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TOPIC:

AN ASSESSMENT OF THE CONTRIBUTION OF AGRICULTURAL NON-POINT SOURCE POLLUTION ON THE WATER QUALITY OF THE VAAL RIVER WITHIN THE GROOTDRAAI DAM CATCHMENT

By

SCOTT NCUBE

Student no: 46729836

Supervisor: **Dr Luxon Nhamo**

Core-supervisor: **Malebo Matlala**

Contact details:
Cell: 0796193239
Email: scottncube@yahoo.com

Dedication

To God the Almighty

Declaration

I, Scott Ncube, do solemnly declare that this dissertation represents my own personal work and has not previously been submitted for any purpose at this or any other university.

Signature..

Date..

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ACRONYMS

❖ **ADP**	**Adenosine diphosphate**
❖ **AP**	**Apatite phosphorus**
❖ **ATP**	**Adenosine tri-phosphate**
❖ **BOD**	**Biological oxygen demand**
❖ **COD**	**Chemical oxygen demand**
❖ **CSIR**	**Council for Scientific and Industrial Research**
❖ **DNA**	**Deoxyribonucleic acid**
❖ **DO**	**Dissolved oxygen**
❖ **DWA**	**Department of Water Affairs**
❖ **GDC**	**Grootdraai dam catchment**
❖ **IEWA**	**Implementing environmental water allocation**
❖ **NPS**	**Non-point source pollution**
❖ **SAC**	**Satellite centre**
❖ **SADC**	**Southern Africa Development Community**
❖ **SRP**	**Soluble reactive ortho-phosphorus**
❖ **RNA**	**Ribonucleic acid**
❖ **WRC**	**Water Research Commission**
❖ **OP**	**Organic phosphorus**
❖ **P**	**Phosphorus**
❖ **PLARG**	**Pollution from land use activities reference groups**
❖ **N**	**Nitrogen**
❖ N_2	**Nitrogen gas**
❖ **NAIP**	**Non apatite inorganic phosphorus**
❖ **NGI**	**National Geospatial Information**
❖ NH_3	**Ammonia**
❖ NH_4	**Ammonium**
❖ NO_2	**Nitrite**
❖ NO_3	**Nitrate**
❖ **NPK**	**Nitrogen, phosphorus and potassium**
❖ **FAO**	**Food and Agriculture Organisation**
❖ **US – EPA**	**United States Environmental Protection Agency**
❖ **USA**	**United States of America**
❖ **UAA**	**Utilised agricultural area**
❖ **SAC**	**Satellite Application Centre**
❖ **SANBI**	**South African National Biodiversity Institute**
❖ **T1**	**Tributary one**
❖ **T2**	**Tributary two**
❖ **T3**	**Vaal River**
❖ **WHO**	**World Health Organization**

DEFINITION OF TERMS

Terms which are used in the study are defined below according to how they are used in this study.

- **Fertiliser:** any synthetic inorganic material that is used to enhance plant growth by supplying nutrients such as nitrogen and phosphorus (UNESCO, 1998).
- **Water Contamination**: the reduction of possible usefulness of water by chemical solutes present in water above concentrations determined by national or international standards for portable, industrial, recreational and other uses (UNESCO, 1998).
- **Leaching:** the loss of water- soluble plant nutrients from the soil, due to rain and irrigation.
- **Nutrients**: chemicals that plants need to grow taken from the environment such as nitrates, phosphates.
- **Pesticides:** in this study refers to all chemicals that are used to control or kill pests such as herbicides, insecticides, nematodes and rodenticides.
- **Pollutant:** refers to a substance that adversely alters the environment by changing the population growth rate of species, interferes with food chain, is toxic or interferes with health, comfort amenities, or property values of people (UNESCO, 1998).
- **Pollution:** in this study refers to the introduction into fresh or marine waters of chemical, physical or biological material that degrades the quality of water and affects organisms living in it.
- **Non - point source pollution**: refers to the contamination that occurs when rain water, snowmelts, or irrigation washes off ploughed fields, city streets.
- **Runoff:** refers to the total amount of water that reaches the stream or river including immediate surface runoff and the rainfall that joins the stream later by infiltration.
- **Water quality**: in this study is a term used to describe the chemical, physical and the biological characteristics of water, usually its suitability to maintain a healthy ecosystem
- **Eutrophication**: refers to the enrichment of surface waters with plant nutrients, such as nitrates and phosphates through fertilizers or sewage.
- **Algal bloom**: is a rapid increase or accumulation in the population of algae in aquatic system such as fresh water or marine environment.

