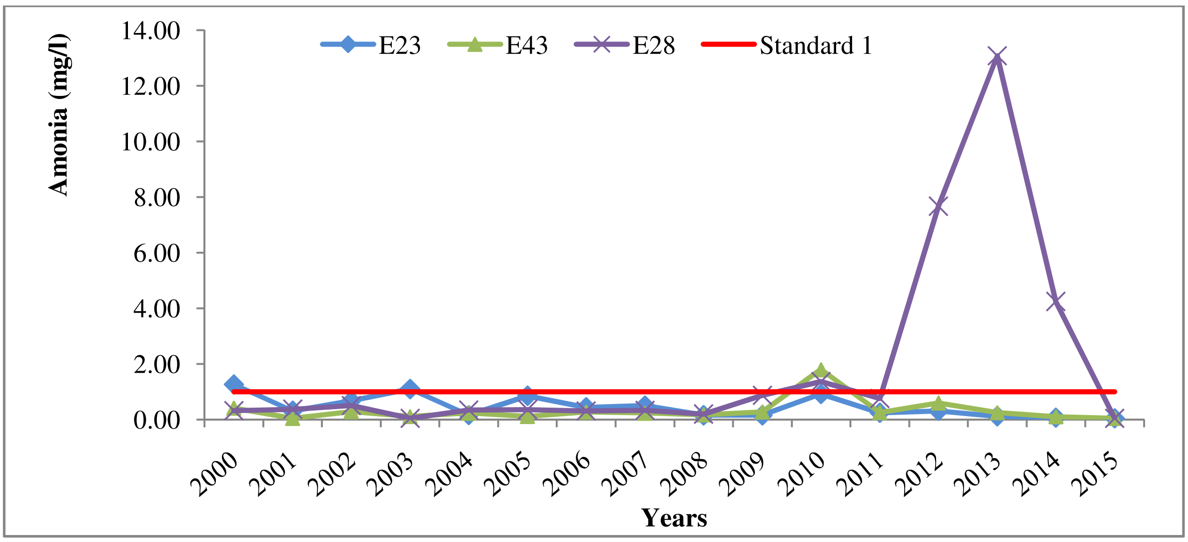

Figure 5.10 Temporal variation of ammonia for 2000 to 2015 for Incomati River

Figure 5.10 shows that ammonia has been out of recommended standards showing its peaks in 2012, 2013 and 2014 of 7.67 mg/l, 13.08 mg/l and 4.24 mg/l respectively. The standards state that concentrations of ammonia should be not more than 1 mg/l. In the case of these three years, it can be seen that there is no influence of upstream catchments since water reaches the country within standards and changes in the region between Magude (near E-43) and Manhiça (near E-28). This might be related to the agricultural effluent discharge located within the two sites. In many other cases in the world, enrichment of stream occurs in regions dominated by agriculture and urban land use (Richards *et al*., 2011).

High concentrations of ammonia in surface waters can cause fish toxicity, leading to disease and mortality of fish (WQA, 2013). The presence of ammonia at higher concentration levels is an important indicator of faecal pollution (WHO, 2003a). Therefore the quality of water in terms of ammonia is not acceptable.

Kapalanga (2015) also studied water quality aiming at developing a remote sensing based algorithims for water quality monitoring in Olushandja dam in Namibia. The study found out that concentrations of ammonia ranged between < 0.01 and 0.13 mg/l. For Kibena (2012) the values for ammonia ranged from 0.001 to 6.8 mg/l, which were considered to be outside the acceptable EPA standards. The results were associated to the presence of human waste in Manyame River, in Zimbabwe.

Similar study was carried out by Huang *et al*. (2013) in China. The study objective was to analyze the influence of landuse on the water quality within the Chaohu Lake Basin. The study was based on the water quality monitoring data and Remote Sensing data from 2000 to 2008. The results from this study reveal that concentrations of ammonia varied from 0.00 to 1.61 mg/l.

e) Nitrates

The results of nitrates are presented in Figure 5.11. From 2000 to 2010, the concentrations of nitrates were low and within the recommended standards, ranging from 0.08 mg/l to 14.17 mg/l up until 2011. From 2011 there is a sharp increase in nitrates making the values out of standards until 2015. The values for nitrates from 2011 to 2015 ranged from 13 to 89 mg/l.

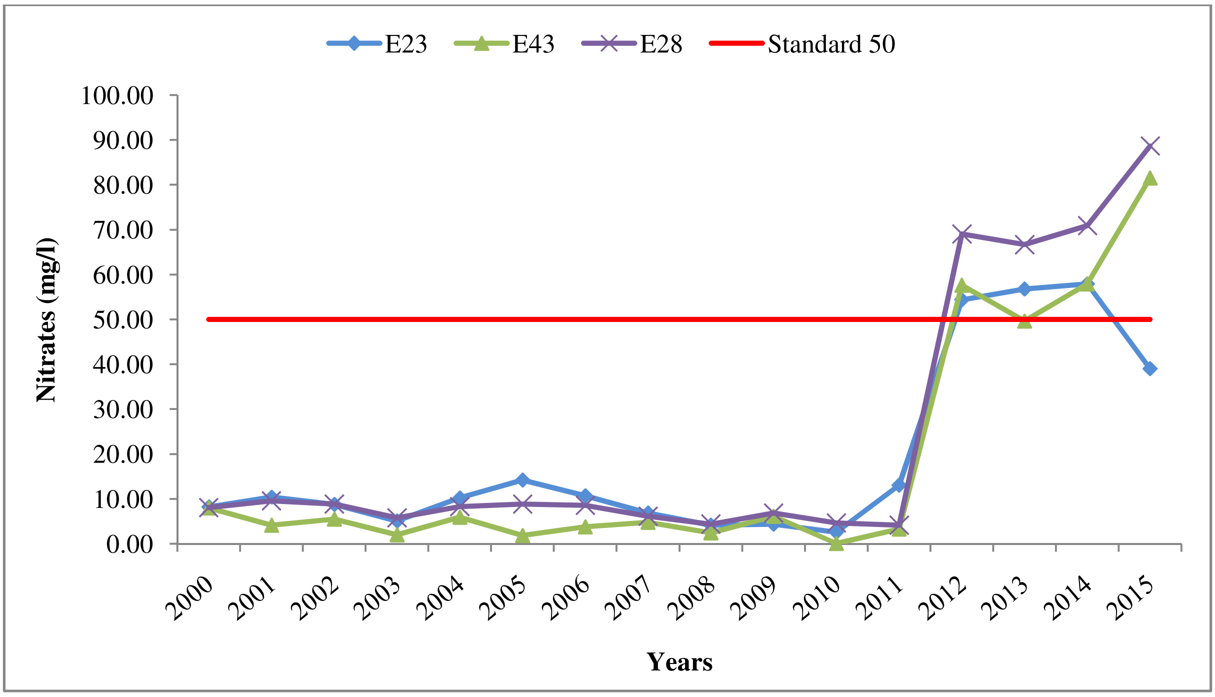

Figure 5.11 Temporal variation of nitrates for 2000 to 2015 for Incomati River

Nitrates in water are responsible for the over stimulate algae and aquatic plant growth lowering the oxygen available in the water, compromising that way the life of fish and invertebrates (NGRDC, 2001). Nitrates are also a concern for drinking water since the increase in nitrates concentrations was once linked to the blue-baby syndrome in the San Joaquin Valley in California (Moore *et al*., 2011). EPA (2013) has determined a limit of 10 mg/l for nitrates in order to protect infants from this syndrome.

The results found in the study area can be associated with the fact that upstream the catchment in South Africa there is decrease in water quality in some reaches for more than 15 years (Roux and Selepe, 2013). The increase in nitrates concentrations are mainly linked to intensification of agriculture (Ruiz *et al*., 2002). This increase in nitrates in the LIRB is as result of the polluted receiving waters from upstream. Figure 5.8 show that the sampling sites E-23 has values above the standards, meaning that the runoff received from South Africa are already polluted.

Contrary to these results, a study carried out by Jonnalagadda and Mhere (2001) in the Eastern Highlands of Zimbabwe revealed not much nitrate encountered in Odzi River, the concentrations vary from 0.44 to 0.96 mg/l. However, the study also suggested that the river in the upstream was relatively clean compared to downstream due to some activities related to fisheries taking place in the catchment. Another study carried out in Malawi found similar results, showing the variation of nitrates from 1.1 to 17.81 mg/l. The study indicated that the highest values were found in a site with concentration of pollutants due to agricultural activities (Pullanikkatil *et al*., 2015).

Sajidu *et al*. (2007) revealed results of nitrates between 0.81 and 20.18 mg/l in the streams and wastewater treatment plants of Blantyre, in Malawi. The study found that the values for nitrates were lower than the drinking standards of WHO of 50 mg/l.

However, these studies were carried out in different catchments, making clear the slight difference in results. Water quality in the LIRB is not satisfactory; hence it can be used for domestic purpose especially after a treatment. Nevertheless the water is acceptable for irrigation purposes.

f) Nitrites

Figure 5.12 shows the concentrations results of nitrites in the LIRB from 2000 to 2015. The nitrites values range from 0.03 mg/l to 0.68 mg/l.

