EFFECTS OF HUMAN SETTLEMENT IN RESERVOIR CATCHMENT AREA: A CASE OF MPIRA DAM

MASTER OF SCIENCE IN SUSTAINABLE ENGINEERING MANAGEMENT

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EFFECTS OF HUMAN SETTLEMENT IN RESERVOIR CATCHMENT AREA: A CASE OF MPIRA DAM

Master of Science Thesis

By

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(BSc. Civil Eng; Dip. Civil Eng.)

A dissertation submitted to the Faculty of Engineering, The Polytechnic, University of Malawi, in particle fulfilment of the requirements for the degree of Master of Science in Sustainable Engineering Management

July, 2017

DECLARATION

I, Emmanuel Felix Stone Chirwa, declare that this research entitled Effects of Human Settlement in Reservoir Catchment Area: A Case of Mpira Dam is my own work. It is submitted in partial fulfilment of the requirements for the Master of Science Degree in Sustainable Engineering Management at The Polytechnic, University of Malawi. It has not been submitted for any other degree to any University.

EMMANUEL FELIX STONE CHIRWA

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SIGNATURE

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DATE

CERTIFICATE OF APPROVAL

The undersigned certify that they have read and approved for acceptance by the University of Malawi, The Polytechnic this thesis entitled Effects of Human Settlement in Reservoir Catchment Area; A Case of Mpira Dam.

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DEDICATION

This is for my family. Dear wife Ruth, sons, Vitumbiko and Yankho and lovely daughter Thandiwe. You make me '*keep on moving*'.

Dad too, though you are no longer with us, you showed us how to go on despite limitations.

ACKNOWLEDGEMENTS

There have been generous efforts from different individuals and organisations for this work to be completed. These efforts would have been in vain without blessings from the Lord our God the Almighty. To Him we will always give thanks and praises.

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God bless you all.

ABSTRACT

Effects of human settlement within the catchment of Mpira Dam were investgated to measure contribution of human activity around Mpira Dam towards nutrient loading in the water. The study estimated the levels of nutrients from natural mineralisation and runnoff from land, examined possible correlation between demographic trends and nutrient loading in the water and possible relationship between removal of vegetative cover in the catchment area and nutrient loading in the water.

Secondary data were collected on nitrate (N) and phosphorus (P) concentrations for Mpira River and dam outlet and on population density for the area for the past 20 years. Historic and current satelite images were employed to determine changes in vegetative cover. Data on inorganic fertilizer utilisation were also obtained.

Differences between wet season and dry season N and P concentrations were statistically insignificant, 4% and 70% for Mpira River and Dam respectively. Population within the area remained around 6,000 from 1985 to 1995 and rose steadily to 9,000 from 1995 to 2013. There was a very strong positive corelation of $r = 0.84$, between population and nitrate concentration in the river and dam water. Land under vegetative cover reduced from 3,890 ha to 2,903 ha within the period 1975 and 1984, but rose to 3,723 ha by 1994. This could be attributed to afforestation interventions introduced in the area as an effort to reverse catchment degradation in 1985 but from 1994 the land cover continued to reduce to 3,397 and 2,064 in 2005 and 2013 respectively. Annual nitrate concentration averages tended to increase with decreasing vegetative cover area while it was not that clear for phosphorus.

Mean annual means of 0.001 mg/l nitrate and 0.0003 phosphorus were obtained between 1990 and 2005 but increased to 0.02 mg/l nitrate and 0.01 mg/s phosphorus between 2006 and 2013. This increase coincided with a subsidised fertilizer distribution program by the Malawi Government to benefit farmers in Mpira area.

Strong positive links were observed between population and nitrate concentration, amount of nitrogenous fertilizer and nitrate concetration in Mpira River while a strong negative link was apparent between vegetative cover and nitrate concetration. The study shows that population growth and respective human activities have increased the nutrient concentrations in Mpira River and Mpira Dam.

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ABBREVIATIONS AND ACRONYMS

AFAP	African Fertiliser and Agribusiness Partnership
ADD	Agricultural Development Division
DADO	District Agricultural Development Officer
CAN	Calcium Ammonium Nitrate
DANIDA	Danish International Development Agency
DFO	District Forestry Officer
EPA	Extension Planning Area
FAO	Food and Agriculture Organisation
GIS	Geographical Information Systems
GoM	Government of Malawi
IETC	International Environmental Technology Centre
IFDC	International Fertiliser Development Centre
IQR	Interquartile Range
IWMI	International Water Management Institute
MSS	Multispectral Scanner
NDVI	Normalised Difference Vegetation Index
NIR	Near Infrared
NSO	National Statistical Office
S/A	Sulphate of Ammonia
SRWB	Southern Region Water Board
TA	Traditional Authority

TM	Thematic Mapper
UNEP	United Nations Environmental Program
UN	United Nations
USA	United States of America
WHO	World Health Organisation
WB	World Bank

1. BACKGROUND TO THE STUDY

1.1. Introduction

Water is a precious natural resource that supports all forms of life. Water constitutes the bulk (70% - 90%) of all living cells (Khan and Ansari, 2005). Freshwater is used in drinking and multiple household chores, manufacturing and other industrial undertakings, power generation, agricultural irrigation and waste disposal. It is also a habitat for numerous living organisms and also the cheapest means of transportation. However, the changing demographics and lifestyles are enhancing demand for water and increasing water pollution.

Human activity in a catchment has detrimental effects on the water quality downstream. The pollution can be physical, biological, chemical and even radioactive. Moss (2008) describes the relationship between the catchment and receiving water as that between a house and its waste bin. Most of the activities in the house are reflected in the contents of the bin.

Among chemical pollutants, nutrient overload of phosphorous and nitrogen resulting from human activity is a major global issue. Nutrients are not pollutants but life givers. They become a problem when excessive inputs affect the original character or functions of the ecosystem (Carpenter, Caraco, Correl, Howarth, Sharply and Smith, 1998). The process of increase in plant nutrient in water to levels that cause a dense growth of plant life and death to animals due to lack of oxygen is called eutrophication. Khan and Ansari (2005) state that eutrophication is in fact a very slow, natural process, but can be greatly accelerated by human activities that increase the rate of nutrient input in the water body.

Nitrogen is accessed by plants as a nutrient in form of nitrate, nitrite and ammonium. It is kept in balance naturally through several processeses in the nitrogen cycle. Nitrate, represented by NO_3^-, is a vital component in all living systems because it is the most readily assimilated form of nitrogen by plants. Phosphorus occurs naturally in rocks and other mineral deposits. Phosphates are formed from this element and are available in three forms: orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate. Each compound contains phosphorus in a different chemical arrangement (Oram, 2012). Orthophosphate is soluble by natural processes and available to the biological community. Metaphosphates are found in boiler waters and detergents and are transformed to orthophosphate in water.

Organically bound phosphates are found in organic material and are converted to orthophosphate after decomposition.

Although phosphorus and nitrogen are considered primary factors that determine a trophic state, it has to be noted that the trophic state of a water body is a biological condition caused by various factors. Apart from nutrient concentrations, the other estimators of the trophic state are algal productivity which is the rate at which light energy is incorporated into plant cells, algal biomass expressed as a concentration and the presence or absence of hypolimnetic oxygen (Carson and Simpson, 1996).

Other literature state that; originally, three states of eutrophication were used in literature and in assessments of the organic enrichment of water bodies: oligotrophic (with total phosphorous <10µg/L), mesotrophic (with total phosphorous 10-20µg/L) and eutrophic (with total phosphorous >20µg/L). With the exponential increase of the nutrient inputs from agricultural and urban point and non-point sources after 1960, a category of *hyper-eutrophic* (with total phosphorous >50µg/L) water bodies was added, which denotes a troublesome trophic state of the water body exhibited by excessive algal biomass of noxious species (Novotny, 2009).

The increased nutrient loading by humans is termed “cultural eutrophication” and in many parts of the world has produced adverse effects such as loss of recreation, reduced fish production, drinking water treatment problems and the presence of phytoplankton toxins in drinking water and seafood (Shaw, Moore and Garnet, 2003). In freshwater systems, phosphorous is often identified as the “limiting nutrient” to phytoplankton development. Main natural sources of phosphorous in aquatic bodies are from the weathering of rocks, leaching of the soil and rain. Major sources are human induced with the main culprits being agricultural runoff and domestic sewage. There is also some contribution from household detergents and pesticides. Domestic and industrial wastewaters are normally discharged to water bodies as point sources while agricultural fertilisers are diffuse sources. Animal feedlots and waste, being rich in both nitrates and phosphates, also contribute to nutrient loading.

Generally low levels of industrialization in Africa mean that eutrophication does not present the same problems as it does in more developed countries. Main natural sources of phosphorous in aquatic bodies are from the weathering of rocks, leaching of the soil and rain.

Major sources from humans are agricultural runoffs and domestic sewage. Deforestation takes place as a result of clearing land for agriculture, and harvesting wood for fuel (about 90% of the population of Malawi uses fuel wood), building materials and a source of income (United Nations Environmental Program – International Environmental Technology Centre (UNEP-IETC), 1999). Elsewhere in the tropics, construction of new reservoirs and increased uses of natural lakes for water supply combined with settlement in the catchments has resulted in cultural eutrophication (Kitaka, Harper and Mavuti, 2002). Initially the relationship between water quality and nutrient concentrations, modulated by reservoir factors such as residence time and thermal stratification, were not well understood (Magadza, 2008). This led to construction of man-made lakes (like Lake Chivero in Zimbabwe) without consideration to the effect of nutrients. Such man-made lakes were eventually invaded by water hyacinth and other evasive exotic plants leading to devastating consequences like offensive smell. Early warning signs of degradation of water quality due to nutrients have been noted in lakes Malawi, Kariba and others (UNEP-IETC, 1999).

Water bodies especially in the tropics rely heavily on rainfall for recharge. The amount of rainfall varies within the year and amongst the seasons, resulting in greater seasonal and inter-annual variations. The variations are worsening with climate change which necessitates a fundamental rethinking of the way water resources and particularly water storage options, are planned and managed (International Water Management Institute (IWMI), 2013). The need for storage has escalated the need for construction of both large and small dams to create water reservoirs. However, large investments in the creation of these reservoirs are threatened by the increasing plant growth accelerated by eutrophication which changes the water quality to levels not suitable for the intended purposes.

Malawi also relies heavily on run-off river systems which have led to construction of about 700 small to medium dams with reservoir capacities ranging from a few cubic meters to about 5 million cubic meters (Chipofya, Kainja and Bota, 2012). Chipofya et al. (2012) observes that the large dams in Malawi have mainly been developed by water boards for urban water supply. These include Lunyangwa Dam in Mzuzu, Chitete Dam in Kasungu, Kamuzu I and II Dams in Malingunde (Lilongwe), Mpira Dam in Ntcheu, Mulunguzi Dam in Zomba, Mudi and Chimwankhunda Dams in Blantyre, Chilingali Dam in Nkhotakota and Lifupa Dam in Kasungu. All these dams are receiving plant nutrient loads of varying amounts and are at different levels of eutrophication. They require protective action before their functionalities are compromised.

This study looked into the major causes of eutrophication in Mpira dam in Ntcheu which has a maximum storage volume of 3,720,000 m^3 and was constructed to supply potable water to about 350,000 people in Ntcheu, Balaka and Neno Districts. Although the Mpira Balaka Rural Water Supply Report on Water Chemistry and Algae of October 1990 indicated the existence of some algae blooms in the reservoir late in the dry season, the blooms have intensified and occur almost every dry season starting from around 2004 (according to treatment plant operators and pre-chlorination records). Nutrient enrichment in such reservoirs and the resultant algae growth have several effects on water quality. There is an increase in particulate organic matter in the form of phytoplankton, zooplankton, bacteria, fungi and detritus. Increases in some of these lead to undesirable colour (green). Increases in dissolved organic compounds impart objectionable tastes and odours, increase colour and are potential precursors for organohalides which provide substrate for bacterial growth in treatment plants and distribution systems and may contribute to corrosion problems in the network. The other effects are increase in pH and its daily fluctuations, and depletion of oxygen. These effects lead to incomplete mineralisation of organic substances and releases of hydrogen sulphide, ammonia, phosphorous, iron, manganese and other metals, methane and other reduced organic compounds into the water column (Walker, 1983).

These alterations on the raw water quality have direct and indirect effects on water supply operations and treatment costs like hindrance of flock formation by dissolved organics in flocculation and increase in chemical costs for pH control. In filtration, the increase in turbidity lead to increased clogging, reducing the filter run times which requires frequent backwashing in rapid gravity and frequent scrapping of top layer (*schmutzdecke*) in slow sand filters. The increase in organic matter and ammonia leads to an increase in chlorine demand and also contributes to taste-odour problems and iron and manganese deposition. There are associated effects on water users like complaints about taste and odour, risk of exposure to pathogenic bacteria, plumbing and clothing replacement due to iron-manganese deposition and organics-related corrosion, treatment costs to quality-sensitive industrial users and increase in water rates due to increased costs of production incurred by the utilities.