ABSTRACT

This study assesses the contribution of agricultural non-point source pollution, to poor water quality of the Vaal River within the Grootdraai dam catchment area. The study evaluates agricultural pollutants affecting the quality of water within the study area. The impact of agricultural non-point source pollution on the water quality of the Vaal River was evaluated by establishing a correlation between the quantity of polluted runoff reaching the River and the quantity of measured nitrates and phosphates in its waters. A questionnaire using random sampling was used to capture data from 15 commercial farmers 35 local residents and the Department of Water Affairs management. The results of the study show that agricultural nutrients are heavily impacting and compromising the water quality of the Grootdraai Dam. The mean concentrations of Nitrogen and Phosphorus were found to be well above the water quality guidelines there by promoting eutrophication.

Key words: Agricultural non-point source pollution; runoff, water quality, agricultural nutrients, eutrophication, buffer zones, Phosphorus, Fertiliser, Quaternary basins, nitrogen.

Chapter 1

1. INTRODUCTION

1.1 INTRODUCTION AND BACKGROUND

Water comprises 70% of the Earth's surface making it one of the most valuable natural resources (Krantz, 2011). Of this about 97.5% is salt water and only about 2.5% is fresh water, (Sandi & Darrin, 2012). It is a fundamental element to all forms of life for various functions such as drinking, cleaning, as a reproductive medium and as habitat for aquatic organisms and for irrigation purposes (Ninhoskinson, 2011). Water makes up 50 to 90% of the body weight of most living organisms. It is also essential as a transport mechanism and for metabolic processes of most living organism, (Sandi & Darrin, 2012).

Water pollution is an aspect of pollution that commonly goes under the radar; however it is a huge aspect of pollution with serious detrimental consequences which needs to be dealt with swiftly to obtain a clean and healthy environment (Ninhoskinson, 2011).

Water pollution decreases the usefulness of water economically and it brings about danger to human health and other aquatic forms of life (James, 2008). Although human beings benefit immensely from water, they are actually one of the main causes of water pollution through marine dumping, industrial wastes, agricultural effluent and mining wastes, (Ninhoskinson, 2011).

South Africa's water quality is fast deteriorating (Bega, 2008). It is estimated that the demand for water in South Africa will exceed available natural supply by the turn of the 21st century. It is projected that South Africa could run out of fresh water by 2025 (Blaine, 2013). This constitutes an economic challenge that can only be met by careful planning and intensifying research on sustainable agriculture, (Cillie & Coombs, 1979). A study by Bega (2008) found out that the cyanobacteria blooms recorded in most rivers in South Africa were, due to high levels of eutrophication.

Agricultural nutrients from farmlands are one of the top running contributors of water pollution. These include fertilizer and pesticides used in agriculture, which find their way into the river system, contributing significantly to the poor quality of water (Ninhoskinson, 2011).

It is therefore of paramount importance that enough information be gathered to understand the major causes of water pollution. When the causes and sources of water pollution are identified it paves way for the assessment of the contributions of each of these factors so that appropriate measures can be taken to address the problem effectively. This study assesses the impact of agricultural nutrients and chemicals from farms within the Grootdraai Dam catchment situated near Standerton in the Mpumalanga Province, determining its contribution to the poor water quality in the Vaal River.