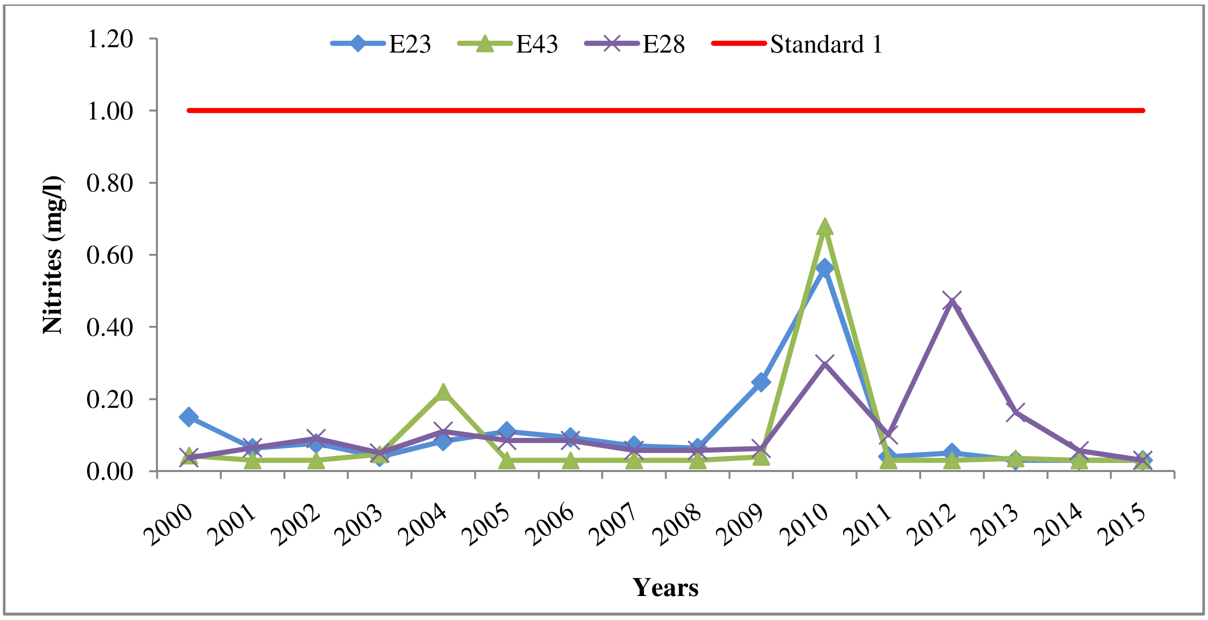

Figure 5.12 Temporal variation of nitrites for 2000 to 2015 for Incomati River

The results show that concentrations of nitrites have been below the recommended standards stated at a maximum of 1 mg/l. The year 2010 shows the highest values (0.7 mg/l) of nitrites in the catchment. However, in 2010 the upstream site (E-23) also had high values of 0.56 mg/l, which might have influenced this increase of nitrites concentration within the catchment. Nitrites are also a concern for drinking water since the increase in nitrate is linked to the blue-baby syndrome (Moore *et al*., 2011). Nitrite levels in drinking water are usually below 0.1 mg/l (WHO, 2007).

A study conducted in Zimbabwe, aiming at assessing the impacts of landuse activities on the water quality of Manyame River, revealed that nitrites values are usually bellow 0.03mg/l and values above that might indicate sewage contamination (Kibena, 2012). The study found out values ranging from 0.001 and 0.095 mg/l. In general, in terms of nitrites water quality in the LIRB is acceptable, requiring a basic treatment for domestic use. The water quality is also suitable for irrigation.

In conclusion, runoff received in Mozambique from South Africa via site E-23 within acceptable condition since the sampling site has values within the standards. However there is need to monitor the variations that occur within the country as caused by human activities that are taking place in the basin.

g) Trend analysis

The trend analysis was done based on the Mann-Kendall trend test. The parameters used are pH, EC, ammonia, nitrate, nitrite and turbidity. The results are presented in Table 5.4 that shows the trend coefficient (MK) as well as the coefficient of variance (CV). The historical data was used for three sampling sites monitored by ARA-sul (E-23, E-43 and E-28).

Table 5.4 Trend analysis showing the Mann-Kendall coefficient and the coefficient of variance

Parameter	**Turbidity**		**pH**		**EC**		**Ammonia**		**Nitrate**		**Nitrite**	
Method	MK	CV	MK	CV	MK	CV	MK	CV	MK	CV	MK	CV
E-23	0.13	0.32	0.35	0.04	0.97	0.34	0.13	0.86*	0.12	0.95*	0.16	0.82*
E-43	0.20	0.74*	0.17	0.05	0.40	0.19	0.89	0.77*	0.14	0.69*	0.53	0.52*
E-28	0.18	0.60*	0.86	0.04	0.83	0.33	0.11	0.54	0.45	0.78*	0.56	0.98*

* represents the significant coefficient of variance (CV > 50 %)

The table shows that there is no trend for all the parameter since the computed p-values is greater than the significance level (alpha = 0.05). There is no significant variance for pH, EC and for turbidity for the sites E-43 and E-28. However, there is high variance in terms of nutrients, since the CV for ammonia, nitrates and nitrites is greater than 50 %.

5.1.3. Seasonal variation of water quality

The seasonal variation of water quality in the LIRB was analyzed based on available data for 2007, 2008 and 2009 for two sampling sites monitored by ARA-sul (E-43 and E28). The results are presented in Table 5.5.

Table 5.5 Seasonal variation of parameters in the LIRB

		pH		**EC (µs/cm)**		**Ammonia (mg/l)**		**Nitrates (mg/l)**		**Turbidity (NTU)**	
Date	**Quarter**	**E-43**	**E-28**	**E-43**	**E-28**	**E-43**	**E-28**	**E-43**	**E-28**	**E-43**	**E-28**
06/01/2007	I	7.68	7.86	321	462	0.08	0.63	3.11	4.81	11	25
03/02/2008	I	8.2	7.25	332	552	0.38	0.42	5.28	3.5	6.5	5
24/03/2009	I	8.42	6.1	212	319	0.27	0.35	2.29	7.12	17.30	14
15/03/2007	II	8.7	7.13	202	648	0.37	0.05	4.14	4.41	12	4
06/05/2008	II	7.59	7.5	377	580	0.18	0.04	1.8	2.96	3	3
13/05/2009	II	8.34	7.07	363	452	0.16	0.4	3.19	8.04	18.90	9.8
10/09/2007	III	7.29	7.49	457	246	0.36	0.26	9.45	7.38	6	9
26/09/2008	III	7.83	7.46	345	584	0.04	0.14	1.58	3.41	0.5	1
27/08/2009	III	7.80	7.37	530	246	0.41	0.5	6.69	8.49	3.50	5.3
12/11/2007	IV	8.07	7.04	471	640	0.11	0.37	2.49	7.87	6	15
12/11/2008	IV	7.58	7.29	457	659	0.08	0.18	1.18	7.72	1.5	0.5
27/11/2009	IV	7.75	7.34	352	465	0.23	0.2	12.39	3.8	5.00	0.5

From Table 5.5 it can be concluded that there is not much variation within seasons. However, pH, turbidity and ammonia suggest that the highest values are found in the first quarter (January to March) and the fourth quarter (October to December). These two quarters happen to be in the wet season, which shows that the wet season is the one with high concentration of pollutants in the LIRB. This could be associated with runoff from polluted land and received pollution from upstream catchments. Similar results were found by (Andrietti *et al*, 2015) when studying water quality indexes and the trophic state of the Caiabi River in Brazil. The study found that the concentrations of the studied parameters (Total coliforms, BOD, nitrites, turbidity, temperature, and TSS) increased during the wet season and the same reduced for the dry season.

5.2. Changes in landuse patterns

Based on Landsat images for 2000, 2005, 2010 and 2015 for the Lower Incomati River Basin, landuse maps were obtained. The resultant maps are shown in Figure 5.13.

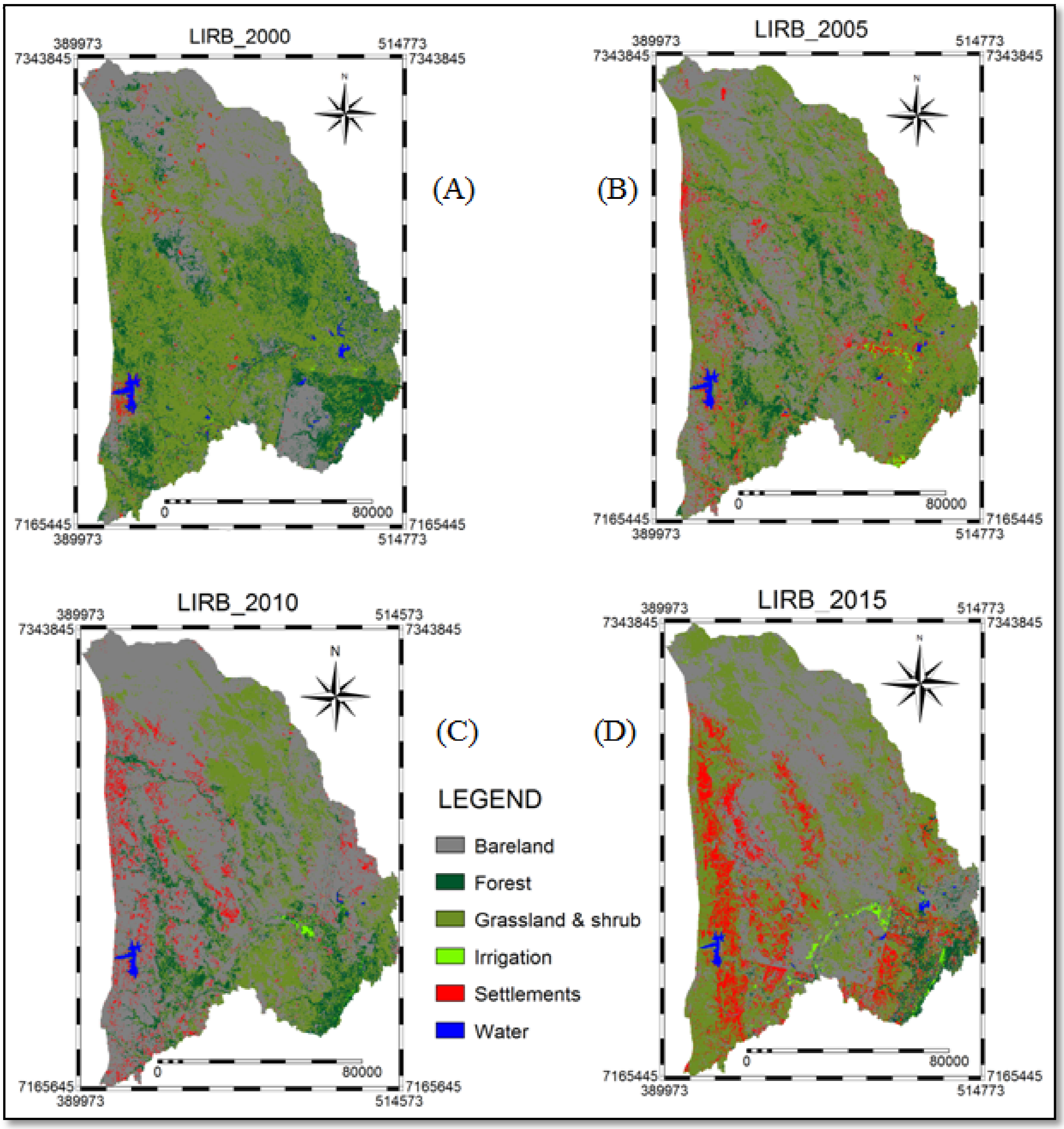

Figure 5.13 Landuse change in the LIRB 2000 (a), 2005 (b), 2010 (c) and 2015 (d)

The results of the maps in terms of area and percentages are presented in Table 5.6. The table shows that between 2000 and 2015 there was an increase in irrigation and settlements by 162 % and 185 % respectively. The increase in irrigation can be attributed to the upgrade in the dominant agricultural activity which is the sugar production (Vaz and van der Zaag, 2003).