All the effects described above may apply to the Mpira-Balaka water treatment and distribution system but the most distinct is the effect of the algae in the blocking of the slow sand filters. The frequent scraping leads to quick reduction in the thickness of the sand layers whose replacement is very expensive. To minimise or avoid such effects, Walker (1983), concludes by stating that watershed management programs are potentially cost-effective in relation to treatment schemes that may be required to meet finished water quality objectives. For example, the expenses involved in constructing and operating a new filtration plant necessitated by increased turbidity in the reservoir may exceed the costs for stabilising some eroding areas of the catchment or vegetative covering denuded areas.

During the construction of Mpira Dam in the late 1990s, a catchment area of 42 km^2 was demarcated, and people living within the area were relocated. Trees were planted in the area to reduce erosion, attenuate flooding, and reduce the effects on water quality discussed in the preceding paragraphs. In the mid-1990's people started resettling and farming within the catchment area. Of late there has also been rampant harvesting of trees, leaving the ground bare and vulnerable to erosion. It is possible that the recent algae blooms are a result of these activities apart from the possibility of natural occurring algae growth. This study investigated man-made conditions contributing towards algae blooms so as to suggest mitigation measures for the same. The study desired to suggest such measures that may optimise resource use in the management of Mpira Dam and its catchment to sustain the original objectives of its construction.

1.2 Problem Statement

During normal periods, Mpira-Balaka Treatment Plant produces 350-400 m^3 per hour, but during algae bloom periods production is 300-350 m^3/hour. Apart from reduced production, pre-chlorination is introduced to reduce the algae (increasing production costs) and sometimes the slow sand filters are bypassed to meet the water demand (compromising water quality).

The original design of Mpira-Balaka treatment plant was that roughing filters were preceding slow sand filters. Due to heavy clogging of roughing filters mostly due to heavy algae presence in the raw water, the media was permanently removed from the filters as the costs for cleaning and replacement were too high for the operating authority. The structures were then converted to function like sedimentation tanks leading to reduced clarification of the raw water. This water clogs the slow sand filters faster, leading to frequent scraping which reduces the sand thickness. This then leads to more frequent sand replacement which is expensive.

There is limited information regarding the contribution of human activities towards the nutrient loading in the Mpira Dam catchment area which prompted this study.

1.3 Objectives of the Study

1.3.1 Main Objective

The main objective of this study was to assess the relative contribution of human activity in the Mpira Dam catchment towards the presence of nutrients in the dam water.

1.3.2 Specific Objectives

Specifically the study was carried out to:

i. Estimate the concentration of nutrients from natural mineralisation and runoff from agriculture and deforestation.

ii. Examine possible correlations between demographic trends in the catchment and nutrients concentrations in the water.

iii. Establish possible relationships between vegetative cover in the catchment and nutrient concentrations.

1.4 Significance of the Study

The results of this study will identify sources of excess nutrients to Mpira Dam. The knowledge on the sources will support science-based decisions for cost-effective management of Mpira Dam and its catchment.

2. LITERATURE REVIEW

2.1. Introduction

This Chapter outlines the possible sources of nutrients that end up in our water bodies focusing on: natural mineralisation, demographic trends, vegetative cover and agricultural activities. This review gave direction to the researcher on how to achieve the objectives stated above.

2.2. Natural Mineralisation as Contributor to Nutrient Concentrations in Water

Phosphorus is a nutrient necessary for plant growth. Commercial fertilisers contain phosphorus which is mined in huge quantities from deposits around the world. In natural waters, phosphate (PO_4^{3-}) is the most abundant stable form of phosphorus, but organic particles containing phosphorus can also be important. Natural sources of phosphate include erosion (weathering) from phosphate-rich rocks and recycling of phosphorus from organic matter. Phosphorus bound to soil particles may also be released to a water body as a result of forest fire or soil erosion. This nutrient is mainly brought to aquatic environment from the weathering of rocks, the leaching of soil and rain (Khan and Ansari, 2005).

Notholt, Sheldo and Davidson (1989) confirmed the availability of phosphate rock in southern Malawi around the Kangankundi area that is about 50 km from the study area. Ground or simply processed phosphate rock can be an effective and appropriate fertiliser when applied under specific soil and climatic conditions (Government of Malawi, 2009). However, Nyirongo, Mughogho and Kumwenda, (1999) and colleagues experimented on using a phosphate rock similar to the Kangankundi one with a combination of several organic and biological catalysts but the results suggest that the potential of the rock phosphate for direct application is rather limited in terms of realising immediate benefits.

2.3. Demographic Trends and Nutrient Loads

The United Nations estimates that by 2050, the world population will surpass 9 billion people – an increase by nearly half of the 2000 population. Most of this growth will occur in developing countries that already suffer from water stress. Growing populations, especially when concentrated in urban settings, create more domestic waste and sewage that can overload streams and treatment systems, leading to even more polluted waters. With more people, there will be a need for increased agricultural productivity. Enlargements in irrigated areas, coupled with an increased reliance on and use of fertilizers and pesticides in developing countries, will lead to increases in polluted irrigation return flows. Deforestation will increase as more cropland and wood for fuel are needed, accelerating erosion and leaching and increasing water pollution (Palaniappan, Gleick, Allen, Cohen,Christian-Smith and Smith, 2010).

The pressures associated with population growth have a negative bearing on water quality downstream. Vushe, Haimene and Mashsuri (2014) looked at water quality change in the Kavango region in Namibia that experienced a ninety percent population increase, and land use change from forests and grasslands into settlements and agricultural lands, which included increased irrigated commercial farming activities along the Okavango River between 1990 and 2011. The results showed that there were no statistically significant differences in total Phosphorus or total Nitrogen in the period which could suggest that other activities trigger nutrient rise in surface waters. The situation is different when the settlement happens to be an urban settlement, as observed by Magadza (2008) where partially treated sewage was discharged into a river.

2.4. Vegetative Cover and Mineral Loading in Surface Waters

The quality of water in rivers and lakes depends substantially on protecting the healthy function of their headwater streams. Forests significantly help protect these streams and preserve water quality in watersheds by performing a number of ecosystem services: moderating stream flow and flooding, controlling surface runoff and erosion, buffering against pollutants and preventing sedimentation and eutrophication of waterways (Wilder and Kiviat, 2009). Forests manage to do this by slowing runoff, thus reducing erosion and sedimentation of rivers and reservoirs. Reduction of runoff also promotes infiltration of water into the soil, eventually recharging groundwater and purifying it by a number of biotic and abiotic processes.

Organic matter, roots and soil fauna maintain the porosity and permeability of the forest floor and evapotranspiration keep soil unsaturated (de la Cretaz and Barten, 2007). Wilder and Kiviat (2009), however, observed that the rates of infiltration, water retention and surface runoff generation of forest soils depend on forest maturity and type, and on the physical characteristics of the watershed. He gives an example of a newly harvested forest which generated high runoff, sediment and nutrients that reduced significantly as the vegetation grew. To the contrary he says that research has also shown that harvesting can also change nutrient cycling dynamics, as young forests may consume more nutrients and prevent their deposition into streams.

Wickham (2005) compared the variation of several geographically different regions all having three land-use types: urban, agricultural and forested. His results showed that the differences in Phosphorous concentrations in the stream among the different regions were insignificant and so was the difference between urban settlement and agricultural land. The difference in P between urban settlement/agricultural land and forests, however, was three times more than differences between regions. This generally indicates that forests greatly reduce mineral loading to water bodies, hence they can be used to control eutrophication.

2.5. Agriculture Contribution to Nutrient Loading

Water quality and agriculture interactions are complex. The development of large irrigation schemes has been an important contributor to global food security, particularly in arid areas, but it has also been associated with land and water salinity problems. Both, expansion and intensification of agriculture have led to increasing use of fertilizers and pesticides that, when not well managed, degrade the water quality of surface waters. Intensification of livestock farming is a case in point: concentrating inputs increases the potential transmission of pollution from both animal waste and fodder production and if not managed well results in eutrophication of freshwater bodies (Mateo-Sagasta and Burke, 2012).

Agriculture destroys natural, independent systems. It clears natural vegetation and changes natural nutrient and soil conservation mechanisms to “leaky” systems in which nutrients removed by harvesting crop and leaching from disturbed soils must be continually replaced by fertilizer (Moss, 2008). Yet it has to be accepted that with a large human population agriculture is necessary. Intensive agriculture is now expanding most rapidly in tropical regions, where the fate of fertilizer P both on and off the farm is less well understood (Riskin, Porder, Neil, Figueira, Tubbesing nd Mahowald, 2013).

Malawi is no exception to the effects of fertilizer application to crops and also the rearing of animals whose phosphorus rich excreta and feed end up in surface and ground water. The pressures for land and proximity to water has led to cultivation up to the river banks, making nutrient washout to rivers common both in rainy and dry seasons (Chimwanza, Mumba, Moyo and Kadewa, 2006; Chikondi, Joshua and Phiri, 2010). It is however a different scenario when we look at well forested areas where there is no recognisable form of agricultural or other economic activities, as observed by Dias, Hoko and Sajidu (2011) when analysing water quality of Mulunguzi Dam in Zomba.

3. RESEARCH METHODOLOGY

3.1. Introduction

This chapter describes the study area, methods used to collect, check, and process the data analysed. It also outlines procedures followed to transform data to a state that could be easily interpreted for use in this research.

3.2. Study Area

The Mpira Dam and its catchment are located in Ntcheu district which lies to the south of the Central Region of the Republic of Malawi (Figure.3.1). It shares an international boundary with Mozambique to the west and district boundaries with Dedza to the north, Neno to the south, Balaka to the southeast and Mangochi to the northeast (Figure.4.159).

The catchment was demarcated during the dam design period using manual delineation of the drainage area on a topographic map, but for this research ArcGIS 10.0 was used. ArcGIS 10.0 is more accurate. The area is 5744 Hectares.

3.2.1. *Vegetation and Soil*

The dominant vegetation type is Miombo Woodland, although it has been replaced in about 30% of the catchment by a plantation of pine trees. The soils in the area are mainly sandy loam.

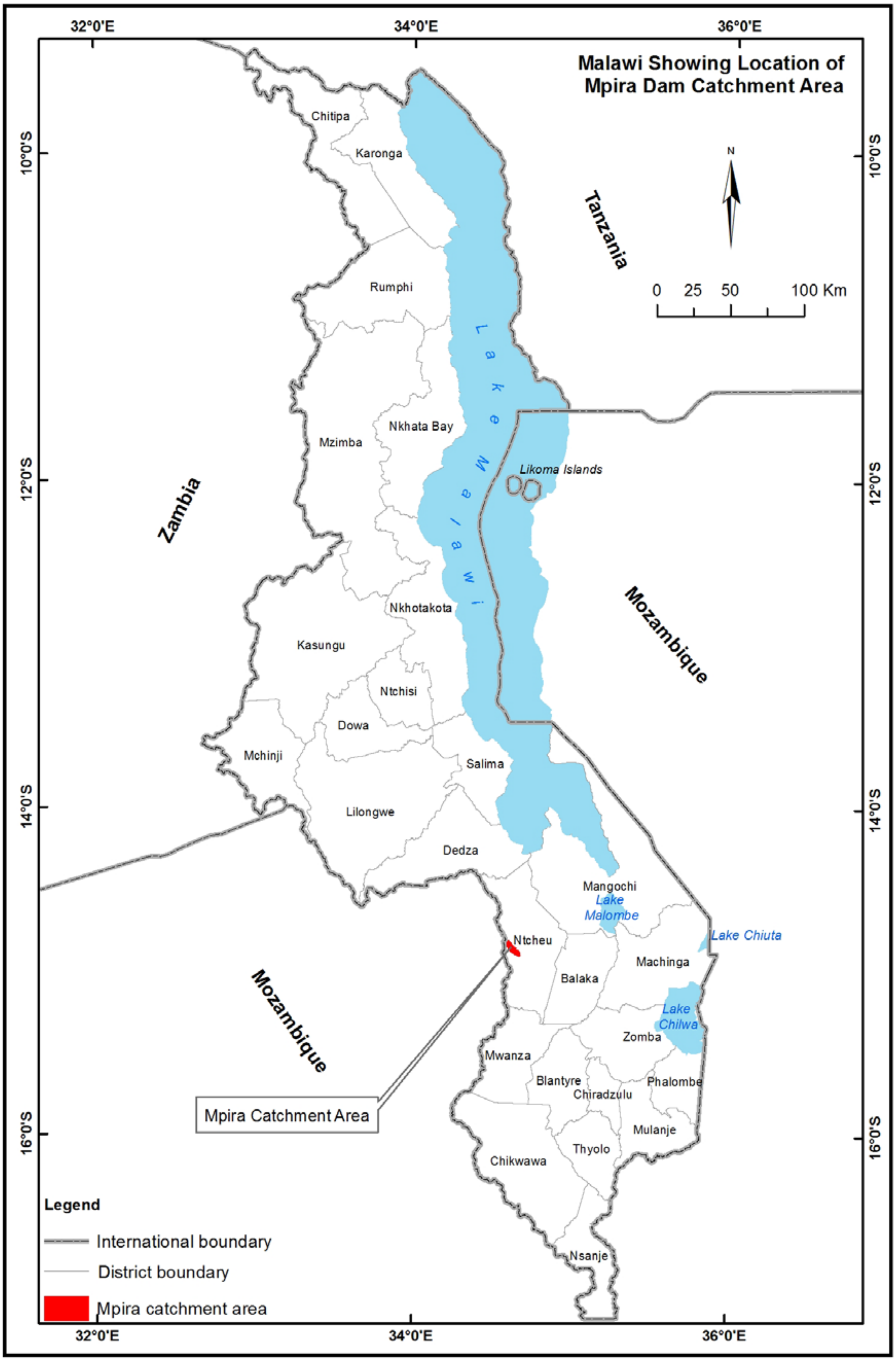

Figure 3.1: Location of study Area in Relation to District and International Boundaries

3.2.2. Drainage

The area is drained by several streams that eventually feed the Mpira River which is the one that has been dammed. According to the Ministry of Irrigation and Water Development Hydrology Section's data, almost all of the streams flow in the rainy season and dry out around the middle of the dry season. Figure 3.2 shows the sampling point on Mpira River towards the end of the dry season.