1.2 STATEMENT OF THE PROBLEM

According to a study by the Water Research Commission (WRC), the state of most of South Africa's rivers continues to deteriorate (Sapa, 2009). There are clear indications from the relatively scanty water quality monitoring data available that water quality of most rivers in South Africa has deteriorated over the past 20 years (Oberholster, 2010). The WRC revealed at the Implementing Environmental Water Allocation (IEWA) conference in Port Elizabeth that some rivers in South Africa showed a huge deterioration in water quality (Sapa, 2009). The Vaal River was classified as the second most polluted river in South Africa after the Olifants River (Sapa, 2009).

Four main categories of water pollution have been identified in past studies. These include the municipal, industrial, mining and agriculture. The pollutants can either be organic or inorganic substances (Wetzel, 1993). Pollutants released from agriculture, are regarded as non- point source pollution (NPS) and they have been identified as one of the leading sources of water pollution in South Africa. Nitrogen and phosphorus from agricultural fertilizers, manure and ammonia is converted into nitrites and phosphates which are then washed into the river system by runoff water. It has been noted that algal production in most rivers appears to be limited by the concentration of phosphate (Wetzel, 1993; Edmondson, 1991).

The prevailing monitoring gaps increase uncertainty and undermine decision making in monitoring water quality (Stuijt, 2012). The assumption is that knowledge is limited to the causes of water pollution however the question that still remains is, what is the contribution of this particular source to poor water quality in this part of the river? Hence this study will estimate the extent of Agricultural contribution to poor water quality of the Vaal River within the Grootdraai Dam Catchment in Mpumalanga Province. This study exclusively assesses the impact of agricultural non-point source (NPS) pollution on the segment of the Vaal River within the Grootdraai Dam Catchment.

1.3 RATIONALE

This study is partially informed by observations of the disturbing state of affairs on the Vaal River situated near Standerton in Mpumalanga Province. There is a disturbing and unusual growth of algal blooms and at times the water in the river has a pungent smell. Figures 1.1 & 1.2 show how pollution is causing algal bloom in a section of the Vaal River in the Grootdraai Dam Catchment.

Figure 1.1 Algal bloom in the Vaal River
(*Photo taken in 2012*)

The study site, Grootdraai Dam Catchment, was selected as there is strong evidence of water pollution within the catchment and especially from agricultural nutrients (Van Ginkel, 2001; Tempelhoff *et al.*, 2007). The study established the role played by agriculture in the degradation of the water of the Grootdraai Dam. Agricultural NPS pollution is the main source of water degradation in the catchment as the landuse of the catchment is heavily altered for agriculture purposes, resulting in an increase in nutrient laden runoff. A study by the Department of Water Affairs (DWA, 2009) found out that the water quality of the Vaal River is affected by salinity, eutrophication and microbiological issues and these need to be addressed urgently.

Figure 1.2: Algal bloom in the Vaal River
(*Photo taken in October 2012*)

The introduction of pollutants into the Vaal River within the Grootdraai Dam Catchment could be as a result of a number of natural processes or influences by human activities within the area. These activities include mining, sewage spillage and agricultural activities among others.

The determination of the extent to which agricultural activities contribute to poor water quality in the Vaal River and the communication of this information to stakeholders will provide an impetus for solving problems associated with agricultural non-point source pollution.

The study shows how the contribution of agricultural nutrients and pesticides have affected the water quality of the Vaal River, and if the effect is significant enough that proper control and mitigation measures would be required to improve the quality of water and consequently the health of downstream biodiversity.

The results of the study benefit decision makers, stakeholders, the community within the Grootdraai Dam Catchment and the catchment management authorities for sustainable development. The control of the poor water quality will benefit the Lekwa Municipality since it could mean a reduction in the cost of purifying water meant for human consumption.

1.4 AIMS OF THE STUDY

This study aims to;

1. To estimate the contribution of the current agricultural activities to the water quality of the Vaal River within the Grootdraai Dam Catchment, and
2. To explore the current agricultural capacity, competence and commitment of the local farming community within the catchment so as to achieve compliance with the environmental legislation.