The sugar sector increase production, expanding the area since 2000; when a South African company purchased 49 % equity in the so called *sociedade Agricola do Incomati* (Vaz and van der Zaag, 2003).

There has been a decrease in bareland and forestland of 28 % and 58 % respectively. The reduction of forest can be related to clearing of woodland for charcoal and wood extraction for domestic and commercial purposes, also for expansion of agriculture and for construction of new settlements. As stated by Marx (2012) urbanization in the catchment increases cooking fuel demands usually in the form of charcoal or wood.

Table 5.6 Percentage change of landuse per class

	2000		2005		2010		2015		
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	% Change
Bareland	8,285	60.5	4,854.8	35.5	8,356	61.1	5,956.6	43.5	-28
Forest	1,239.6	9.06	1,207.6	8.82	1,128.6	8.25	519.68	3.80	-58
Grassland	3,367.7	24.6	6,735.2	49.2	3,076.7	22.5	5,134.4	37.5	52
Irrigation	135.2	0.99	144.36	1.05	265.2	1.94	354.12	2.59	162
Settlements	580.64	4.24	671.76	4.91	789.64	5.77	1,654.2	12.1	185
Water	76.76	0.56	71.16	0.52	68.76	0.50	66	0.48	-14

The changes in landuse are represented graphically on Figure 5.14 from 2000 to 2015. It can be observed that there is a decrease in bareland, forest and water by 28 %, 58 % and 14 % respectively; it can also be noticed that there is an increase in grassland of 52 %, irrigation of 162 %, and settlements of 185 %.

Macuacua (2011) carried out a study for the Incomati Catchment, assessing the changes in landuse from 1990 to 2010 and found out similar results, with emphasis for increase in irrigation (310 %) and settlements (285 %) and decrease in forest (46 %) and water bodies (37 %). This must be a typical characteristic of the study area; an area with high development pressure and over exploitation of natural resources. Another study was carried out with the same objective but in a different catchment in Zimbabwe also found similar results, Kibena (2012) found that water bodies (13 %) and forest (24 %) have decreased from 1984 to 2011 in the Upper Mayame Catchment at the same time as settlements (46 %) and irrigation (24 %) increased.

Gumindoga *et al*. (2014) studied the hydrological impacts of urbanization of Mukuvisi and Marimba catchments in Zimbabwe. The study used Landsat images for the years 1986, 1994 and 2008 to determine changes in landuse. The study revealed a decrease in forest more than 40 % for both catchments with a greater decrease in Marimba catchment. It also revealed that urban areas increased by more than 600 % in the Mukuvisi catchment and by more than 200 % in the Marimba catchment between 1986 and 2008.

Another study by Gumindoga *et al*. (2014) was carried out in Ethiopia with the objective of predicting streamflow for land cover changes in the Upper Gilgel Abay River Basin. The study revealed agricultural land changing from 30 % in 1973 to 62 % in 2001. As a result of this, forestland decrease from 52 % to 17 % for the same period.

The same happens worldwide as revealed in China by Weng (2002) who analysed landuse change in the Zhujiang Delta using satellite remote sensing from 1989 to 1997. The study found out that forest has decreased (18 %), settlements and irrigation have increased in 47 % and 88 %, respectively. In India, a study also found that forestland has decreased in 116 % and while settlements increase by 18 %. This study was carried out in Umtrew Basin for 1977 to 2007 (Sharma *et al*., 2011).

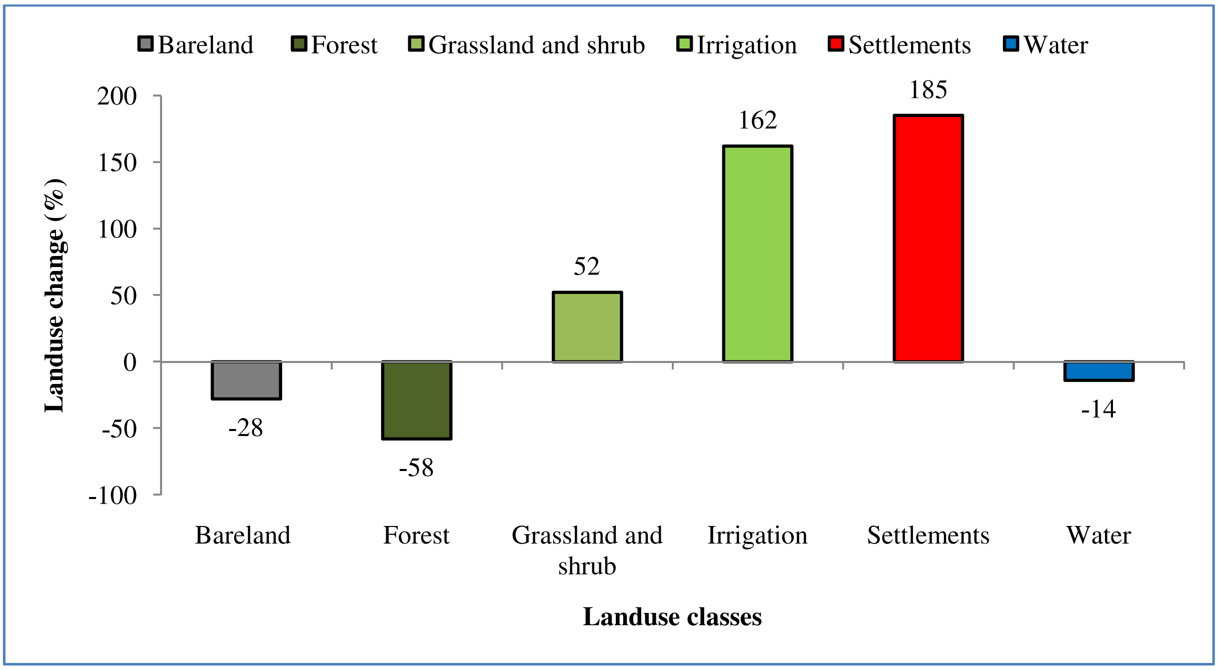

Figure 5.14 Representation of changes in landuse in the catchment from 2000 to 2015

5.2.1. Accuracy of landuse change classification process

The validation was performed for the 2015 classified map since the ground control points (GCPs) available were for the same time. The study used a total of 200 GCPs. The overall accuracy was 81 % meaning that, 81 % of the total number of pixels classified was correctly classified. Areas with settlements and grassland were the most difficult to classify, hence a degraded accuracy of 57 % and 76 % respectively (see Table 5.7). According to Weng (2002) and Tillmann (2012) accuracy is considered fair when it is above 50 % and good above 70 %.

Table 5.7 Confusion matrix for the 2015 landuse map

Landuse class	Bareland	Forest	Grassland	Irrigation	Settlements	Water	Accuracy
Bareland	117	1,9	0	41	1,4	0	0.97
Forest	842	8,8	48	5	0	11	0.91
Grassland	30	1,9	107	135	1,1	73	0.76
Irrigation	0	15	0	2,4	0	0	0.99
Settlements	6,9	417	22	0	39	0	0.57
Water	0	0	1	0	0	1,6	1
RELIABILITY	0.76	0.68	0.83	0.93	0.94	0.95	-
Average Accuracy							86.8 %
Average Reliability							84.7 %
Overall Accuracy							80.1 %

5.2.2. Future projections of landuse

From the changes observed from the year 2000 to 2015, Markovian analysis was performed and scenarios for 2020 and 2030 were determined. Table 5.8 shows the probability of a given landuse to change to another based on Markov chain principle. The future landuse/cover that can be expected in the catchment is shown in Table 5.9.

Table 5.8 Transitions probability grid

	Irrigation	Bareland	Grassland	Water	Forest	Settlements
Irrigation	0.9982	0.0006	0.0007	0.0000	0.0002	0.0003
Bareland	0.0109	0.5670	0.2599	0.0061	0.0240	0.1321
Grassland	0.0086	0.3263	0.4730	0.0005	0.0369	0.1547
Water	0.0371	0.1419	0.1048	0.5796	0.1057	0.0280
Forest	0.0031	0.4311	0.4897	0.0003	0.0108	0.0650
Settlements	0.0124	0.3923	0.3457	0.0991	0.0991	0.1476

The probability of a given landuse type to change to another type was calculated by the Makov Chain. The probabilities to change to bareland and grassland are high and there is less probability of a given landuse to change to water. This might be caused by the fact that water bodies are reducing giving space for other landuse types. A study carried out in Mexico, aimed at predicting landuse change in Morelia city, found similar results. The study found out that grassland and shrubland were the ones with high probability of change. This study concluded that grassland and shrubland were the least stable landuse variables (López *et al.*, 2001).

Table 5.9 Projected future landuse in the LIRB for 2020 and 2030

	2015		**2020**		**2030**		
	Area (km^2)	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**	**% Change**
Bareland	5,96	43.5	5,16	37.7	7,36	53.82	24
Forest	520	3.80	437	3.19	8	0.06	-98
Grassland and shrub	5,13	37.5	5,8	42.4	3,03	22.12	-41
Irrigation	354	2.59	415	3.03	561	4.10	58
Settlements	1,65	12.1	1,8	13.2	2,66	19.42	61
Water	66	0.48	66	0.48	66	0.48	0

The results shown in Table 5.9 suggest a continuous increase in irrigation and settlements by 58 % and 61 % respectively. A drastic decrease of 98 % in forestland is expected. A similar study conducted in India, was carried out on assessment of historical and future landuse change in the Upper Ganges Basin. The study found similar results, despite that the study predicted a decrease in water bodies (Tsarouchi *et al.*, 2014).