Figure 3.2: Partially Dry Mpira River at Sampling Point in Late Dry Season

3.2.3. Climate

The climate of the area is typical tropical savannah type with wet and dry seasons. The wet season is generally October to April while the dry season runs from May to September. Temperatures range from 8 to 28 degrees Celsius while the average annual rainfall is 1,000 mm (Ntcheu District Forestry Office - 2014).

3.3. Conceptualisation of Key Variables

3.3.1. Nitrate and Phosphorus

The research was designed to understand an existing problem: eutrophication in the dam. The colour of the water comes from the growth of microscopic plants whose growth is accelerated by the presence of nutrients (nitrogen and phosphorus) in the water.

Literature indicates that sources of these nutrients could be both natural and linked to human activity. Natural sources include decomposition of vegetative matter and natural mineralisation from the local geology. Natural mineralisation and decomposition of vegetative matter would be occurring throughout the years and seasons and would be evidenced by relatively constant nutrient concentrations in the river. In contrast, human induced nutrient sources, like agricultural and deforestation, would mainly be in surface runoff in the rainy season.

The presence of nutrients in the dry season can be attributed to infiltration of minerals from land to the groundwater which ends up being gradually released into the streams when there is no runoff, as explained by the findings of Fadiran, Dlamini and Mavuso (2008).

There has been increased agricultural activity in the catchment, as alluded to in the introduction which brings in the need for farmers to apply fertilizers to increase production. Some nutrients get washed away by rainwater into the feeder streams and eventually the dam. Understanding the impact of this practice necessitated quantifying of mass of N and P in fertilizers applied in the catchment.

3.3.2. Population

An increase in population in and around the catchment can also lead to increased nutrient loads because all human induced nutrient releases into the water would increase. This effect made it necessary to estimate demographic trends and correlate them to nutrient trends. A steady population rise would be followed by a steady rise in nutrient loads.

3.3.3. Vegetative Cover

Although trees were planted in the catchment to reduce peak runoff and nutrient loads, there has been considerable deforestation in the area. This made it worthwhile to measure the forest cover variation and relate it to the variation in nutrient concentrations over time.

3.4. Data Collection and Analysis

3.4.1. Nitrate and Phosphorus Data

Quantitative data were used in this study. Data for nitrate (NO_3^-) and total phosphorus (TP) from 1990 to 2013 were collected from the Mpira-Balaka Treatment Works laboratory. Data from two sampling sites were targeted:

- **Mpira River**: Mpira River water flowing under Mpira Bridge into the dam, and
- **Dam Outlet**: Dam water flowing to the treatment plant.

Nutrient concentration data were collected at two points; at a point in Mpira River before the water reaches the dam and at a point where the water leaves the dam. No difference or a small difference in mean concentrations at the two points would mean that the nutrients concentrations were reflecting the catchment. A big difference would be interpreted for other changes that occur in the reservoir like nutrient accumulation over time that would reduce the concentration as the sediments settle or increase the measured concentration if there could be mixing of settled sediments and reservoir water due to wind or thermal currents.
The samples were supposed to be taken on monthly basis but were not the case as can be observed in Appendix 1. Calorimetric methods (methods that measure heat energy during a chemical reaction to determine concentration of nutrients – in this case) with a lower limit of 0.001 mg/l were used for testing both nitrate and total phosphorus.

The total amount of fertilizer applied in Tsangano and Nsipe Extension Planning Areas (EPA) under the Ministry of Agriculture, Irrigation and Water Development in Ntcheu District were obtained from the District Agriculture Development Officer (DADO). The data available was from 2010 to 2014.

There were also some data on national subsidised fertiliser use from the World Bank and International Fertiliser Development Centre which were obtained online. Data collected for both Nitrate and Phosphorus from the Mpira River and Dam Outlet were arranged in ascending order to determine the first quartile (Q_1) and third quartile (Q_3). The inter-quartile ranges (IQR) were calculated using the formula:

$$IQR = Q_3 - Q_1$$

The lower limit (L_1) and the upper limit (L_2) of the valid data were determined using the outlier formulae:

$$L_1 = Q_1 - 1.5IQR$$

$$L_2 = Q_3 + 1.5IQR$$

The clean data were then separated into dry season (May to September) and rainy season (October to April) according to Ministry of Agriculture, Irrigation and Water Development. The average N & P concentrations for the dry and rainy seasons for both sampling points were determined. The mean difference between wet and dry season concentrations is interpreted to be the additional nutrient load from agriculture and deforestation.

All the types of fertilisers used in the Tsangano and Nsipe EPA were summed up to yearly totals. Based on their N, P, K percentages, the masses for N and P were calculated and yearly uses determined. Using Microsoft excel, the yearly N and P totals were correlated to the corresponding annual averages of Nitrate and Phosphate concentrations for both the Mpira River and Dam Outlet points.

3.4.2. *Population Data*

Population data were collected from the National Statistics Office's (NSO) 1987, 1998 and 2008 Population and Housing Census Reports. The population for 2008 was used to represent the population that could have an effect on the catchment's concentration of nutrients. This was because the population figures were from enumeration areas which could be easily located around the dam catchment (Figure 4.15) unlike the past years where Traditional Authority areas were being used. These figures (Table 4.5) were then projected to 2013 population using the formula:

$$F_p = C_p(1 + GR)^n$$

Where F_p = Future population, C_p = Current population,

GR = annual growth rate and n = number of years.

The same 2008 census figures were discounted to 1998 and then to 1987 using the appropriate growth rates from the census reports and a transformed formula from the one above.

The average annual concentrations for Nitrate and Phosphorus were calculated and correlated to the corresponding populations using Microsoft Excel.

3.4.3. Vegetative Cover

The vegetative cover in the watershed for different years was obtained by processing satellite images.

Image Processing

Multi-temporal satellite data of different sensors from two Landsat systems were used in this exercise: Thematic Mapper (TM) and Multispectral Scanner (MSS). All images were acquired for the dry season for consistency. Landsat MSS and TM data were acquired for different dates as seen in Table 3.1.

Table 3.1: Image Acquisition Date

Platform	Date of acquisition
Landsat 2 (MSS)	9 July 1975
Landsat 5 (TM)	7 October 1984
Landsat 5 (TM)	16 June 1995
Landsat 5 (TM)	18 November 2005
Landsat 5 (TM)	13th September 2013

[1]

The exercise used different bands to produce different images and are summarised in Tables 3.2 and 3.3 together with some of their characteristics.

[1] Landsat 2 and 5 have spatial resolutions of 60 m and 30 m, respectively.

Table 3.2: Major Characteristics of the Bands in Landsat 5 (TM)

Band Number	Spectral region	Spatial Resolution	Wavelength Range (µm)
1	Visible	30	0.45 – 0.52
3	Visible	30	0.63 – 0.69
4	Near Infrared	30	0.76 – 0.90
7	Short Wave Infrared	30	2.08 – 2.35

Table 3.3: Major Characteristics of the Bands in Landsat 2 (MSS)

Band Number	Spectral region	Spatial Resolution	Wavelength Range (µm)
4	Visible	60	0.5 – 0.6
5	Visible	60	0.6 – 0.7
6	Visible	60	0.7 – 0.8
7	Near Infra Red	60	0.8 – 1.1

One of the techniques used as an indicator to analyse vegetated areas within the catchment area over the years is the Normalised Difference Vegetation Index (NDVI). NDVI uses bands 3 and 4 to calculate the ratio between the two bands in the thematic mapper and bands 6 and 7 in the multispectral scanner.

The calculation is preferred in vegetation mapping because chlorophyll in plants reflects better in the near-infrared range than in the visible range of the electromagnetic spectrum. As such, in the NDVI images, areas with healthy vegetation have values approaching one and areas with poor or no vegetation cover are negative.

NDVI values range from -1 to 1 where:

- Vegetated areas will generally yield high values because of their relatively high near-infrared reflectance and low visible reflectance.
- In contrast, water, clouds, and snow have larger visible reflectance than near-infrared reflectance. Thus, these features yield negative index values.

- Rock and bare soil areas have similar reflectance in the two bands and result in vegetation indices near zero.

The images were processed using Image Analyst in ArcGIS 10.0. Various land cover types observed from the NDVI images were classified depending on their spectral signatures after the NDVI calculations. Those types were vectorised to obtain shapefiles where further analyses including area calculations were made.

In the colour composite images, all areas with green vegetation appear green, water areas blue and grassland/bare areas brown and pinkish.
Another technique that was applied in this exercise was Supervised Classification. In this technique, representative samples for each land cover in the digital image were selected as “Training Sites” in a “training set.” The image classification software (ArcGIS 10.0) uses the training sites to identify the land cover classes in the entire image.

The classification of land cover is based on the spectral signature defined in the training set. The digital image classification software determines each class on what it resembles most in the training set.

Areas of vegetative were then correlated to corresponding year’s mean annual mineral concentration using Microsoft Excel.

3.4.4. *Correlation*

Pearson’s correlation coefficient (*r*) has been used to measure strength of linear relationships between inorganic fertilizer used within the catchment area and nutrient concentration, population and nutrient then vegetation cover area and nutrient concentration where:

$-1 \leq r \leq 1$

Positive values denote positive linear correlation, negative values negative linear correlation and a value of zero denotes no linear correlation. In this document, the correlation has been described using the Evans (1996) guide which suggests for the values of absolute *r*:

.00 - .19 “very weak”

.20 - .39	“weak”
.40 - .59	“moderate”
.60 - .79	“strong”
.80 – 1.0	“very strong”

It is only in Section 4.5 that R Squared is used to measure how the cultivated area and area under vegetative cover relate within a period.

4. RESULTS AND DISCUSSIONS

4.1. Introduction

This chapter presents the results of the study. The results are presented in the order of the objectives of the study followed by observations and then postulates that can be drawn for each set of results.

4.2. Seasonal Variation of Mineral Loading

The mean wet and dry season NO_3^- and TP concentrations (mg/l) for both sampling points are summarised in Table 4.1:

Table 4.1: Wet and Dry Season Mean Nutrient Concentrations

Sampling Point	Nutrient	Mean (mg/l)	Wet Season Mean (mg/l)	Dry Season Mean (mg/l)
Mpira River	NO_3^-	0.015±0.003	0.019±0.003	0.013±0.004
	P	0.008±0.002	0.006±0.002	0.010±0.003
Dam Intake Point	NO_3^-	0.010±0.002	0.011±0.002	0.008±0.002
	P	0.011±0.001	0.015±0.001	0.009±0.001

Testing for statistical significance of the results on wet season concentrations being above the mean using the Chi test show a result of 4% and 70% for the Mpira River and Dam Outlet respectively. Therefore, the differences in wet and dry season concentrations are insignificant.

The results cannot be used to estimate concentrations in objective (i).

4.3. Inorganic Fertilizer Application

Types fertilisers used in Nsipe and Tsangano EPAs are summarised in table 4.2 with corresponding percentages of Nitrogen (N) Phosphorus (P) and Potassium (K).