1.5 RESEARCH QUESTIONS

The major research questions of the study include:

1. Do the local communities within the Grootdraai Dam Catchment have sufficient knowledge on the threats of poor agricultural methods on the poor water quality of the Vaal River in general and of the Grootdraai Dam in particular?
2. Do farmers have sufficient knowledge on the efficient use and application of fertiliser?
3. What are the major agricultural pollutants affecting the water quality of the Vaal River within the Grootdraai Dam Catchment?
4. What is the level of effect do these pollutants have on the quality of water quality within the study area?

1.6 OBJECTIVES

The specific objectives of the study are;

1. To determine what the local communities within the Grootdraai Dam Catchment know and feel about the water quality of the Vaal River,
2. To determine the major type of fertiliser that is used by the farming community,
3. To determine the extent to which agricultural activities contribute to poor water quality of the Vaal River and the Grootdraai Dam, and
4. To determine the competence and commitment of the local farming community to achieve compliance with environmental legislation.

1.7 DESCRIPTION OF THE STUDY AREA

The Grootdraai Dam Catchment (GDC) is located in the headwaters of the Vaal River, in Mpumalanga Province, South Africa. Described as the heartbeat of South Africa, the Vaal

River water system is essential to human life, agriculture, industry, aquaculture and an entire aquatic ecosystem. The Grootdraai Dam, the tenth largest dam in South Africa, is situated in the upper reaches of the Vaal River less than 10km upstream of Standerton. The Grootdraai Dam has a catchment area of 8 195 km^2, a mean annual precipitation of approximately 750mm, a mean annual potential evaporation at the dam site of 1 400mm and a natural inflow of 580 million m^3/a. The full supply capacity of the reservoir is 364 million m^3, making it a 0.7 MAR dam (Midgley *et al*., 1994). The Grootdraai Dam is one of the major attractions for recreational activities such as boating, canoeing, swimming and fishing which bring in revenue from visitors wishing to see the dam and enjoy these activities. Bass fishing in the dam is very popular amongst the locals. However, the water quality of the dam has been degrading due to an increase in agricultural non- point source pollution (NPS).

The landuse of the Grootdraai Dam Catchment (GDC) is characterised by agriculture, coal mining and power generation at the Tutuka, Camden and Majuba Power Stations. The dam supplies water to Sasol Secunda and the Tutuka Power Station. The supply from Grootdraai Dam is supported by transfers of water from the Zaaihoek and Heyshope Dams (DWA, 2009). The land use of the Grootdraai Dam Catchment (GDC) is heavily altered due to human activities, exposing its waters to the impacts of agricultural NPS pollution. The industries and mining activities in the catchment also contribute to the poor water quality problems of the dam.

1.7.1 Soils

Tables 1.1 and 1.2 give a summary of the soil type and their depths within the Grootdraai Dam Catchment.

Table 1.1: Summary of soil types within the catchment

Soil type	*Area (ha)*	*%*
Clay	68 523.3	15
clayey	94 036.1	24
Loam	88 914.5	21
Loam and clay	6 643	19
Sandy	5 896.4	1.4
Sandy loam		1.3
Very clayey	80 862.8	18

Source: IRIR, 2005

Table 1.2: Summary of soil depths within the catchment

Soil depth	*Area(ha)*	*%*
Deep	92 473.6	20.2
Medium deep	66 737.7	14.6
Shallow soils	169 369.2	36.9
Steep slopes	1 050.9	0.2
Very shallow soil	78 181.0	17

Source: IRIR, 2005

1.7.2 Topography

Tables 1.3 and 14 give a summary of the topography and slopes of the Grootdraai Dam Catchment.