However the present study reveals something different by suggesting that the water bodies are likely to remain the same. From the results shown in Table 5.9, two landuse maps were created and the results are presented on Figure 5.15. The figure shows what is likely to happen in the LIRB fifteen years from now.

A graph was created from the results in Table 5.9, and its results are presented in Figure 5.16. The figure shows what are likely to be the changes in landuse from now to 2030. From the figure, it can be noticed an increase in irrigation of 58 %, bareland (24 %) and settlements (61 %); and also a decrease in grassland (41 %) and forest (98 %).

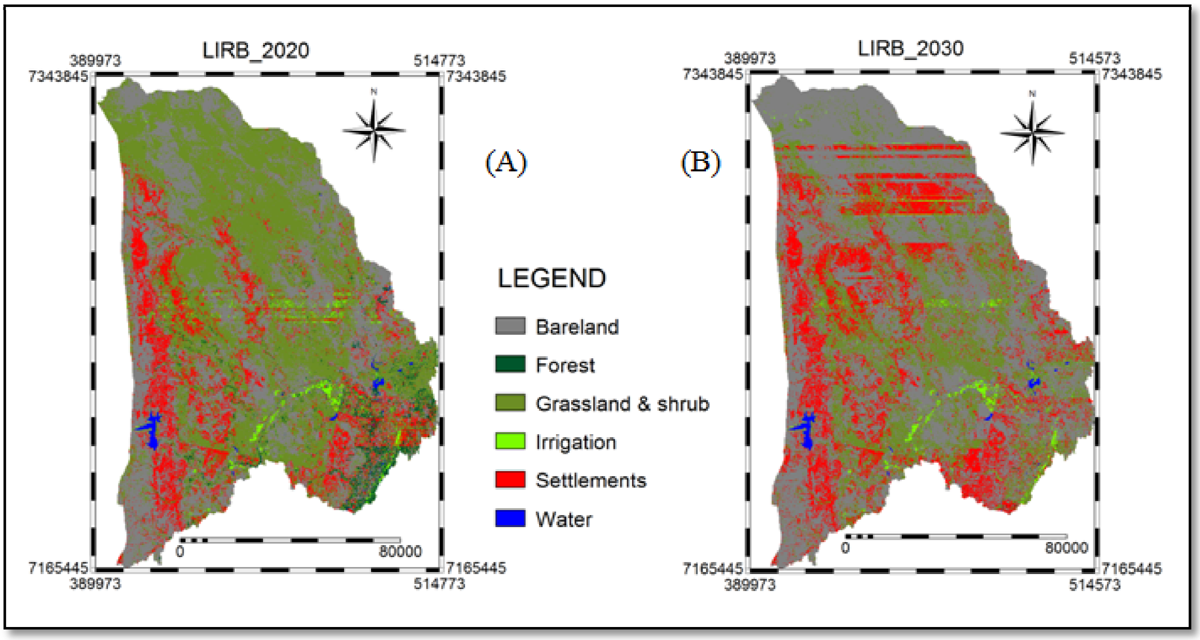

Figure 5.15 Projections of future landuse for the LIRB for 2020 (a) and 2030 (b)

A recent study was carried out in China by Han *et al*. (2015), aiming at predicting future landuse and land cover change in Beijing. In concordance to this, the study found that settlements have increased and grassland decreased, despite the predicted decrease in irrigation found by this study. This can be related to the development trade that vary for different catchments.

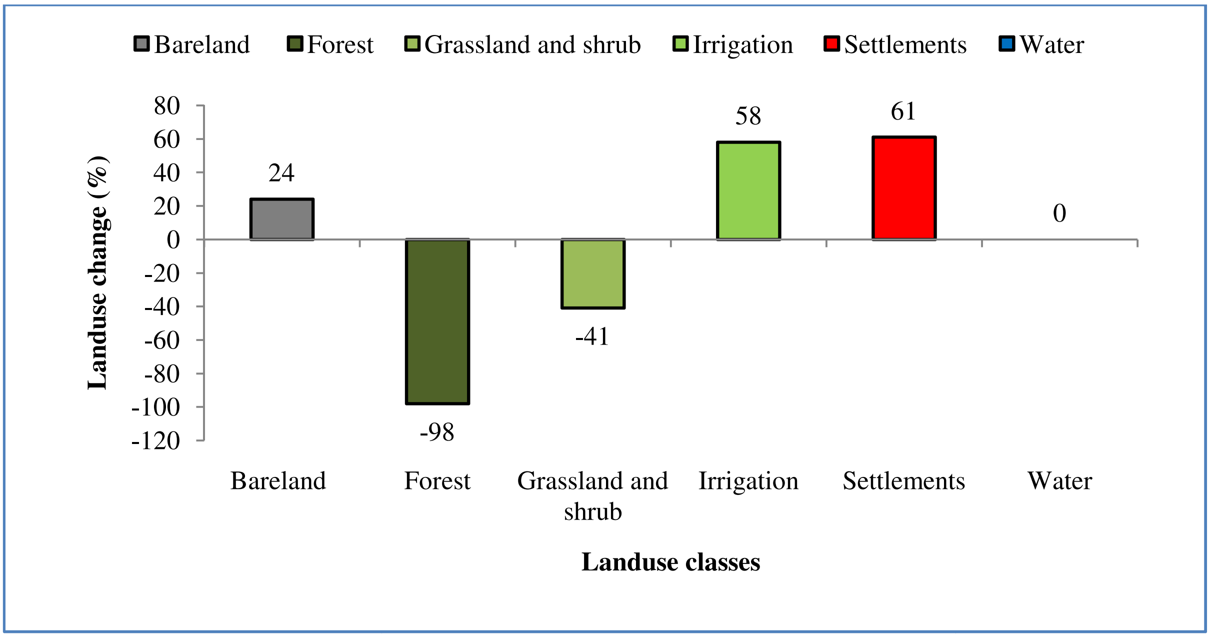

Figure 5.16 Landuse per class for the next 15 years (2015-2030)

5.2.3. Accuracy assessment of predicted future maps

The validation of the model was performed based on the 2015 classified map which is the year with available ground information. The study used maps for 2000 and 2010 to predict a map for 2015. Then the classified and the predicted map were used in the validation panel of *Terrset* software to assess the accuracy of predicted maps. The overall accuracy was 72.6 %. The accuracy obtained is acceptable, since the minimum of 70 % is required (Eastmen, 2015). The data for the maps of 2015 (classified and predicted) were also submitted to a t-test for comparing means in SPSS and the results suggest that there no significant difference between the two maps since the *p*-value (0.192) was found to be grater then the significant level of 0.05.

5.3. Relationship between water quality parameters and the landuse change patterns

The landuse and water quality data were analysed using SPSS. The model used to establish the relationship between landuse changes and water quality parameter is an econometric model based on previous researches (Huang *et al*., 2013). The model is simplistic and it is based on the standardized coefficients (β) determined by regression analysis between water quality variables and landuse variables presented in Table 5.10.

Table 5.10 Regression standardized coefficients (β) between water quality and landuse change

Variable	pH	Nitrates	Turbidity
Bareland (B)	-0.31	0.51	0.19
Forest (F)	-1.45*	-0.97*	-0.53
Grassland and shrub (G)	-0.30	-0.95*	-0.83
Irrigation (I)	-0.46	0.65	0.95*
Settlements (S)	0.95*	0.98*	0.52
Water (W)	0.58	0.04	0.34
Constant	8.5*	21*	11.2*
R-squared	0.86	0.94	0.86

* Significant at the 0.05 level

The regression analysis suggests that from the parameters studied only pH, nitrates and turbidity are the parameters that can be predicted in the LIRB. The results show that nitrates have a positive relationship with irrigation (0.65) and settlements (0.98) and a significant negative relationship with forest (-0.97) and grassland (-0.95). A study conducted by Chu *et* *al*. (2013) revealed that agriculture, forestry, and anthropogenic activities impact the water quality in the Tseng-Wen watershed in Taiwan. Nitrogen was mostly found in agricultural areas. The study concluded that landuse change was significantly influencing nitrogen loadings in the watershed. Similar results were found by Huang *et al*. (2013) when studying impacts of landuse on water quality in the Chaohu Lake Basin in China. The study associated this to the developed agriculture in the basin in study and the application of chemical fertilizers. In the LIRB, this can be mainly because the irrigated agriculture also involves the application of chemical fertilizers such as NPK and urea (Marx, 2012). These fertilizers used in the irrigated agriculture, get into the runoff and flow into the water bodies during the rainy season and also through direct discharge of effluent that ultimately pollute the water in the river.

Grassland and forestland were negatively related to all the parameters. This negative relationship can explain the important role played by forests and grassland in reducing the nitrogen pollutants and the controlling role played by this landuse in regulating the water quality (Near, 1999). Similar results were found by Tong and Chen (2002) when modelling the relationship between landuse and surface water quality in the state of Ohio in the United States of America. The study correlated different landuse types and water quality parameters and found out that forestland was negatively related to most of the water quality parameters, and it has a strong relationship with nutrients. The study related this to the fact that in forested areas there had less concentration of nutrients. A study conducted by Ding *et al*. (2015) also found the same relationship when impacts of landuse on surface water quality in Dongjiang River Basin in South-eastern China. The study revealed that forested landuse had significant impacts on water quality in the study area showing that catchments with more forests and less urbanization had better quality of water.

There is also a positive and strong relationship between settlements and, pH and nitrates. Huang *et al*. (2013) also found that built up areas were positively related to total nitrogen. It indicates that the increase in settlements is also dilapidating water quality in the LIRB, since there are no waste water treatment plants for domestic sewerage and agricultural discharges as well (SWECO, 2003). A study was carried out in California with the aim of assessing the influence of landuse and on water quality in the western Sierra Nevada. The study revealed that settlements did not have a significant influence on stream nitrogen until a waste water treatment plant (WWTP) was constructed within the basin. This WWTP works as a point source of pollution, then the contribution of settlements to nitrogen in the stream increase (Ahearn *et al.*, 2005).