Table 4.2: Fertilisers Used in Nsipe and Tsangano EPAs

Fertilizer	Nutrient Percentage		
	N (%)	P (%)	K (%)
NPK	23	21	0
Urea	46	0	0
Sulphate of Ammonia (S/A)	21	0	0
Calcium Ammonium Nitrate (CAN)	27	0	0
D Compound	10	20	10

It was not possible to wholly compare the organic fertiliser use in and around the Mpira River catchment to the Nitrate and Phosphate concentrations from the Mpira River and Mpira Dam intake point because the nutrient data spans a longer period (1990 to 2014) than the inorganic fertiliser data (2010 to 2014). Nonetheless, some trends can be observed in the period the fertilizer data was available.

There was a general decline in the quantities of inorganic fertilisers from 2010 to 2014 (Figure 4.1). The amount of fertiliser for almost all types of fertilisers used in 2009/2010 was more than that of 2013/ 2014 though there was some peak in the 2012/2012 season as compared to 2010/2011.

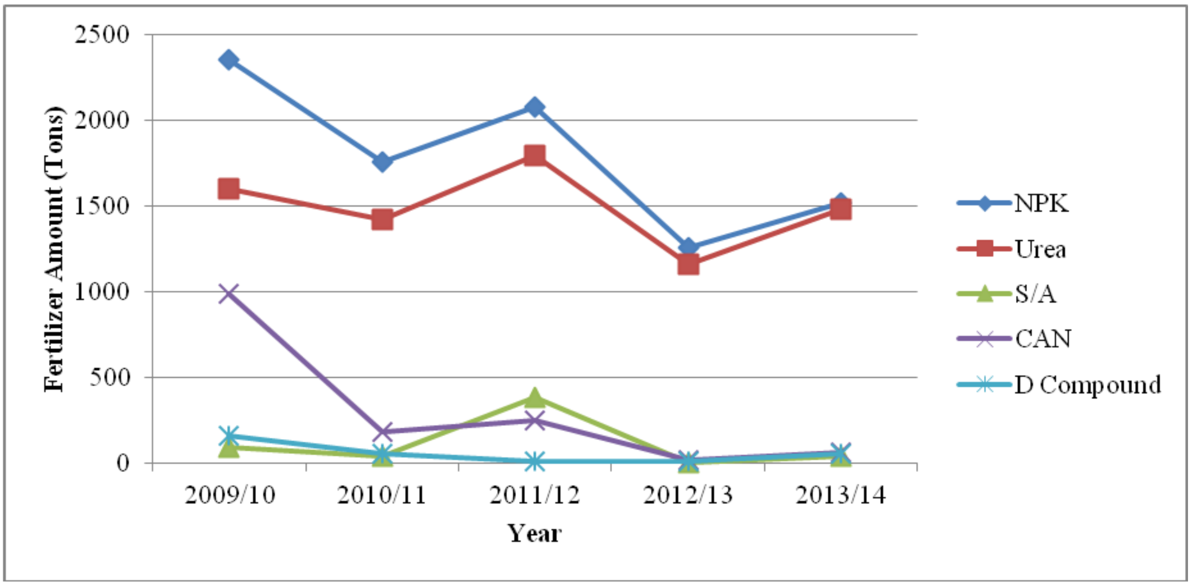

Figure 4.1: Total Amount of Fertilisers Used in Nsipe and Tsangano EPAs

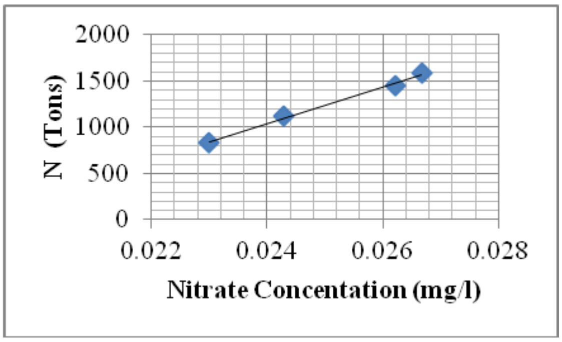

Figure 4.2: Nitrogen/Nitrate Concentration (Mpira River)

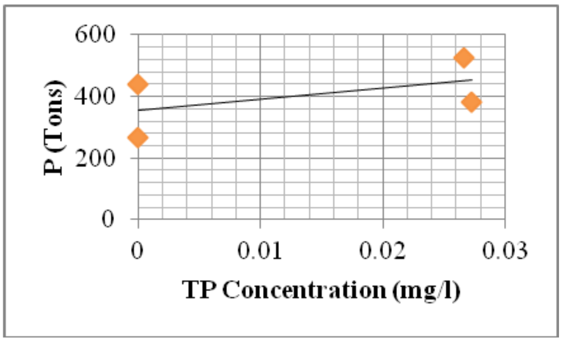

Figure 4.3: Phosphorus/TP Concentration (Mpira River)

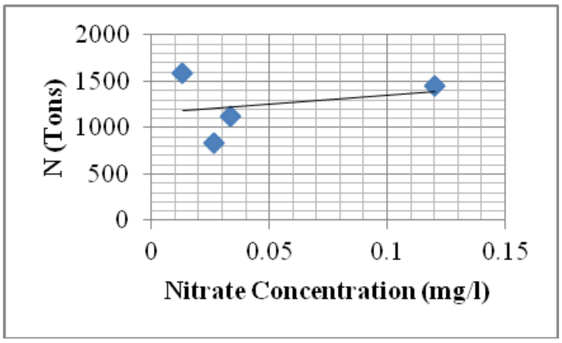

Figure 4.4: Nitrogen/Nitrate Concentration (Dam Outlet)

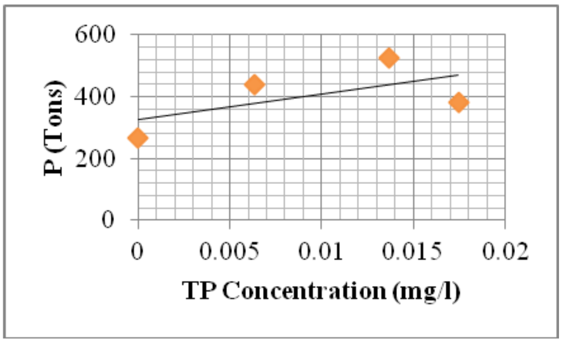

Figure 4.5: Phosphorus/TP Concentration (Dam Outlet)

For Nitrates at both sampling points, there is an isolated reading for Nitrate in 1999 followed by a gap up to around 2005 where continuous notable readings to 2014 (Figure 4.6 and Figure 4.8).

TP shows notable concentrations from 2005 to 2012 at Mpira River sampling point while at the Dam intake from around 2006 to 2008, Figure 4.7 and 4.8.

The quantities of nutrients applied through inorganic fertilisers in Nsipe and Tsangano EPAs are summarised in table 4.3 and table 4.4.

Table 4.3: Amount of Nitrogen Fertiliser Used in Nsipe and Tsangano EPAs

Fertilizer	Nitrogen (Tons)				
	2009/10	2010/11	2011/12	2012/13	2013/14
NPK (23:21:0)	541.7	404.3	479.3	290.3	349.6
Urea (46:0:0)	738.3	653.7	826.6	534.1	683.1
S/A (21:0:0)	19.7	7.8	80.0	-	9.2
CAN (27:0:0)	267.0	48.6	67.5	5.7	17.8
D/Comp (10:20:10)	15.9	5.5	1.2	1.4	5.9
Totals	**1,582.6**	**1,119.4**	**1,454.7**	**831.4**	**1,065.1**

Table 4.4: Amount of Phosphorus Fertiliser Used in Nsipe and Tsangano EPAs

Fertilizer	Phosphorus (Tons)				
	2009/10	2010/11	2011/12	2012/13	2013/14
NPK (23:21:0)	494.6	369.2	437.6	265.0	319.2
Urea (46:0:0)					
S/A (21:0:0)					
CAN (27:0:0)					
D/Comp (10:20:10)	31.8	6.6	2.4	2.8	6.6
Totals	526.4	380.2	440.0	267.8	331.0

Correlating the total annual amount of fertiliser input nutrient quantities to the average annual nutrient concentrations in this period, the Pearson value is very strong, r = 0.99 for Nitrates (Figure 4.2). This shows that the amount fertilizers applied to crops in the catchment area directly corresponds to the amount of nitrate in Mpira River water. The moderate correlations r = 0.51 for TP in the Mpira River (Figure 4.3) and r = 0.59 for TP at the Dam Outlet (Figure 4.5) show some existence of a positive relationship between the amount of phosphate fertilizers in the catchment and TP concentrations in the river and the dam. This could be to the fact that not all fertilizers applied in the catchment area contained phosphates.

The high positive correlation of Nitrates in the River could be due to the fact that almost all the fertilisers used contain nitrogen as compared to Phosphorus though the value reduces to r

= 0.28 at the Dam intake (Figure 4.4). This reduction could be attributed to the changing in form of Nitrates to other compounds in the dam.

The general picture in these results is that the inorganic fertilisers applied for agriculture contribute to the presence of nutrients in the Mpira River and then the Dam which could be contributing to the eutrophication.