Table 1.3: Summary of the topography of the catchment

Range	*Elevation Area (ha)*	*%*
1501-1600	282 978	61.7
1601-1700	174 557	38.1
1701-1800	1 084	0.2

Source: IRIR, 2005

Table 1.4: Summary of the slope of the study area

Class	*Slope Area (ha)*	*%*
Level (0–3%)	345 340	75.3
Moderate (4–15%)	109 981	24
Steep (16–25%)	2 200	38.1
Very steep (>25%)	1 100	0.2

Source: IRIR, 2005

1.7.3 Landuse

The landuse in the catchment is dominated by cultivated temporary commercial dry land and cultivated temporary commercial irrigation which constitute approximately 40% combined, (Lekwa Report, 2005). The main agricultural activities in the catchment area consist of mixed farming. This includes animal husbandry, which consist of beef and dairy farming, sheep and poultry farming, while crop husbandry consist of maize , grain sorghum, wheat , sun flower seed and potatoes. This is practised mainly along the Vaal River, (Lekwa Report, 2005). Table 1.5 summarises the land use within the study area.

Table 1.5: Landuse in the catchment area

Land use	*Area (ha)*	*%*
Cultivated- commercial dry land	181 960,7	39,7
Cultivated-temporary commercial irrigation	1373,8	0,3
Degraded unimproved grassland	187,1	0,0
Forest plantation	1131,5	0,1
Unimproved grassland	264540,9	57,7
Urban-commercial	503,1	0,1
Urban-industrial	2139,4	0,5
Wetlands	669,6	0,2

Source: IRIR, 2005

The Grootdraai Dam Catchment (GDC) slopes gently from about 2 000m in the east to 1 500m in the west of the Grootdraai Dam. The predominant soil type in the catchment is sandy loam (DWA, 2004). Figure 1.3 is a map of the GDC showing the location of the catchment in South Africa, its elevation and quaternary basins that form the catchment. The catchment has abundant wetlands of various types which help in enhancing water quality, but many of them have also been altered for agriculture compromising the environmental regulating benefits they offer.