Since the regression analysis suggested that pH, nitrates and turbidity were the parameters that could be predicted in the catchment, the model was used to determine the relationship between these three water quality parameters. The model used states that:

$\mathrm{WQV} = \beta 1 * \mathrm{land1} + \beta 2 * \mathrm{land2} + \cdots \beta \mathrm{i} * \mathrm{landi} + \alpha$......................................Equation (5.1)

Where WQV is the water quality variable in the study area, β is the correlation coefficient between land use (%) and the water quality variable, and α is a constant. From this formula, when βi is positive, that means the land use type (i) has a positive effect on that water quality parameter. When βi negative so that means the land use type i has a negative effect on that water quality parameter. From the regression coefficients in Table 5.8, one can come up with the relationship between water quality parameters and landuse type:

$pH = -0.31B - 1.45F - 0.30G - 0.46I + 0.95S + 0.58W + 8.5$...................... Equation (5.2)

$Nitrates = 0.51B - 0.97F - 0.95G - 0.65I + 0.98S + 0.04W + 21$................ Equation (5.3)

$Turbidity = 0.19B - 0.53F - 0.83G + 0.95I + 0.52S + 0.34W + 11.2$ .... Equation (5.4)

Where: B is bareland, F is forest, G is grassland, I is irrigation, S is settlements and W is water. However, the degree of relationship between most landuse types and water quality parameters was not significant (at the 0.05 level). The lack of correlation does not mean that the changes in water quality were not related to landuse, because not all factors involved were considered in this study. The contribution of factors such as precipitation, evaporation, contributions of upstream catchments and seasonal variations may need to be investigated in future work.

Other important parameters that are proved to be related to landuse change such as total phosphorus, total nitrogen, faecal coliforms, COD, BOD, and chlorophyll a, have to be considered (Tong and Chen, 2002; Chu *et al.*, 2013; Ding *et al.*, 2015). These parameters were not considered in the current study because of lack of historical data.

5.4. Future projections of water quality

Based on Equations 5.2, 5.3, and 5.4; and predicted land use for the years 2020 and 2030 in Table 5.9, the future status of water quality for ammonia, nitrates and turbidity was predicted and the results are presented in Table 5.11.

Table 5.11 Water quality predicted for 2020 and 2030

Water quality variable	2015	2020	2030
pH (-)	6.90	8.32	8.43
Nitrates (mg/l)	81.5	20.9	21.3
Turbidity (mg/l)	0.5	11	11.3

The results show an increase of pH and turbidity, and a decrease in nitrates from 2015 to 2020. From 2020 to 2030 there is an increase for all the parameters. It is important to note that these results are likely to be affected by climate change, influence from upstream catchments and changes in management practices of socio-economic activities (Du Plessis *et al*., 2014). One way of controlling the increase in pollution in the catchment can be through the adoption of new agricultural practices and construction of wastewater treatment plants at catchment level. Another simplistic method for pollution control, with low operation cost is constructed wetlands. This method can be adopted for municipal and agro-industrial wastewater treatment (Sultana *et al*., 2015).

A similar study was conducted in South Africa by Du Plessis *et al*. (2014) on quantifying and predicting the water quality related with landuse change of the Blesbok Spruit Catchment. The study predicted land use for 2020, 2030 and 2050. Based on the equations established from the correlation between landuse and water quality, they predicted future landuse. The results reveal not much variation for the years 2020, 2030 and 2050 for ammonia (0.95, 1.03 and 1.20, respectively) and nitrate (1.02, 1.02 and 1.00, respectively).

Several authors have revealed significant relationship between landuse change and water quality (Ahearn *et al*., 2005; Chu *et al*., 2013; Huang *et al*., 2013 and Ding *et al*. 2015), and others have predicted future landuse conditions and concluded that grassland and shrubland were the least stable landuse variables (López *et al*., 2001; Reveshty, 2011; Mishra *et al*., 2014 and Han *et al*., 2015). Combining these thoughts is possible to predict the water quality expected in the future. With this knowledge, water authorities can be advised on the risk of environmental degradation. Therefore, measures can be taken in order to prevent that such situations happen in the LIRB and other catchments in the world.

5.4.1. Validation of the models

To validate the equations generated in this study, landuse data for the year 2008 were used to predict water quality variables (pH, nitrates and turbidity) for the same year. The ground information used was the one measured by ARA-sul. The results were then compared based on t-test methods for comparing means in SPSS. Results are presented in Table 5.12.

Table 5.12 Comparison of water quality measured and predicted for the year 2008

Parameter	2008 measured	2008 predicted
pH (-)	8.01	8.14
Nitrates (mg/l)	22.3	21.8
Turbidity (mg/l)	12.0	12.9

Table 5.12 does not show much difference between the measured and predicted values for the three parameters. The results for the t-test also suggest that there is no significant difference between the measured and predicted parameters ($p = 0.08$). These results suggest that the equations can be used to determine water quality in the LIRB based on landuse information. Nevertheless, there is need to validate the models using future ground information when it is available.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

From the study the following conclusions were drawn:

1. pH, nitrates and turbidity are the parameters that could be predicted in the catchment. The variations of water quality from 2000 to 2015 show that the downstream sampling site E-28 (located in Manhiça District) has high concentrations of nutrients as compared to the upstream sites. The key parameters in the LIRB are TSS, EC, TDS and COD, the most contributing on the water quality status. The concentrations of most parameters were high but are expected to decrease in the dry season.

2. Landuse in Lower Incomati River Basin changed significantly from 2000 to 2015. Irrigation and settlements had the most variable change of 162 % and 185 %, respectively. And a considerable decrease in forestland of 58 %. From 2015 to 2030 it is expected that there will be a continuous increase in irrigation and settlements of 58 % and 61 %, respectively; while an extreme decrease in forestland of 98 % will occur. The rapid alteration of vegetative land into built up area will have serious environmental impacts.

3. There is significant relationship between water quality (nitrates) and forestland (-0.97), grassland (-0.95), settlements (0.98) and irrigation (0.65) between 2000 and 2015, showing that these changes in landuse could have caused a deterioration in water quality in the Lower Incomati River Basin. From this relationship, it is expected that in 2020 and 2030 the concentrations of pH will be 8.32 and 8.43, nitrates 20.9 mg/l and 21.3 mg/l and turbidity 11.0 mg/l and 11.3 mg/l, respectively.

6.2. Recommendations

Therefore it is recommended that:

1. To the water authorities: improvement on the monitoring network in coordination with upstream catchments. Increase in sampling frequency from quarterly to monthly, and increase the sampling parameters to include the key parameters that are not being monitored (TSS, TDS and COD).

2. To the water managers: best practices in irrigated agriculture have to be encouraged and proper environmental management plans should be implemented for the urban area in order to improve water quality. This can be done through integrated water and land resources management.

3. To general water and land users: enhancement of management practices in order to control the increase in pollution caused by landuse activities in the catchment. One way of assuring this is through the adoption of new agricultural practices and construction of wastewater treatment plants.

6.2.1. Recommendation for Future Research

1. Future research is needed in the catchment to assess the variations during the dry season, and assessing for different parameters.

2. River and stream water quality index is recommended for assessing the overall heath and integrity of the Incomati River.

3. Cross-validation of the models of future prediction when future ground information is available in 2020.

4. Assessment of landuse/cover and water quality relationship for other catchments in the country.

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APPENDICES

Appendix A: Results from the interviews

A1) ARA-sul

i. The water quality situation is stable for some parameters. Salinity increases when the water levels are low mostly during the dry season.

ii. According to the Manager the monitoring started late in a situation of polluted river what makes difficult to revert the situation. The aquatic plants where increasing.

iii. Also the entity responsible for regulating the environmental law (MINATER) does not have a specific regulation for effluent discharge, thus there is no standards for effluent discharge.

iv. There is no licence for users discharge, thus the monitoring done is only for ARA-sul knowledge.

A2) Manhiça Municipalities

i. The water supply sector is a government branch managing three water supply systems.

ii. Groundwater is used for supplying to people, as the quality of water from the river would require high treatment costs

iii. Water table is high, no problems of water availability

iv. Water is for good quality as it is supplied without treatment

v. There is no wastewater treatment plant but they are concerned about the environmental impacts, planning to install one.

vi. The discharges are done straight to the river without any treatment

A3) ILOVO Maragra sugar

i. The estates are 70 km from the ocean and uses surface and 1/3 groundwater for irrigation

ii. The water quality status is acceptable for agricultural purpose. There is a monthly monitoring done to check the quality of water used in 12 points for pH and EC

iii. They fallow the national standards for industrial discharge but there are no standards for agriculture.

iv. There are facing water quality (salted) in Cuenga tributary

Appendix B: Photographs showing the current situation of water quality

Figure B.1 Drainage of Manhiça Municipality into the Incomati River

Figure B.2 Drainage from Agricultural fields of Maragra into the Incomati River

Figure B.3 Agricultural drainage from Xinavane into Incomati River

Appendix C: Results from field measurements of water quality

Table C.1 Water quality results from field measurements

Sampling date	Time	Site	Temperature (°C)	pH (-)	EC (µS/cm)	Salinity (SAL)	TDS (mg/l)
	09:15	SS01	25	7.94	244.1	0.1	127.7
	07:58	SS02	25	8.48	291.6	0.2	159.4
	07:03	SS03	25	7.54	536	0.3	322.1
	07:19	SS04	25	7.76	1426	0.8	914.9
	06:31	SS05	25	7.4	4233	2.3	2784.3
	05:25	SS06	25	6.87	477.6	0.3	283.3
13.01.2016	05:10	SS07	25	8.41	771	0.4	478.7
	11:46	SS01	31.7	7.67	285.3	0.2	289.8
	13:10	SS02	30.4	7.88	291.4	0.2	292.2
	14:23	SS03	30.1	7.09	784	0.4	782
	13:51	SS04	30.3	7.66	1464	0.8	1459
	15:40	SS05	29.6	7.53	935	0.5	932
	14:48	SS06	29.1	7.09	668	0.4	670
25.01.2016	15:04	SS07	29	7.25	853	0.5	852
	18:17	SS01	29	7.81	578	0.3	582
	16:45	SS02	28.1	8.56	489.7	0.3	487.3
	16:24	SS03	28.4	7.33	1423	0.8	1424
	16:19	SS04	29.2	7.55	2085	1.1	2096
	14:31	SS05	33.1	7.04	2801	1.5	2830
	15:02	SS06	30.3	7.19	1412	0.8	1562
08.02.2016	15:50	SS07	29.8	6.87	831	0.5	828

Table C.2 Water quality results from field measurements (Cont.)