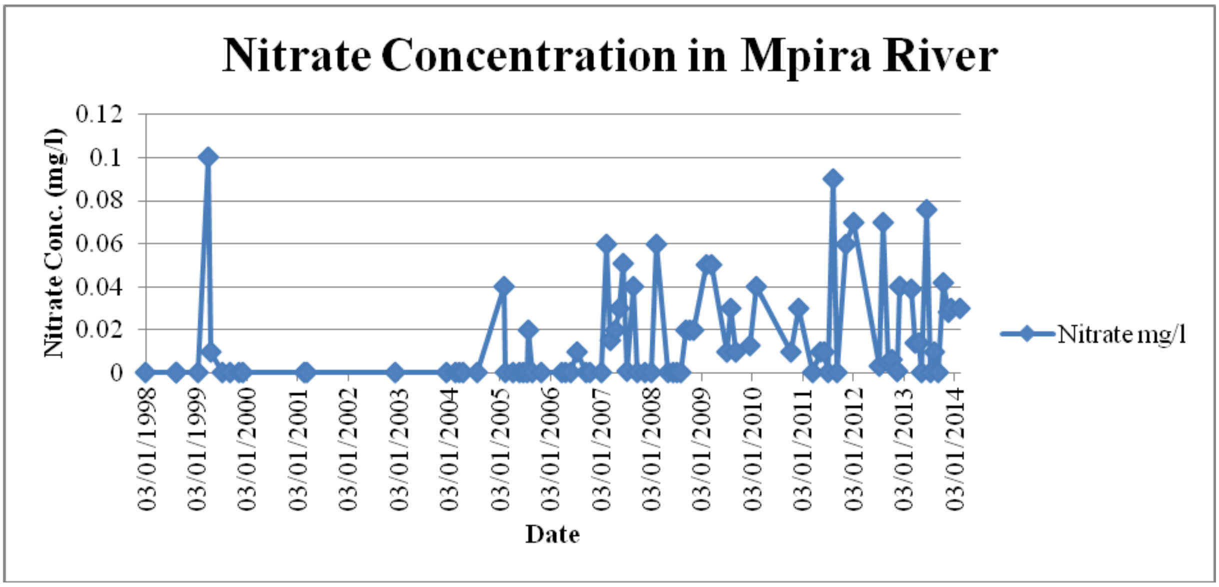

Figure 4.6: Nitrate Concetration in Mpira River

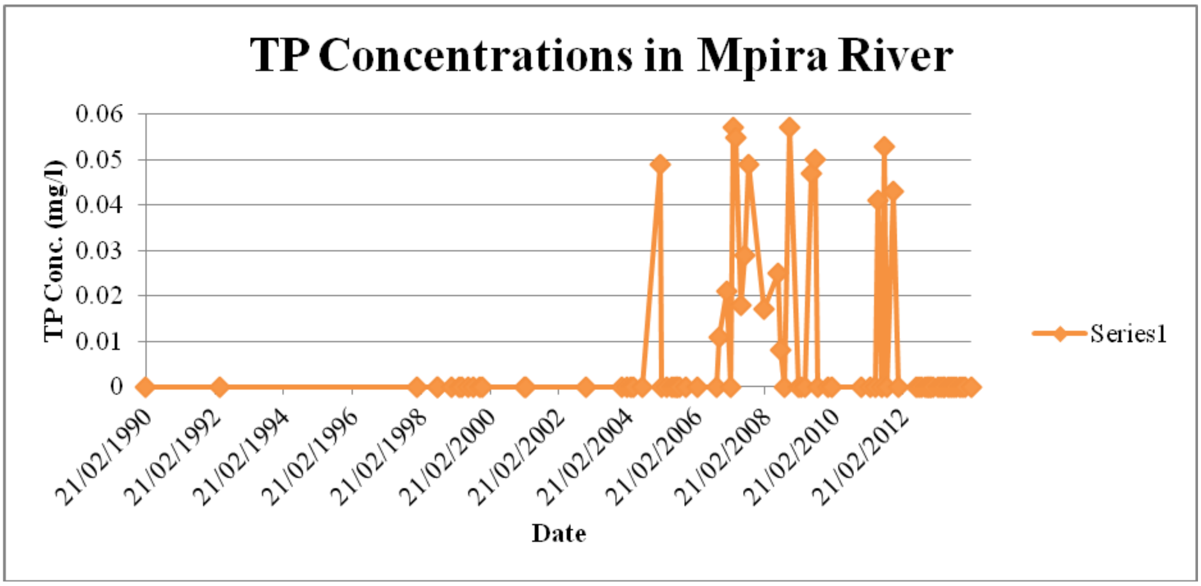

Figure 4.7: TP Concentration in Mpira River

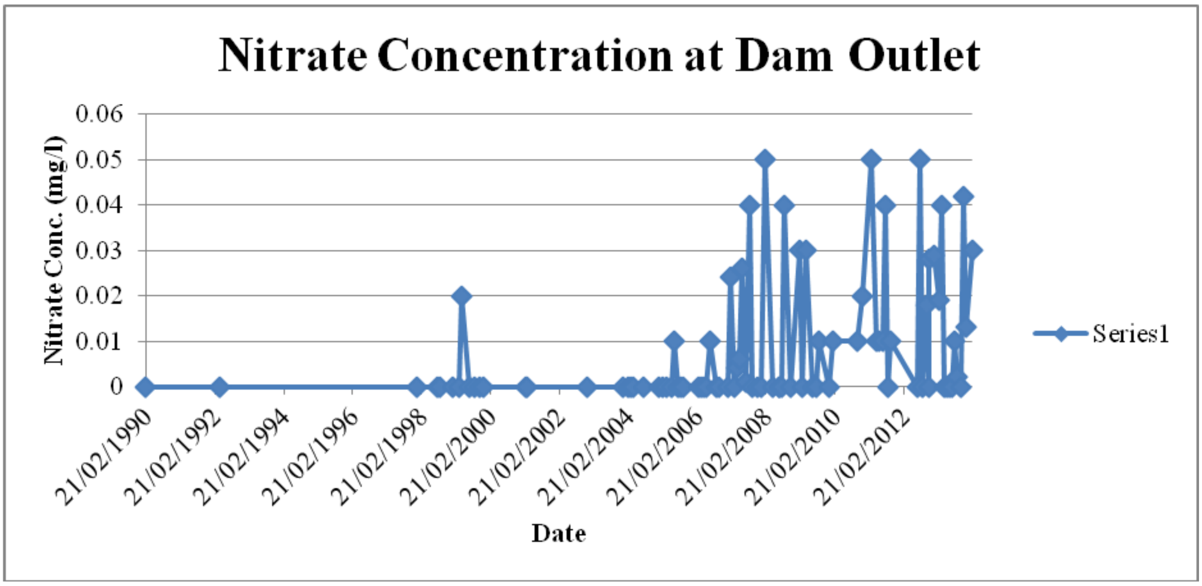

Figure 4.8: Nitrate Concentration at Dam Outlet

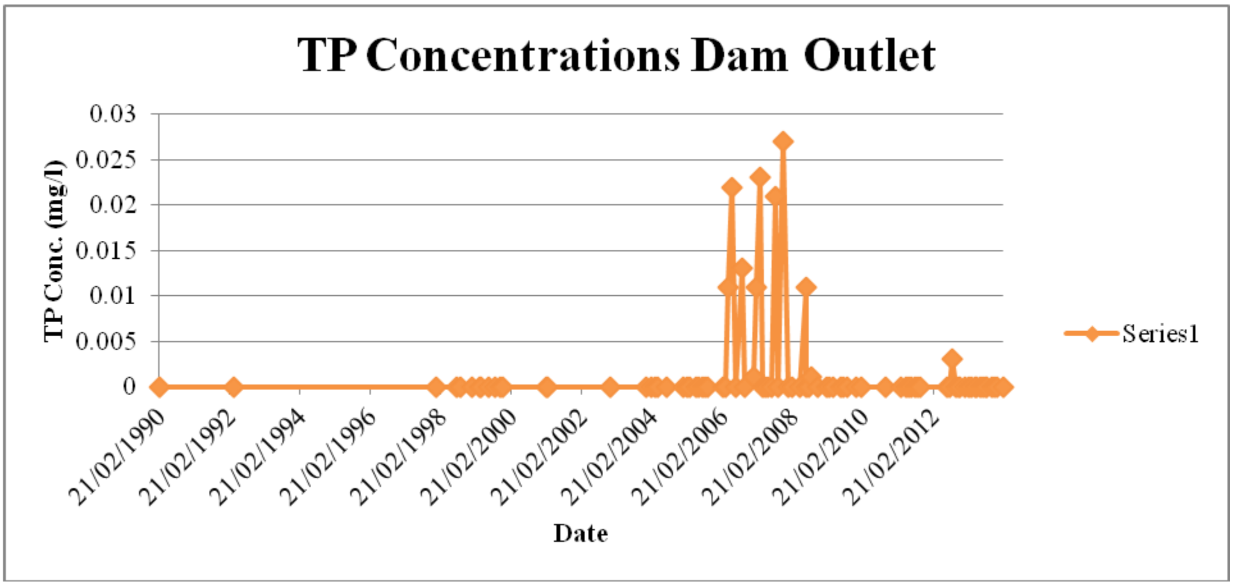

Figure 4.9: TP Concentration Dam Outlet

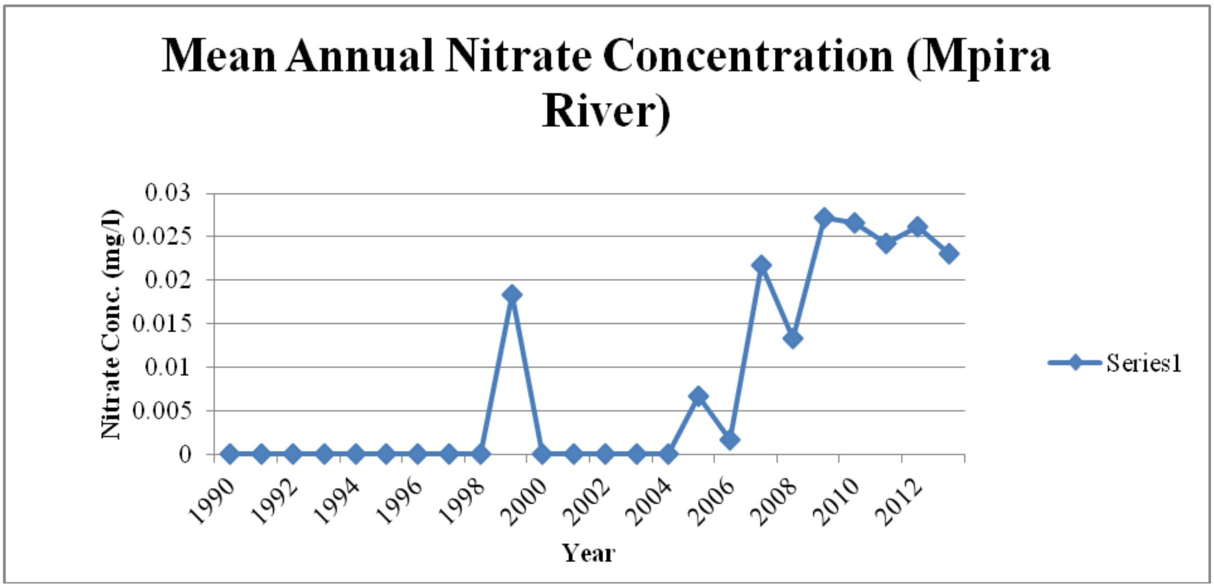

Figure 4.10: Nitrate Mean Annual Concentration in Mpira River

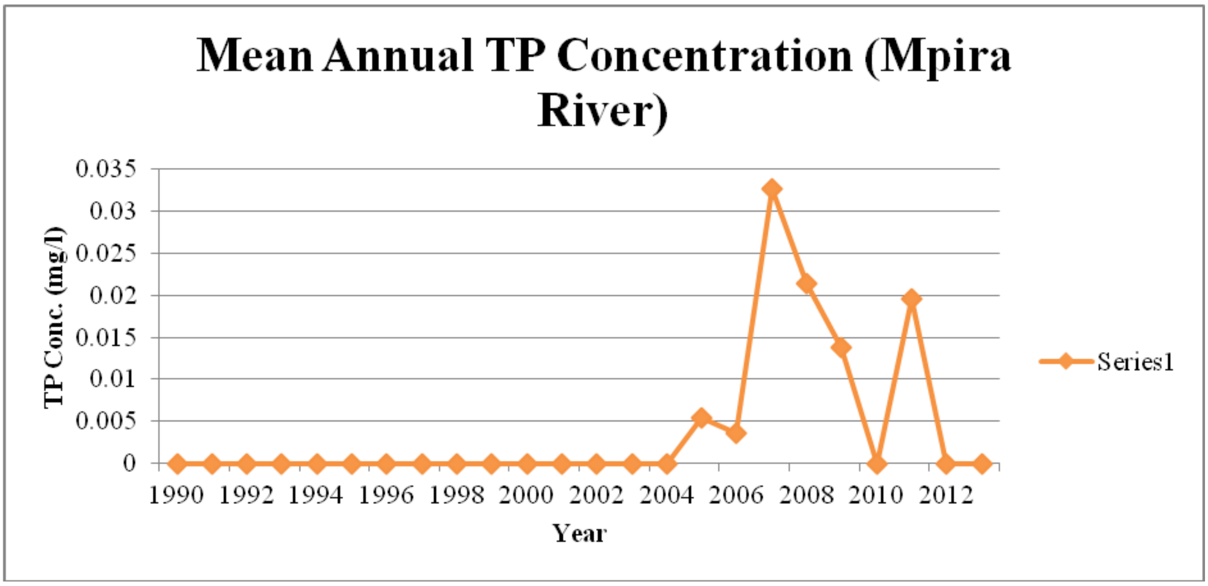

Figure 4.11: TP Mean Annual Concetration in Mpira River

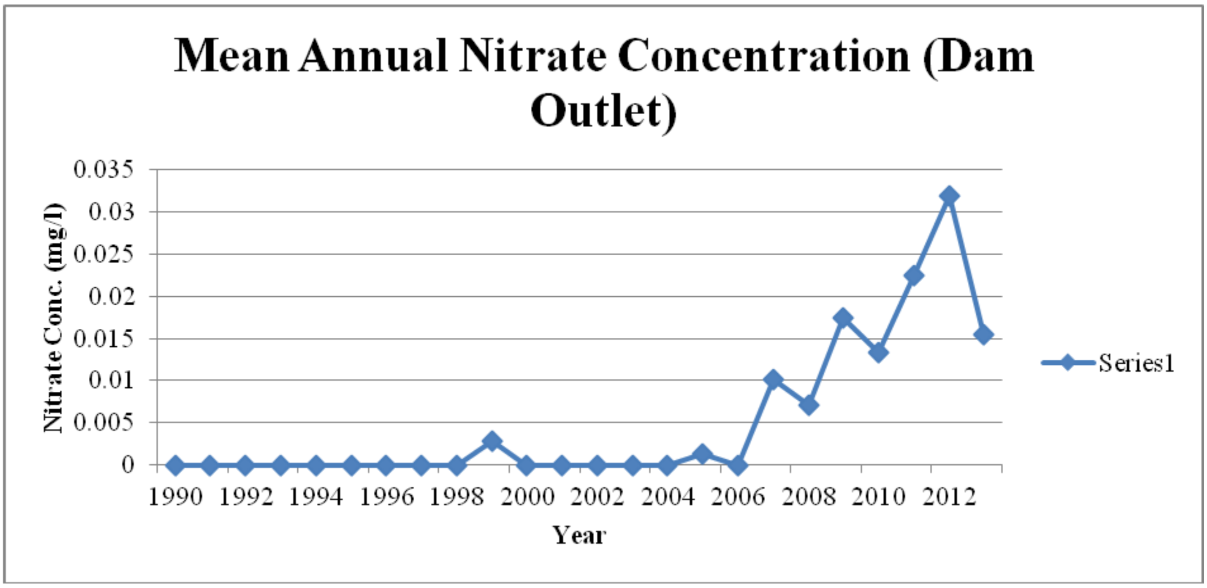

Figure 4.12: Nitrate Mean Annual Concentration (Dam Outlet)