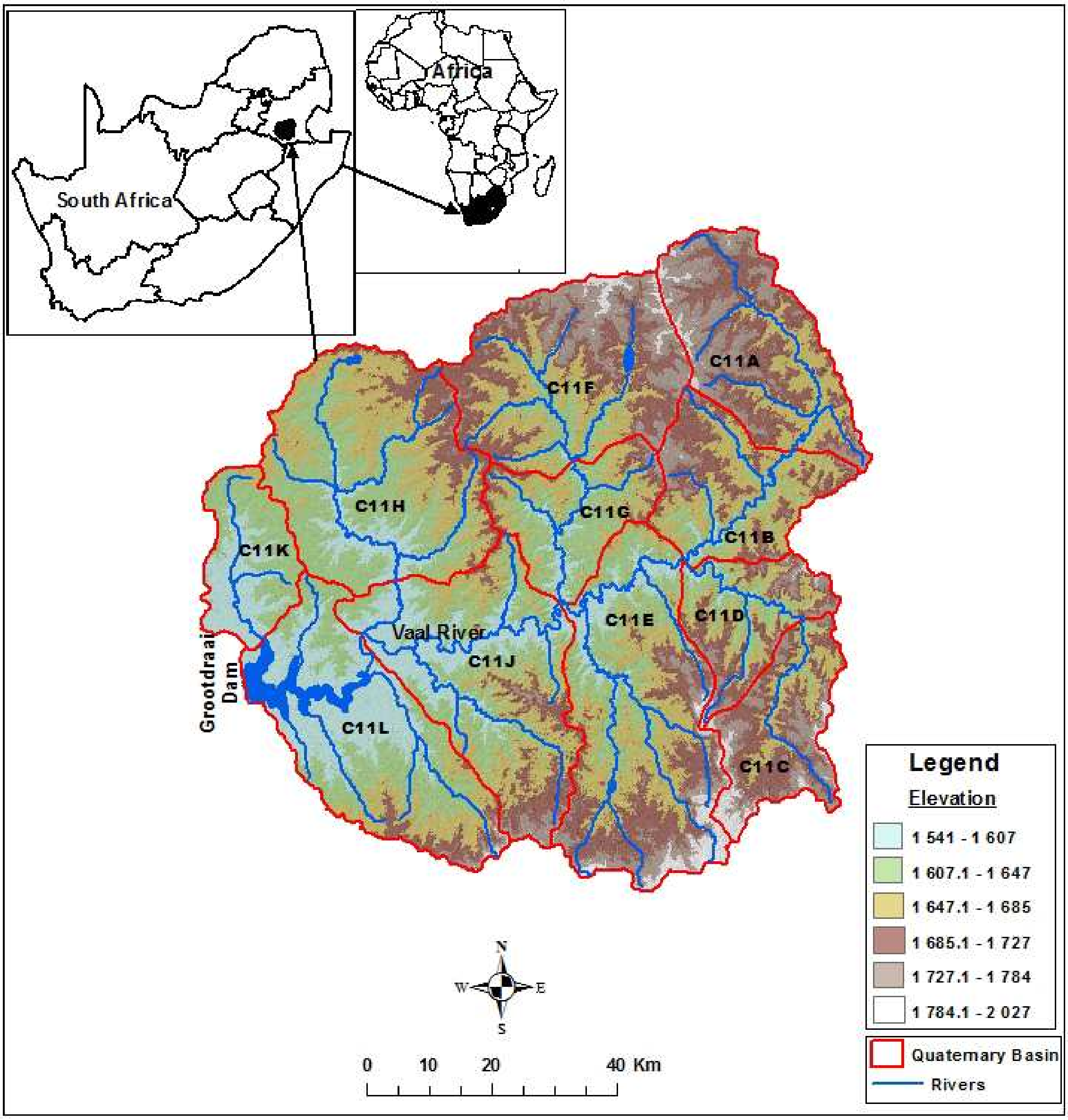

Figure 1.3: Location of the Grootdraai Dam Catchment in South Africa and its elevation

1.8 CLASSIFCATION OF DRAINAGE BASINS IN SOUTH AFRICA

Drainage basin refers to the extent or area of land where surface water from rainfall, melting snow or ice drains downhill to a single point at a lower elevation such as a river, lake, reservoir or wetland (DeBarry, 2004). It acts as a funnel by collecting all the water from the area covered by the basin and channelling it to a single point (DeBarry, 2004). Drainage basins are separated topographically from adjacent basins by geographical barriers such as ridges, hills or mountains.

Drainage basins in South Africa are classified into primary drainage regions which are further subdivided into secondary drainage regions. The secondary drainage regions are further subdivided into tertiary drainage regions. Tertiary drainage regions are subdivided into quaternary drainage regions. Therefore, a quaternary catchment is the fourth order catchment in a hierarchal classification system in which a primary catchment is the major unit. In South Africa quaternary catchments are the principal water management units, basic hydrological units for water resources management. Hence quaternary drainage regions are the basic unit of a drainage basin. In South Africa the quaternary basins are coded as shown on the map in Figure 1.4 which also shows the landuse types of the Grootdraai Dam catchment.

Figure 1.4: Quaternary basin and landuse types of the Grootdraai Dam Catchment

As surface water flows through each quaternary basin it picks up nutrients sediment and pollutants. These get transported towards the outlet of the basin (DeBarry, 2004). On reaching the outlet of the basin, these nutrients may affect the ecological processes along the way and the receiving water sources (DeBarry, 2004). Modern usage of artificial fertilizers containing nitrogen, phosphorus and potassium has affected the mouths of most watersheds. Hence the exit point mouths of the quaternary basins are important points to study of the effects of land usage on the quality of water in the receiving water sources such as rivers, dams and lakes**.**

Chapter 2

2 THEORETICAL FOUNDATION

2.1 INTRODUCTION

Water quality is a term used to describe the chemical, physical and the biological characteristics of water, usually its suitability to maintain a healthy ecosystem. Water quality can be changed or affected by both natural processes and human activities which lead to the pollution of water bodies (DWA, 2011).

The main causes of poor water quality are the contamination by human and other animal wastes, poisonous chemicals, heavy metals and oils. These can affect rain, rivers, lakes, oceans and underground water. The major causes of water pollution can be classified into industrial wastes, domestic wastes and agricultural wastes. Pollution from the latter involves rainwater flowing as runoff from farmlands into streams, carrying chemical fertilisers and pesticides used by farmers (Schueller, 2000).