Sampling date	Time	Site	Temperature (°C)	pH (-)	EC (µS/cm)	Salinity (SAL)	TDS (mg/l)
	15:32	SS01	27.8	7.86	572	0	375
	14:10	SS02	28.5	8.26	591	0	383
	13:48	SS03	28.2	7.18	1588	0.1	1035
	13:33	SS04	29.1	7.74	2497	0.1	1624
	12:03	SS05	27.9	7.09	6720	0.3	4360
	11:20	SS06	27.4	7.15	1219	0.1	788
22.02.2016	11:07	SS07	27.1	6.91	1476	0.1	972
	18:48	SS01	31	7.95	601	0	393
	17:31	SS02	29.3	7.75	654	0	431
	16:29	SS03	30.5	7.31	2254	0.1	1465
	16:43	SS04	31.9	7.82	2531	0.1	1646
	15:03	SS05	35.6	6.87	7090	0.4	4590
	15:54	SS06	31.6	7.38	1137	0.1	741
07.03.2016	15:45	SS07	33.6	6.94	1521	0.1	987
	17:55	SS01	30.1	7.81	595	0	395
	16:29	SS02	29	7.2	616	0	372
	15:18	SS03	31	7.65	1594	0.1	1210
	15:33	SS04	30	7.73	2591	0.1	1627
	14:10	SS05	33.4	7.07	6920	0.4	4536
	14:46	SS06	32.3	7.28	1317	0.1	778
22.03.2016	14:32	SS07	31.2	6.89	1425	0.2	973

Appendix D: Results from laboratory analysis for physical-chemical parameters

Table D.1 Water quality results from laboratory analysis

Sampling date	Time	Site	pH (-)	EC (µS/cm)	Turbidity (NTU)	Nitrates (mg/lNO3)	Nitrites (mg/LNO2)	Ammonia (mg/lNH4)	TSS (mg/l)	TDS (mg/l)	Alkalinity (mg/lCaCO3)	Total Phosphorus (mg/l PO4)
	09:15	SS01	7.22	331	80	<0.5	<0.03	<0.04	1470	130	60	0.33
	07:58	SS02	7.84	278	50	<0.5	<0.03	<0.04	690	290	80	0.35
	07:03	SS03	7.31	450	50	<0.5	<0.03	<0.04	530	350	96	<0.25
	07:19	SS04	7.4	1282	10.5	<0.5	<0.03	<0.04	430	760	290	0.43
	06:31	SS05	6.7	574	80	<0.5	<0.03	<0.04	360	250	130	0.66
	05:25	SS06	6.58	3870	50	<0.5	<0.03	<0.04	430	2570	270	0.52
13.01.2016	05:10	SS07	6.6	709	40	<0.5	<0.03	<0.04	440	400	300	<0.25
	11:46	SS01	7.72	277	100	<0.5	<0.03	<0.04	520	60	100	0.38
	13:10	SS02	7.81	297	50	<0.5	<0.03	<0.04	710	160	80	0.25
	14:23	SS03	7.09	8120	50	<0.5	<0.03	<0.04	330	9397	186	<0.25
	13:51	SS04	7.74	1700	<5	<0.5	<0.03	<0.04	200	520	290	0.37
	15:40	SS05	7.35	895	30	<0.5	<0.03	<0.04	400	350	188	0.29
	14:48	SS06	7.23	716	200	<0.5	<0.03	<0.04	260	400	178	1.22
25.01.2016	15:04	SS07	7.19	974	10	<0.5	<0.03	<0.04	290	410	178	<0.25

Table D.2 Water quality results from laboratory analysis (Cont.)

Sampling date	Time	Site	pH (-)	EC (µS/cm)	Turbidity (NTU)	Nitrates (mg/lNO3)	Nitrites (mg/LNO2)	Ammonia (mg/lNH4)	TSS (mg/l)	TDS (mg/l)	Alkalinity (mg/lCaCO3)	Total Phosphorus (mg/l PO4)
	18:17	SS01	6.68	402	55	<0.5	<0.03	<0.04	200	600	20	<0.25
	16:45	SS02	7.4	340	17.5	<0.5	<0.03	<0.04	110	370	70	<0.25
	16:24	SS03	6.61	930	<5	<0.5	<0.03	<0.04	210	330	75	<0.25
	16:19	SS04	6.52	1346	<5	<0.5	<0.03	<0.04	60	830	110	<0.25
	14:31	SS05	6.21	2360	25	<0.5	<0.03	<0.04	410	1490	80	<0.25
	15:02	SS06	6.53	692	<5	<0.5	<0.03	<0.04	310	530	100	<0.25
08.02.2016	15:50	SS07	6.27	763	70	<0.5	<0.03	<0.04	230	460	125	<0.25
	15:32	SS01	7.7	330	62	<0.5	<0.03	<0.04	250	230	50	<0.25
	14:10	SS02	7.8	326	13	<0.5	<0.03	<0.04	170	280	20	<0.25
	13:48	SS03	7.3	862	25	<0.5	<0.03	<0.04	30	620	70	<0.25
	13:33	SS04	7.6	1340	<5	<0.5	<0.03	<0.04	180	820	90	0.25
	12:03	SS05	7.03	3500	7	<0.5	<0.03	<0.04	160	229	125	<0.25
	11:20	SS06	7.3	663	40	<0.5	<0.03	<0.04	320	420	125	<0.25
22.02.2016	11:07	SS07	7.1	810	28	<0.5	<0.03	<0.04	50	550	100	<0.25
	18:48	SS01	7.42	340	93	<5	<0.03	<0.04	150	250	20	<0.25
	17:31	SS02	7.41	335	52	<5	<0.03	<0.04	230	260	50	<0.25
	16:29	SS03	6.89	830	50	<5	<0.03	<0.04	50	850	90	<0.25
	16:43	SS04	6.6	1329	<5	<5	<0.03	<0.04	140	840	150	<0.25
	15:03	SS05	6.78	260	30	<5	<0.03	<0.04	220	930	90	<0.25
	15:54	SS06	7.6	790	25	<5	<0.03	<0.04	320	450	100	<0.25
07.03.2016	15:45	SS07	7.72	736	80	<5	<0.03	<0.04	190	320	120	<0.25