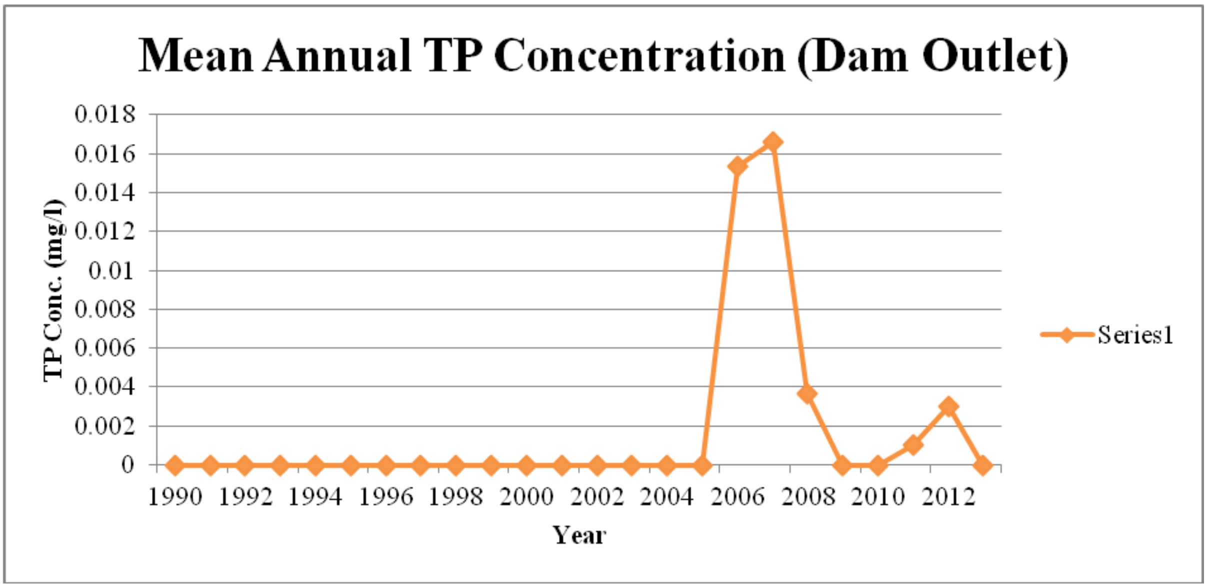

Figure 4.13: TP Mean Annual Concentration (Dam Outlet)

Figures 4.6 to 4.9 show concentration of nutrients for the actual dates for both sampling points. It is notable from these figures that generally the peaks are frequent from 2006 but their spread and maximum values are not very comparable. Their mean annual concentrations also show a similar trend.

The upsurge of nutrient concentrations notable in Figures 4.10 to 4.13 from around 2006 – 2011 is not explained by the information available. However, it is probable that some change in farm practices occurred resulting in excessive transportation of leached fertilizer into Mpira River in the preceding years. The fertilizer subsidization programme in 2006 may have led to over-use of inorganic fertiliser in years 2006 to 2011.

Nutrient concentration trends in this study are comparable to the trend in national annual use of subsidized fertilizer (Figure 4.14). It is very likely that the fertiliser use trend was similar to the Mpira Dam catchment area because most of the people are subsistence farmers.

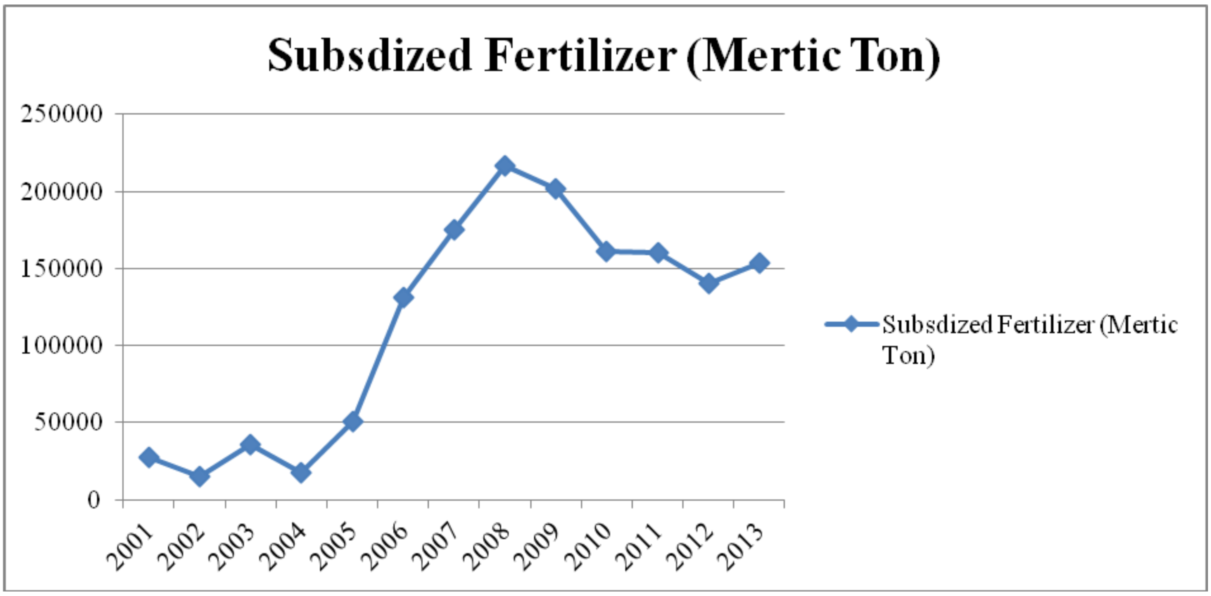

Figure 4.14: National Annual Subsidised Fertiliser Use

Sources: (World Bank, 2013: IFDC, 2013)

Use of subsidized fertiliser increased sharply from 2006 and it can also be noted that it is the same period that annual mean concentrations for both Nitrate and TP picked up (Figure 4.10 to Figure 4.13).

4.4. Demographic Trends and Nutrient Loading

The population for the catchment and surrounding areas for the 2008 census per enumeration area is summarised in Figure 4.15 while Table 4.5 presents the same per Traditional Authority (TA).

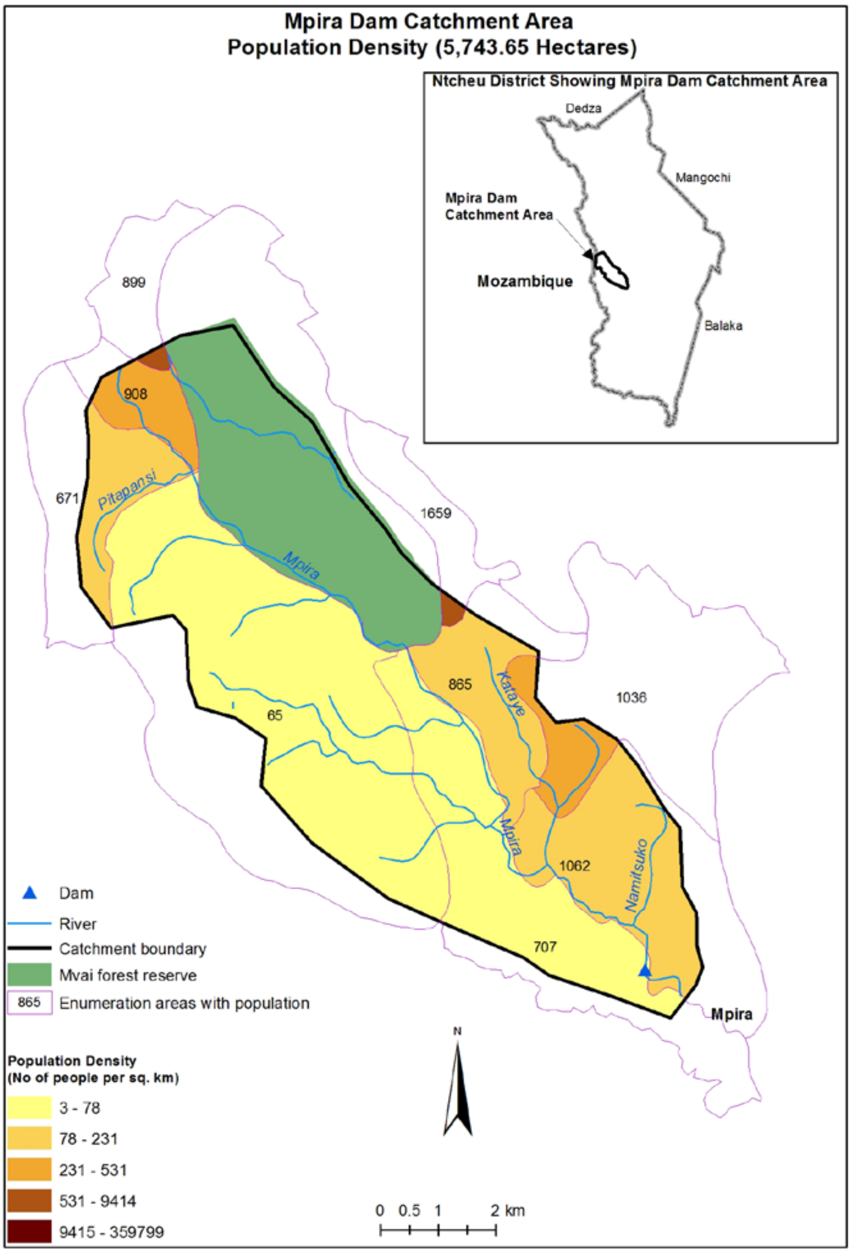

Figure 4.15: Study Area Showing Enumeration Areas

Table 4.5: Population in Study Area Enumeration Areas

Traditional Authority	Enumeration Area	Population
Mpando	EA 036	1,036
	EA 037	1,062
	EA 038	865
	EA 040	1,659
Kwataine	EA 002	899
	EA 003	908
	EA 004	671
	EA 017	707
	EA 902	65

The population growth in the catchment area was very minimal (3% per annum) before year 2000 when it increased to 5.5% Figure 4.16. It has to be noted however, from Figure 4.15 that some enumeration area boundaries are outside the catchment area boundaries.

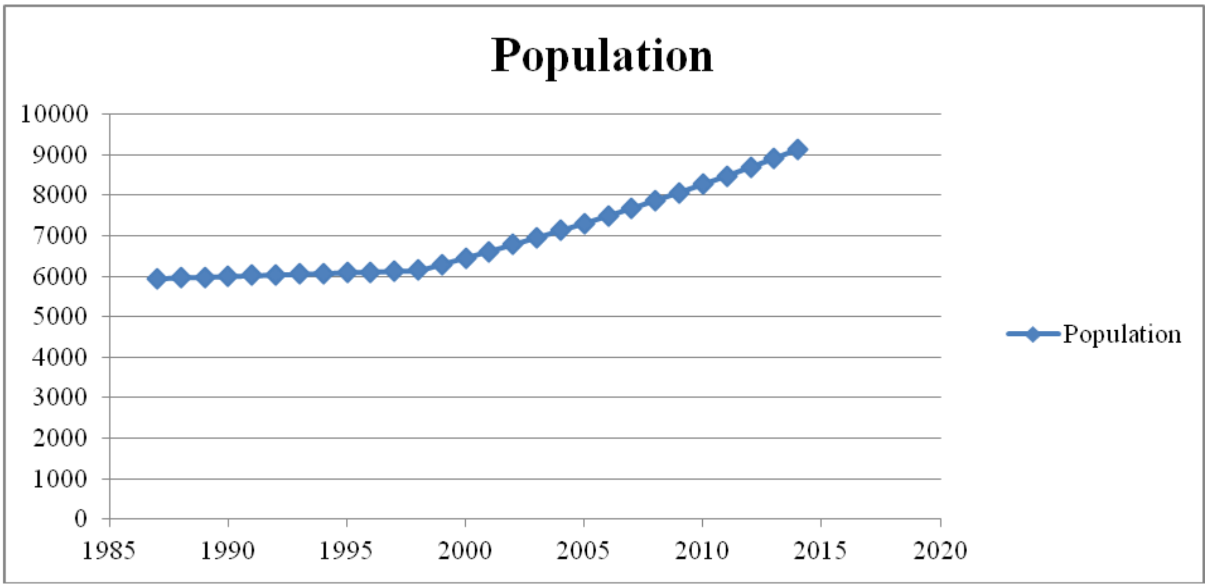

Figure 4.16: Population Trends Around Mpira Dam

Results from both sampling sites show a strong positive correlation between population and Nitrate loading with very strong Pearson values r = 0.84 for Mpira River (Figure 4.17) and r = 0.84 also for Dam Outlet (Figure 4.18) while for TP there is a moderate positive correlation of r = 0.46 for the river (Figure 4.19) and a weak correlation r = 0.36 for the dam outlet (Figure 4.20).