Appendix E: Graphic representation of the results of water quality

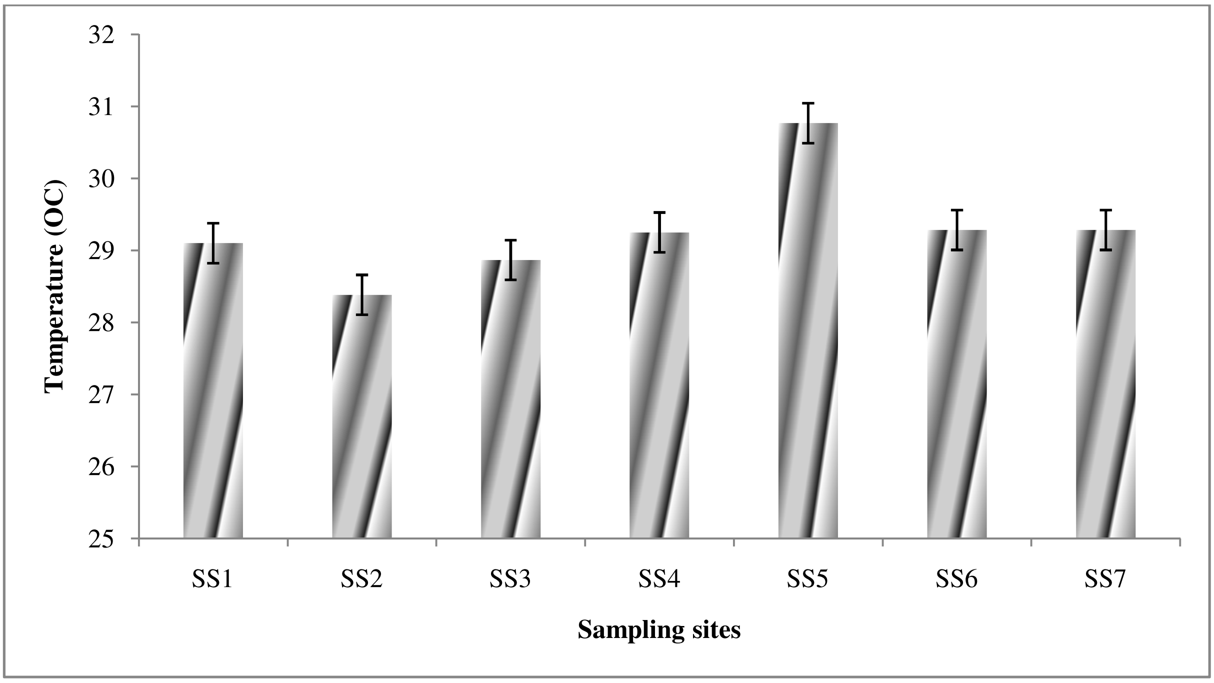

Figure E.1 Variation of temperature for January to March 2016 for Incomati River

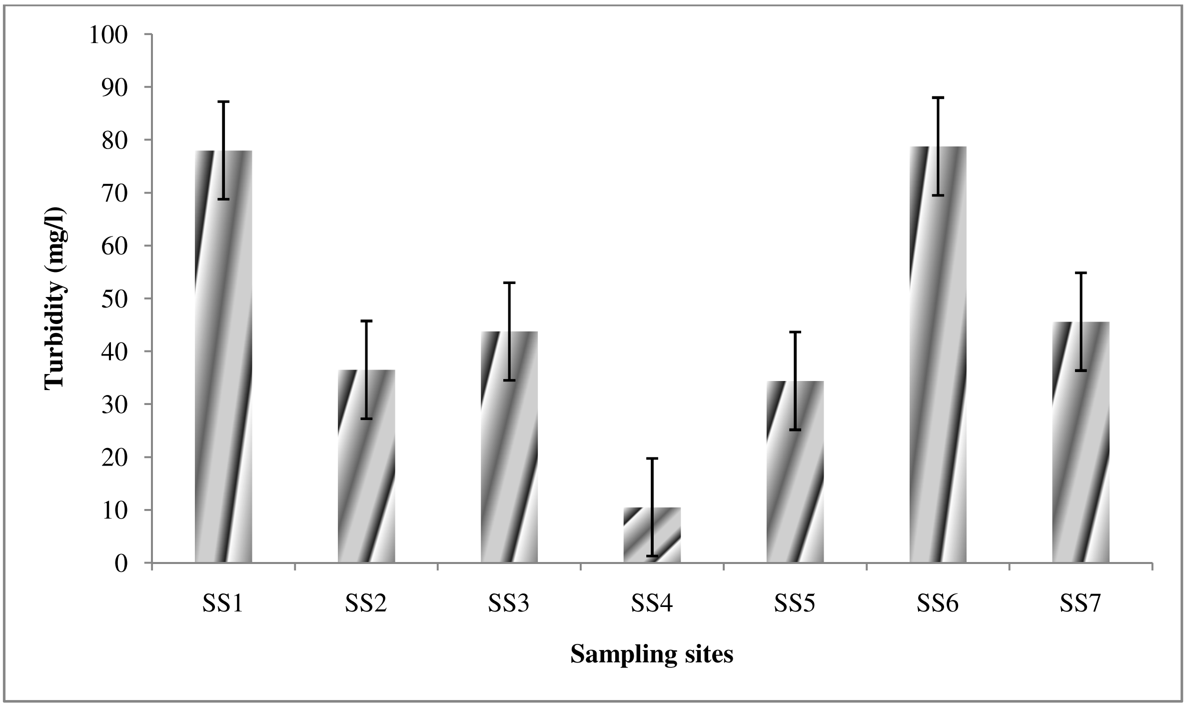

Figure E.2 Variation of turbidity for January to March 2016 for Incomati River

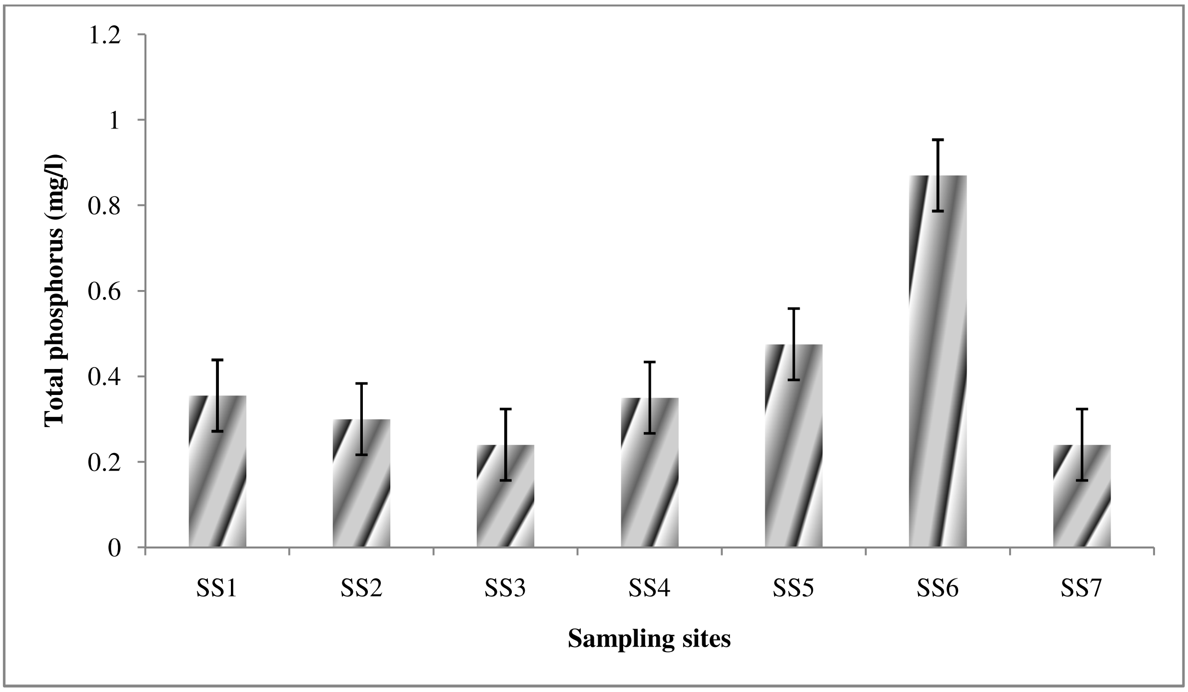

Figure E.3 Variation of total phosphorus for January to March 2016 for Incomati River