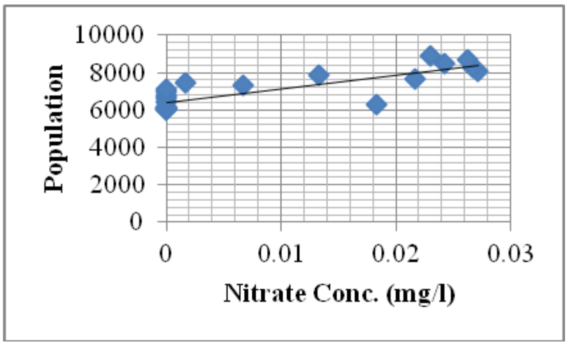

Figure 4.17: Population/Nitrate Concentration in Mpira River

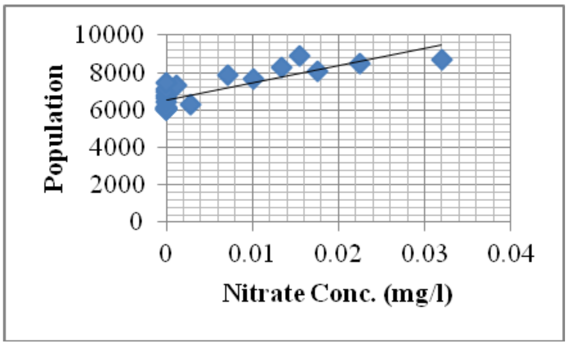

Figure 4.18: Population/Nitrate Concentration at Dam Intake

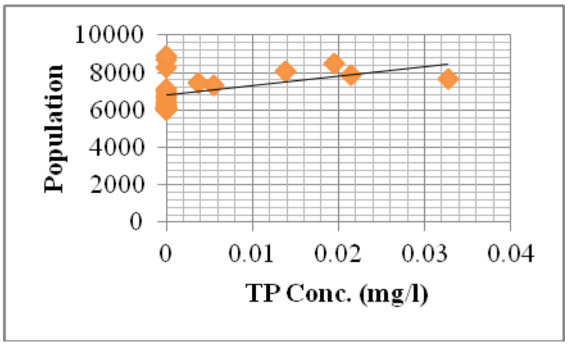

Figure 4.19: Population/TP Concentration in Mpira River

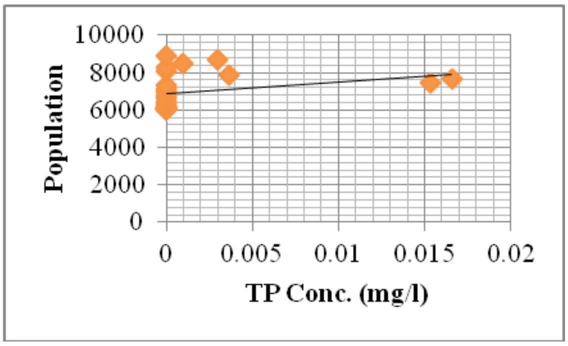

Figure 4.20: Population/TP Concentration at Dam Outlet

The very strong Nitrate correlation could be attributed to the rise in the use of inorganic fertiliser triggered by the rise in population however, the lower positive corelation between TP concentration in water and fertiliser usage seem not to support this suggestion. This anomaly could be attributed to the associated inorganic fertiliser use; universal presence of nitrogen in all fertilisers used in Nsipe and Tsangano EPA's whereas some fertilisers did not contain Phosphorus.

As alluded to by Palaniappan et al. (2010), increase in population increases the demand for more food production, and hence the need for agriculture to produce the highest possible per unit hectare. In the case of the Mpira Dam catchment, similar pressure was exerted on the community to the extent that they had to encroach into the protected area in the quest to increase their crop land. It is therefore probable that rise in population enhanced nutrient loading into Mpira river and consequently Mpira Dam.

4.5. Vegetative Cover and Mineralisation

4.5.1. Land Use

Land use appeared to have changed between 1975 and 1984 as depicted by a decrease in vegetative cover from 3890 ha to 2903 ha (Figures 4.21 and 4.22). Land area under vegetative cover subsequently rose to 3723 ha by 1994 (Figure 4.23).

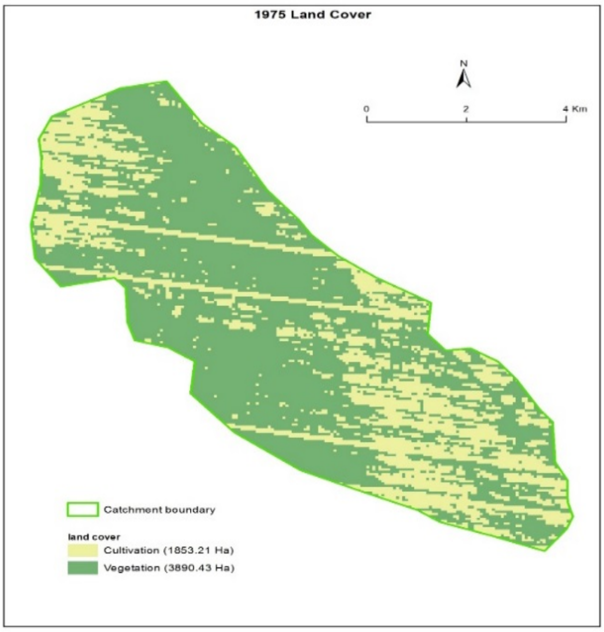

Figure 4.21: 1975 Vegetative Cover

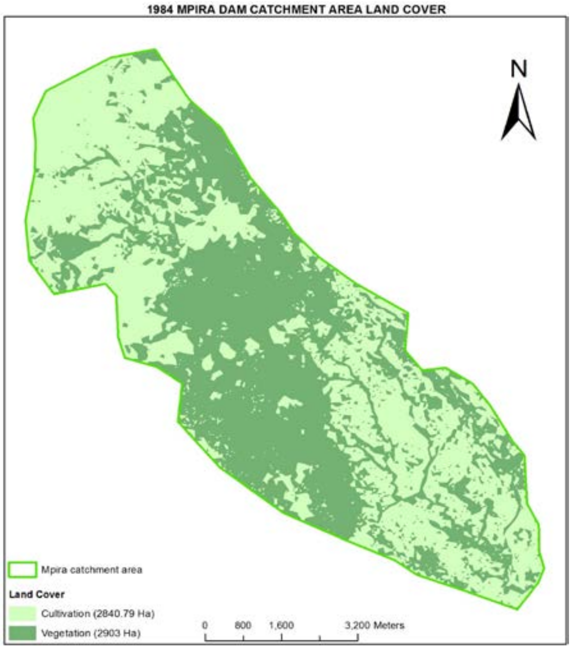

Figure 4.22: 1984 Vegetative Cover

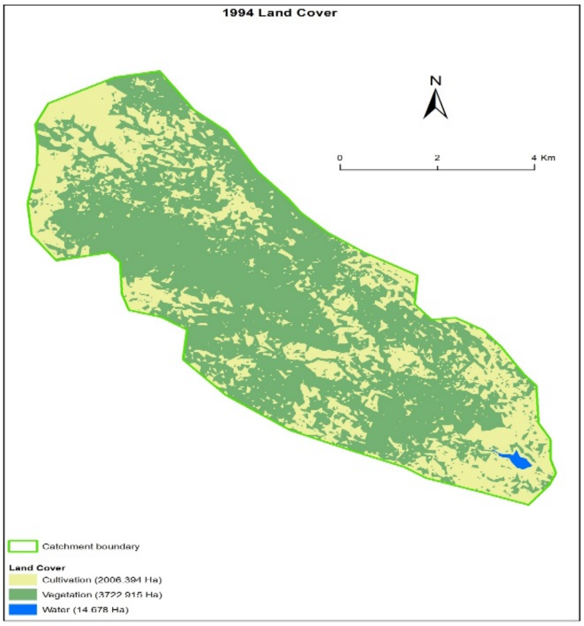

Figure 4.23: 1994 Vegetative Cover

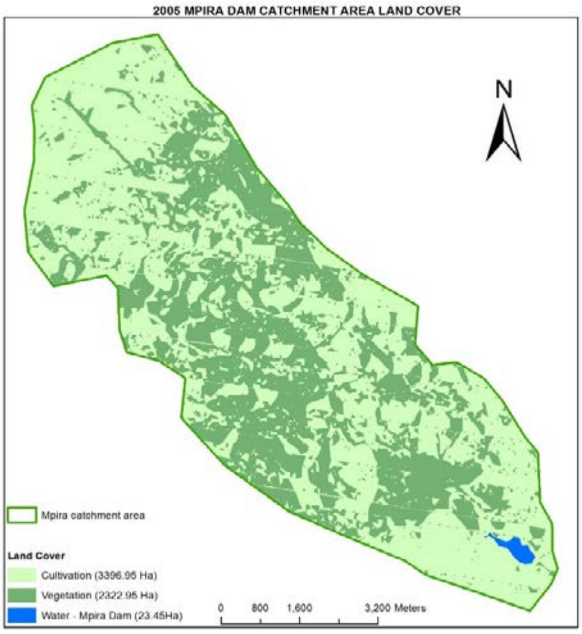

Figure 4.24: 2005 Vegetative Cover

The increase in vegetative cover observed between 1984 and 1994 could be attributed to afforestation interventions introduced in the area in 1985 as an effort to reverse catchment degradation. Land under cultivation increased from 1853 ha in 1975 to 3890 ha in 1984. There was, however, a decline of land under cultivation to 2006 ha by 1994. This correlated well (R^2 = 0.91) with changes in land-area under vegetative cover within the same period.

After 1994 land area under cultivation increased and while in land area under vegetation decreased. A comparison of Figures 4.24 and 4.25 with Figure 4.23 illustrates this point.

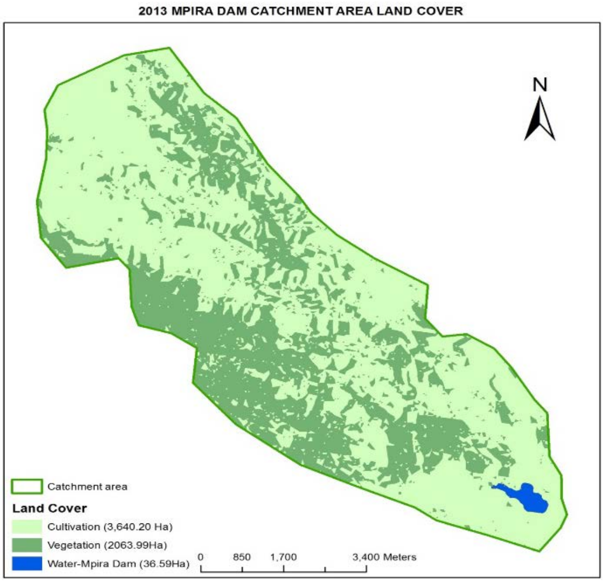

Figure 4.25: 2013 Vegetative Cover

Land under cultivation increased from 2006 ha (1994) through 3397 ha (2005) to 3640 ha in 2013. This proceeding along decline in vegetative cover from 3,723 ha (1994) through 2,323 ha (2005) to 2,064 ha in 2013. The plot in Figure 4.26 illustrates the relatively changes in land cover and use patterns.

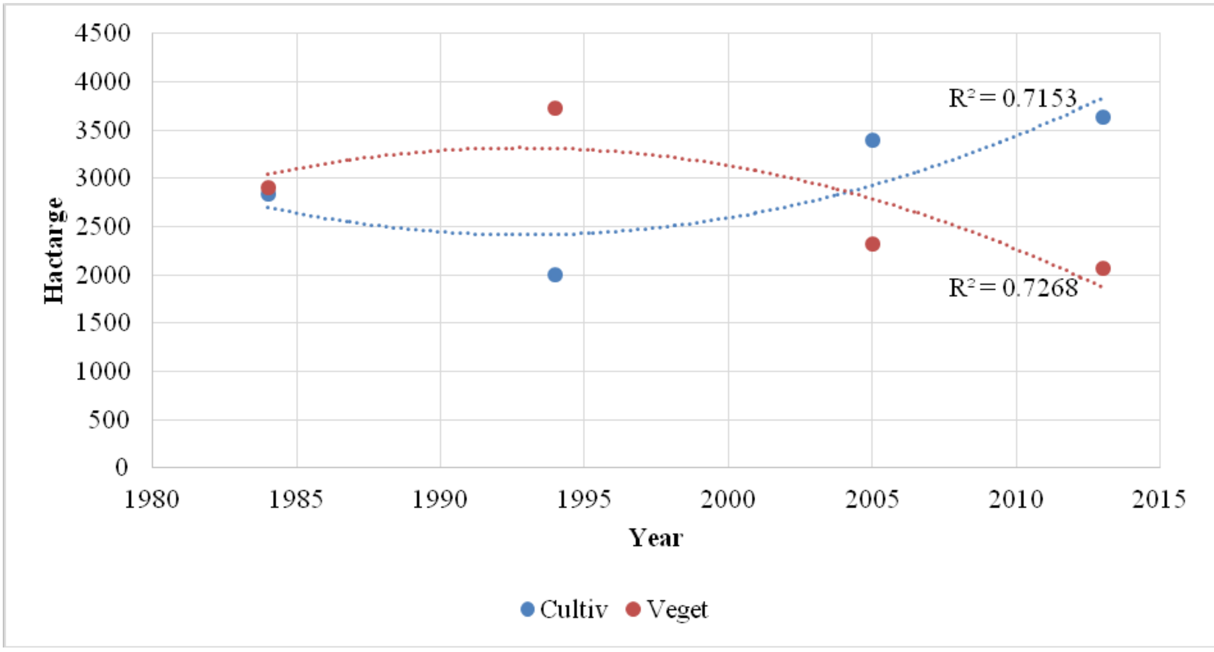

Figure 4.26: Land Use Trends in Mpira Catchment Area

Typical illustrations of deforestation and cultivation in the catchment area are captured in Figure 29 and Figure 30.