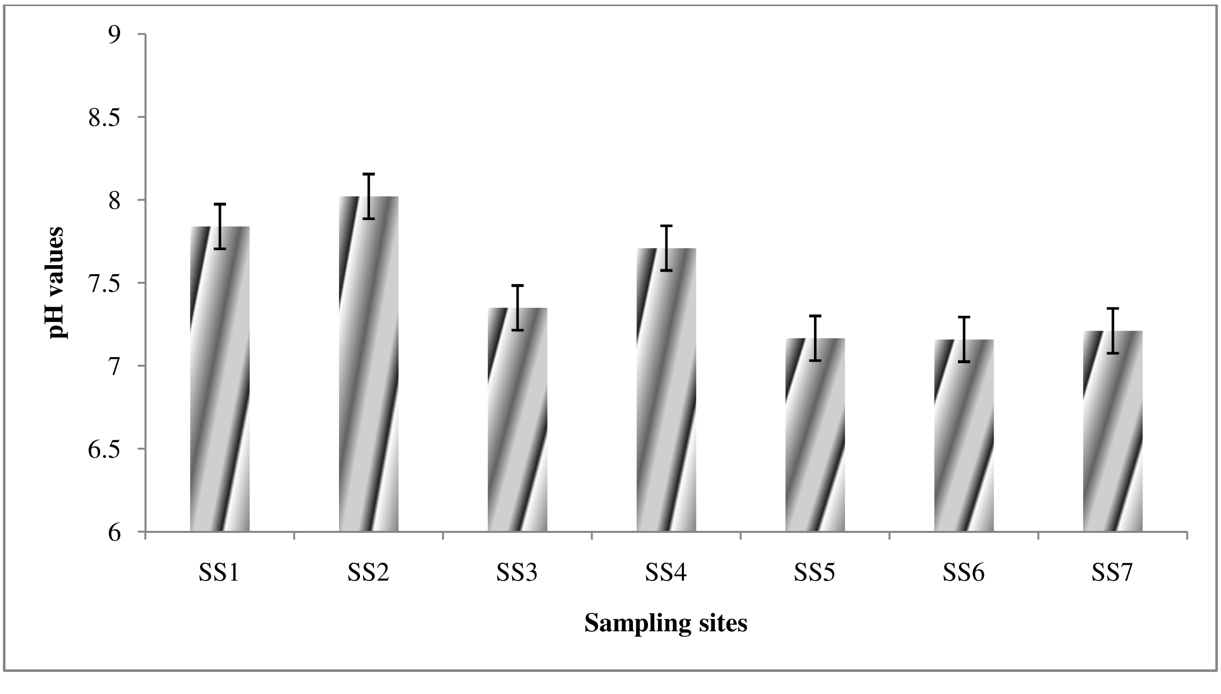

Figure E.4 Variation of pH for January to March 2016 for Incomati River

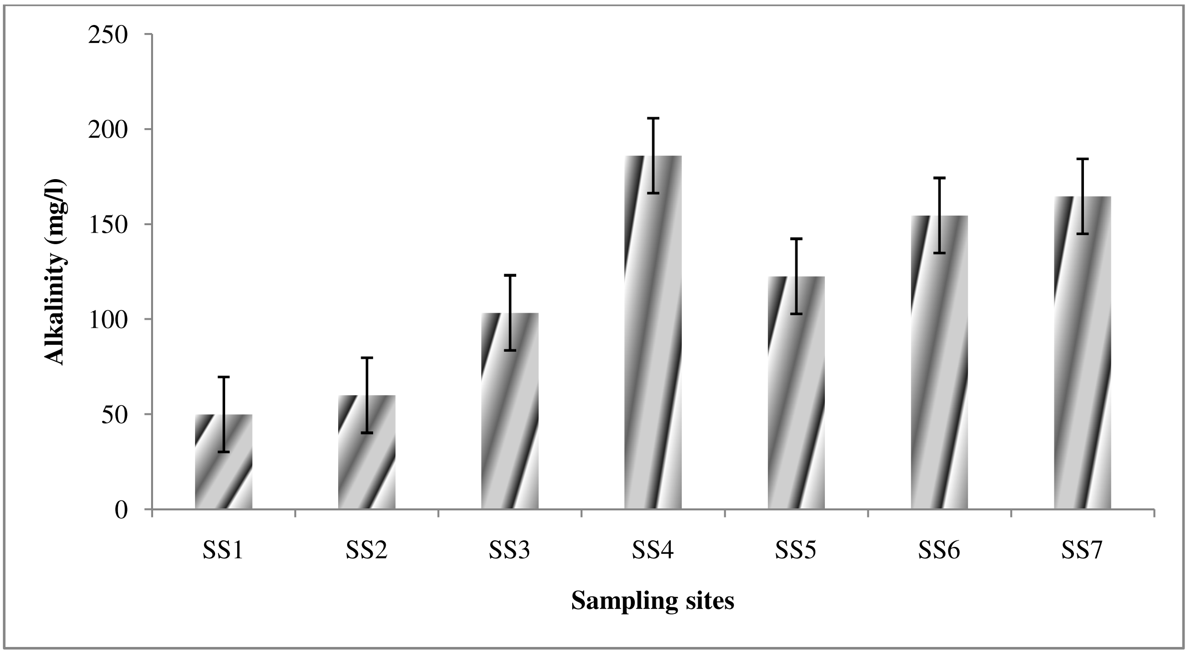

Figure E.5 Variation of alkalinity for January to March 2016 for Incomati River

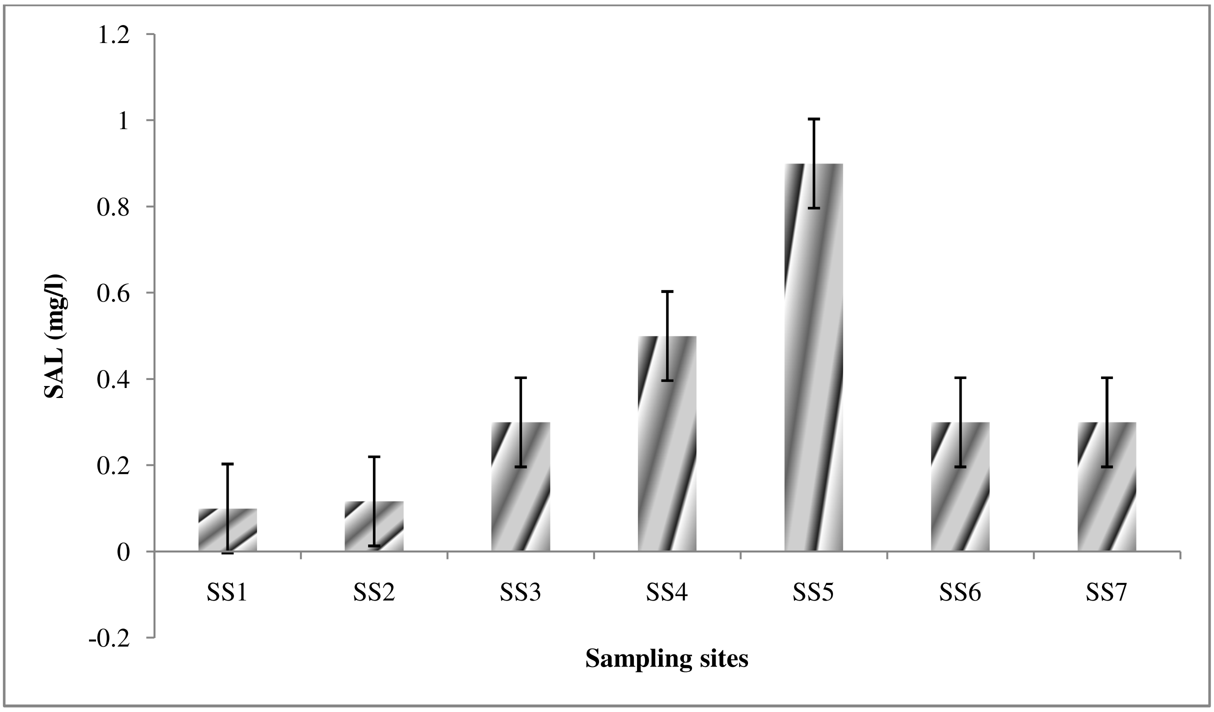

Figure E.6 Variation of salinity for January to March 2016 for Incomati River

Appendix F: Results from laboratory analysis for micro-biological parameters

Table F.1 Results from laboratory analysis for micro-biological parameters

Parameter	18:48 SS01	17:31 SS02	16:29 SS03	16:43 SS04	15:03 SS05	15:54 SS06	15:45 SS07
COD mg/l O2	320	8700	7120	512	6400	11200	3280
Total coliforms (ufc/100ml)	>100	>100	64	57	85	>100	>100
Faecal coliforms (ufc/100ml)	100	100	47	49	78	100	100
Escherichia coli (ufc/100ml)	>100	>100	47	49	78	>100	>100

Appendix G: Inco-Maputo agreement standards for monitoring of water quality

Table G.1 Water quality standards for Inco-Maputo agreement, South Africa and WHO

Parameter		**INCO-MAPUTO**			**SOUTH AFRICA**			**WHO**	
	units	**min**	**mean**	**max**	**min**	**mean**	**max**	**min**	**max**
Temperature	^{o}C				<25	30	<40		
PH		6.5		8.5	6-9	5.5-9.5	4-11	7	8.5
Electrical conductivity (EC)	mS/cm		150		70	300	400	750	2,250
Dissolved Oxygen (DO)	% saturation				70	30	10		
Alkalinity (PH-4.5 CaCO3)	mg/l								
Alkalinity (PH-8.3 CaCO3)	mg/l								
Total Hardness (CaCO3)	mg/l				20-300		1,300	100	500
Deposit									
Chloride (Cl)	mg/l		250		250	600	1,200	200	600
Sulphate (SO4)	mg/l				200	600	1,200	200	400
Nitrate (Nmg/l)	mg/l		50		6	10	20	50	100
Nitrite (Nmg/l)	mg/l		1						
Carbonate (CO3)	mg/l								
Bicarbonate (HCO3)	mg/l								
Carbon dioxide (CO2)	mg/l								
Silica (SiO2)	mg/l								
Oxygen Consumed (O2)	mg/l								
Ammonia (NH^{+4})	mg/l		1		1	2	4	0.05	
Calcium (Ca)	mg/l				150	200	400	75	200
Magnesium (mg^{+})	mg/l				70	100	200	30	150
Total Iron (Fe^{+})	mg/l				0.1	1	2	0.1	1
Manganese (Mn)	mg/l				0.05	1	2	0.05	0.5
Sodium (Na^{+})	mg/l				100	400	800		
Potassium (K^{+})	mg/l				200	600	800		
Suspended Solids	mg/l							500	1500
Turbidity	NTU		5		1	5	10		
Total Coliforms	NMP/100ml)		10,000		0	5	100		
Faecal Coliforms	NMP/100ml)		2,000		0	1	10		

Appendix H: Landuse change from 2000 to 2015 in the Lower Incomati River Basin

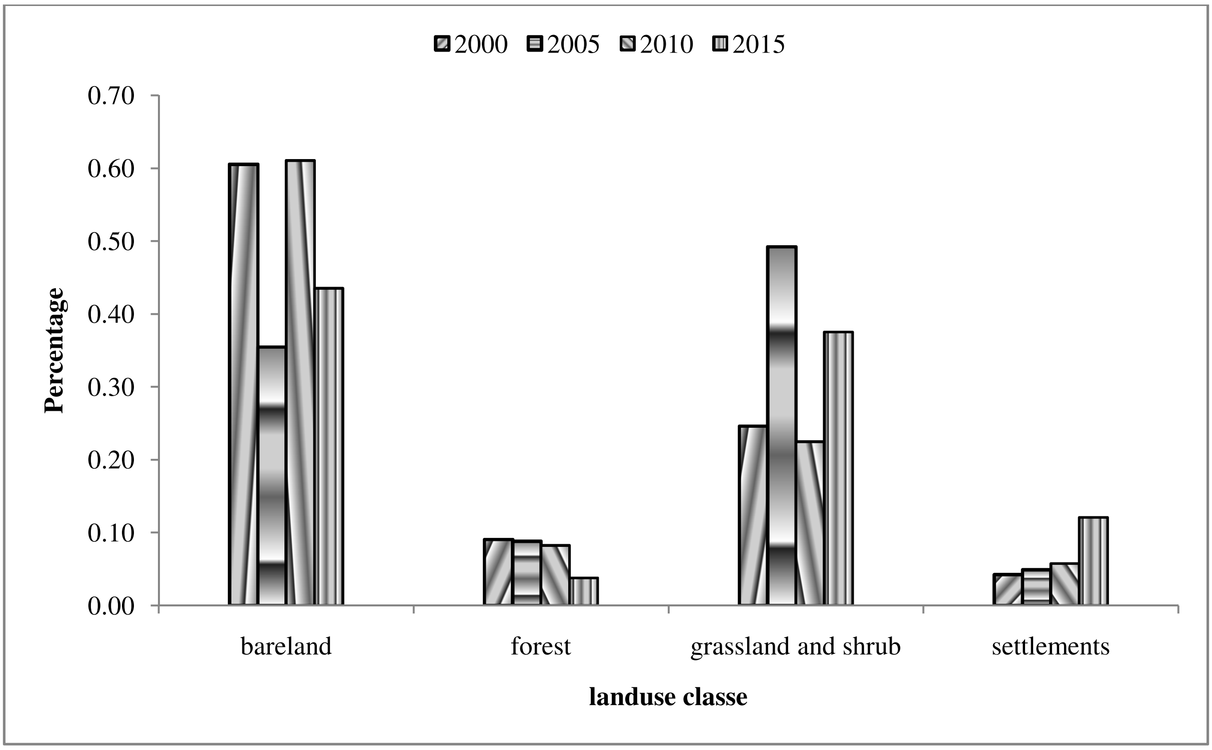

Figure H.1 Landuse change for bareland, forest, grassland and shrub and settlements in the LIRB

Figure H.2 Landuse change for bareland, forest, grassland and shrub and settlements in the LIRB

Appendix I: Correlation between landuse and water quality

Table I.1 Results of correlation between landuse and water quality

		pH	EC	Ammonia	Nitrates	Nitrites	Turbidity
Bareland	Pearson Correlation	-.065	-.338	.701	-.322	.586	.254
	Sig. (2-tailed)	.935	.662	.299	.678	.414	.746
	N	4	4	4	4	4	4
Forest	Pearson Correlation	.887	.220	-.329	-.977*	-.216	.699
	Sig. (2-tailed)	.113	.780	.671	.023	.784	.301
	N	4	4	4	4	4	4
Grassland and shrub	Pearson Correlation	.208	.353	-.701	-.197	-.602	-.136
	Sig. (2-tailed)	.792	.647	.299	.803	.398	.864
	N	4	4	4	4	4	4
Irrigation	Pearson Correlation	-.990**	.028	.128	.986*	.248	-.883
	Sig. (2-tailed)	.010	.972	.872	.014	.752	.117
	N	4	4	4	4	4	4
Settlements	Pearson Correlation	-.892	.177	-.311	.967*	.192	-.728
	Sig. (2-tailed)	.108	.823	.689	.033	.808	.272
	N	4	4	4	4	4	4
Water	Pearson Correlation	.807	-.446	-.097	-.615	-.262	.688
	Sig. (2-tailed)	.193	.554	.903	.385	.738	. 212
	N	4	4	4	4	4	4

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).