Figure 4.27: Deforestation in Dam Catchment

Figure 4.28: Cultivation in Mpira Dam Catchment

4.5.2. Vegetative Cover and Mineral Presence

Table 4.6 is the compilation of the forest cover area for some years and the corresponding annual average concentrations of Nitrate and TP for both sampling points.

Table 4.6: Vegetative Cover and Mineral Concentrations

Year	Vegetative cover (ha)	Average Annual Mineral Concentration			
		Mpira River		Dam Intake	
		NO_3^- (mg/l)	TP (mg/l)	NO_3^- (mg/l)	TP (mg/l)
1994	3722.92	0	0	0	0
2005	3396.95	0.00667	0.0054	0.00125	0
2013	2063.99	0.023	0	0.0155	0

(Note: 0 means reading less than 0.0001 mg/l)

Area of vegetative cover correlated negatively very strongly to nitrate for both Mpira river and Dam outlet; r = -1 (Figure 4.29) and r = -0.99 (Figure 4.30) respectively while it correlated positively weakly to TP r = 0.33 (Figure 4.31) for Mpira River and there was no correlation at all for Dam outlet (Figure 4.32).

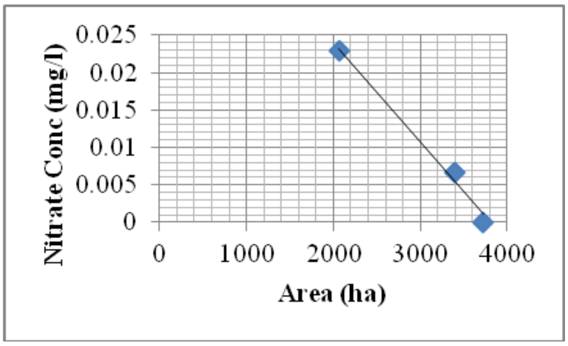

Figure 4.29: Land Area vs Mean Annual Nitrate Concentration Scatter (Mpira River)

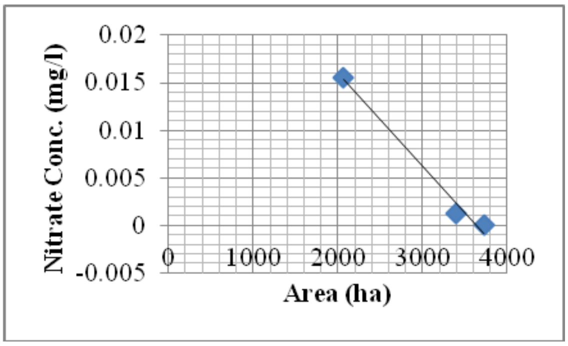

Figure 4.30: Land Area vs Mean Annual Nitrate Concentration Scatter (Dam Outlet)

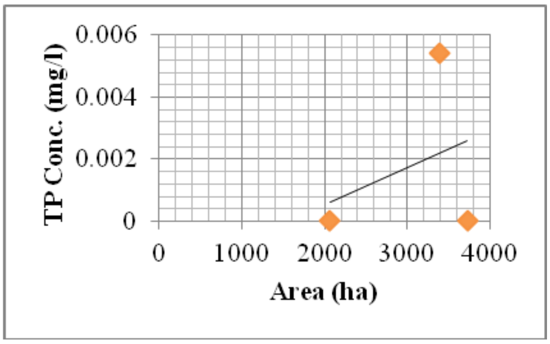

Figure 4.31: Land Area vs Mean Annual TP Concentration (Mpira River)

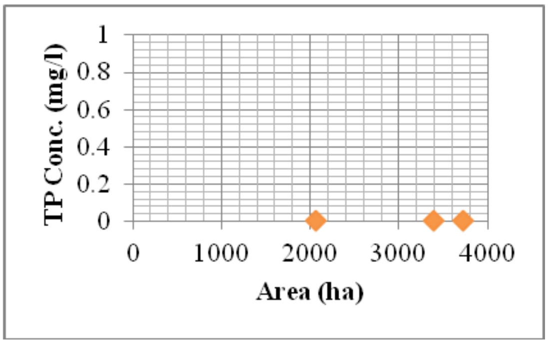

Figure 4.32: Land Area vs Mean Annual TP Concentration (Dam Outlet)

This observation is similar to the findings of Ding, Jiang, Fu, Liu, Peng and Kang (2015) who also observed that Nitrate concentration increases in a river as the area under forest cover decreased. Ding et al., 2015 observed similar trends for phosphorus; however, this was not the case in the present study.

A negative correlation between vegetative cover and release of nitrogen into Mpira Dam was apparent; nevertheless, phosphorus release and vegetative cover did not seem correlated in the present study. In general, it can be concluded that the loss of vegetative cover increased concentrations of nitrate in Mpira River and Mpira Dam.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

The results of this study show that population growth and associated human activities have an impact on nutrient loading in Mpira River and Dam water.

Referring to the first specific objective of this study, the results showed statistically insignificant differences in concentrations of both nitrate and TP in the rainy season (when there is runoff) and dry season (when there is no runoff). They further linked nutrients to the fertilizers being applied in the catchment area. It can therefore be concluded that human settlement and activities in the catchment increased nutrient concentrations in the Mpira River.

It was established by the positive correlation of the nutrients to the population growth that the growth in population is linked to the increase in the nutrients in the water which happened to be the second specific objective of the study. However, the growth in population per se did not lead to the increase in nutrients. Rather, the human activities like agriculture and deforestation drove the release of minerals from the land.

Removal of vegetative cover was also established as a contributing factor to the increase of Nitrogen in the water though the results of this study did not come out clearly on TP. Literature however shows similar contribution to phosphorus as is with Nitrates.

5.2. Recommendations

5.2.1 The catchment management authority should re-demarcate the boundary and regulate farming practices in the catchment. This will identify areas and individuals that were left in the catchment in the earlier demarcation.

5.2.2 The catchment management authority should relocate and compensate people who resettled in the catchment. Population which is positively linked to nutrient concentration will be reduced. Assurance that subsistence farming and eventual nutrient loading of the dam will be enhanced.

5.2.3 Promote farming practices within the catchment that minimize the release of nutrients into streams. Growing crops that do not require fertilizer application would minimize the washing away of nutrients. Encouraging growth of fruit trees would also increase forest cover.

5.2.4 Promote sustainable forest management practices. This would improve and maintain the forest cover in the catchment resulting in less nutrients into the dam.

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APPENDICES

Appendix 1: Nitrate and phosphorus concentration data in Mpira River

Date	Nitrate mg/l	Phosphorous mg/l
21/02/1990	0.57	0
09/04/1992	0.15	0
10/08/1998	0	0
07/08/1998	0	0
03/01/1998	0	0
12/01/1999	0	0
30/03/1999	0.1	0
20/04/1999	0.01	0
08/07/1999	0	0
01/09/1999	0	0
01/11/1999	0	0
01/12/1999	0	0
22-2-1-2001	0	0
10/03/2001	0	0
12/12/2002	0	0
19/12/2003	0	0
13/02/2004	0	0
19/03/2004	0	0
16/04/2004	0	0
24/07/2004	0	0
07/04/2005	0	0
24/07/2005	0	0
26/06/2005	0	0
27/07/2005	0.02	0
30/08/2005	0	0
30/01/2005	0.04	0.049
10/02/2005	0	0
29/05/2005	0	0

26/10/2005	0	0
28/02/2006	0.2	0
26/03/2006	0	0.08
26/04/2006	0	0.09
27/05/2006	0	0.102
12/07/2006	0.01	0.112
18/09/2006	0	0
13/10/2006	0	0.011
07/01/2007	0	0.021
13/02/2007	0.06	0
18/03/2007	<.0.015	0.057
17/04/2007	0.02	0.055
15/05/2007	0.03	0.103
14/06/2007	0.051	0.018
14/07/2007	0.001	0.029
31/08/2007	0.04	0.049
20/09/2007	0	0.09
21/11/2007	0	0.073
04/01/2008	0	0.2
09/02/2008	0.06	0.017
04/05/2008	0	0.121
05/06/2008	0	0.101
10/07/2008	0	0.025
06/08/2008	0	0.008
06/09/2008	0.02	0
06/10/2008	0.02	0.211
07/11/2008	0.02	0.057
09/02/2009	0.05	0
12/03/2009	0.05	0
14/04/2009	0.18	0
01/07/2009	<0.01	0.047
02/08/2009	0.03	0.05
04/09/2009	0.01	0

15/12/2009	0.013	0
03/02/2010	0.04	0
10/10/2010	<0.01	0.08
07/12/2010	0.03	0
17/03/2011	7	0
10/05/2011	0.01	0
07/06/2011	0.01	0.041
07/07/2011	5.5	0
09/08/2011	0.09	0.053
07/09/2011	4.5	0
06/10/2011	0.22	0.081
09/11/2011	0.06	0.043
12/07/2012	0.003	0
08/08/2012	0.07	0
09/09/2012	0.005	0
10/10/2012	0.006	0
18/11/2012	<0.01	0
06/12/2012	0.04	0
10/01/2012	0.07	0
18/11/2012	<0.01	0
06/12/2012	0.04	0
10/01/2013	0.7	0
25/02/2013	0.039	0
25/03/2013	0.014	0
25/04/2013	0.014	0
15/05/2013	0	0
17/06/2013	0.076	0
18/07/2013	0	0
14/08/2013	<0.01	0
04/09/2013	8.11	0
18/10/2013	0.042	0
19/11/2013	0.028	0
13/12/2013	0.03	0

13/02/2014	0.03	0

Appendix 2: Nitrate and phosphorus data at the Dam Outlet.

Date	Nitrate mg/l	Phosphorous mg/l
21/02/1990	0.35	0
09/04/1992	0.25	0
10/08/1998	0	0
07/09/1998	0	0
03/01/1998	0	0
12/01/1999	0	0
30/03/1999	0	0
20/04/1999	0.02	0
08/07/1999	0	0
01/09/1999	2.4	0
01/11/1999	0	0
01/12/1999	0	0
22/02/2001	0	0
10/03/2001	0	0
12/12/2002	0	0
19/12/2003	0	0
13/02/2004	0	0
19/03/2004	0	0
16/04/2004	0	0
24/07/2004	0	0
07/01/2005	0	0
24/02/2005	0	0
26/03/2005	0	0
30/05/2005	0	0
26/06/2005	0.01	0
29/07/2005	0	0
27/08/2005	0	0
26/09/2005	0	0
28/02/2006	0	0

26/03/2006	0	0.054
26/04/2006	0	0.011
27/05/2006	0	0.022
18/09/2006	0	0.013
13/10/2006	0	0
07/01/2007	0	0.001
13/02/2007	0.024	0.011
18/03/2007	0	0.023
17/04/2007	0.004	0.038
15/05/2007	0.006	0
14/06/2007	0.026	0.03
14/07/2007	0.001	0.029
31/08/2007	0.04	0.021
20/09/2007	0	0.073
21-Nov	0	0.027
04/01/2008	0	0.028
10/02/2008	0.05	0.033
04/05/2008	0	0.071
05/07/2008	0	0.011
10/07/2008	0	0
06/08/2008	0	0
06/11/2008	0	0.043
09/02/2009	0.03	0
12/03/2009	0	0
14/04/2009	0.03	0
01/07/2009	0	0.047
02/08/2009	0.09	0.05
04/09/2009	0.01	0
15/12/2009	1.123	0
03/02/2010	0.01	0
10/10/2010	0.01	0.041
07/12/2010	0.02	0
17/03/2011	0.05	0

12/07/2006	0.01	0
10/05/2011	0.01	0
06/09/2008	0.04	0.001
07/06/2011	0.01	0.052
07/07/2011	0.01	0
09/08/2011	0.04	0
07/09/2011	0.12	0.07
06/10/2011	0.01	0.034
12/07/2012	0.443	0
08/08/2012	0.05	0.035
09/09/2012	0	0.003
10/10/2012	0.018	0
18/11/2012	0.028	0
06/11/2012	0.062	0
10/01/2013	0.029	0
25/02/2013	0.019	0
25/03/2013	0.04	0
25/04/2013	0	0
15/05/2013	0	0
17/06/2013	0.082	0
18/07/2013	0	0
14/08/2013	0.01	0
04/09/2013	0.002	0
18/10/2013	0.084	0
19/11/2013	0.042	0
13/12/2013	0.013	0
13/02/2014	0.03	0