Water pollution is a major problem in the global context. It has been suggested that it is the leading cause of deaths and diseases worldwide (Pink, 2006). In addition to the acute problems of water pollution in developing countries, industrialised countries continue to struggle with pollution problems as well. For example in a recent national report on water quality in the United States of America (USA), of the 45% of assessed miles, 47% of assessed lake acres and 32% of assessed bay and estuarine square miles were classified as polluted (Schueller, 2000).

Pollution of rivers, lakes and aquifers from domestic and industrial waste water discharge, mining runoff and agrochemicals is now a growing threat to water resources in most countries in Southern Africa. The quality of water supplies in the Southern African Development Committee (SADC) region, once taken for granted, is becoming the focus of major concern. Due to increased urbanisation in the Southern African Development Committee (SADC) region, expects say that most of the cities have not been able to develop basic utilities for water and environmental services (solid waste disposal systems, sewage treatment and agricultural pollution control) to keep pace with rapid population growth (Cillie & Coombs, 1979).

In South Africa it is estimated that water demand will exceed available natural supplies by the turn of the 21st century (Cillie & Coombs, 1979), a problem already evident as South Africa is classified as a water scarce country (Ashton, 2002). This crisis is mainly caused by low rainfall that the country receives and high rates of evaporation, the expanding economy and a growing population whose demands for water do not conform to the distribution of exploitable water supplies (Oberholster, 2010). This anticipated shortage of water constitutes a challenge that can only be solved by careful planning and intensified research in water management.

Water research in South Africa involves a variety of government departments' statutory bodies, industries and universities (Cillie & Coombs, 1979). Previous studies involving analysis of water quality in the South African aquatic systems have involved physio-chemical and microbial assessment (Lin *et al*., 2004; Mthembu, 2004). Bio-monitoring is another valuable assessment tool that is receiving increased use in water quality monitoring programmes of all types (Kennish, 1992). This involves the use of biological response to assess changes in the rivers. Indicators and indicator species and communities such as fish and algae are used for this purpose. This type of analysis assesses water quality from a pollution and human health perspective.

Microbial assessment involves quantification of *Escherichia coli* (E *coli*) form of bacteria and provides an indication of the degree of faecal contamination and the presence of pathogenic organisms. This is very important in the context of water portability and safety. The Lekwa Municipality pollution control departments, in their river testing programme, routinely monitor for the presence of *Escherichia coli* and other pathogenic organisms.

The presence of different chemical concentration like aluminium, ammonia, chlorine, chromium, cadmium and selenium among other chemicals may be monitored in the evaluation of water quality and the presence of high levels of these chemical substances would be indicative of pollution, possibly from one or any of a range of applicable industrial and or domestic sources (DWA, 1996). Hence this is very relevant to this study which seeks to determine the contribution of agriculture to water quality.

Nutrient enriched (eutrophic) water systems are characterised by excessive growth of algae and macrophytes (algal bloom). Phosphorous is a widely accepted indicator of eutrophic status of water system due to its strong implication in the growth of algae (Van Ginkel, 2002). High concentration of inorganic nitrogen can influence eutrophication however; the presence of sufficient phosphorous enhances the eutrophication effect of even low levels of phosphorous, (DWA, 1996).

In a freshwater habitat algal growth is very rapid and the death rate is also very high resulting in the accumulation of dead organic matter followed by its decay. This process of decaying consumes large amounts of dissolved oxygen in the water and increased biological oxygen demand (BOD) and this leads to the depletion of essential oxygen resulting in the death of aquatic flora and fauna (Sonali, 2011).

Biological Oxygen Demand (BOD) is a measure of the amount of oxygen required by microorganisms to breakdown organic matter while chemical oxygen demand (COD) is a measure of the amount of the oxygen required for breakdown of both organic and inorganic matter (Akan*, et al*., 2008). Mostly the evaluation of dissolved oxygen (DO) content is vital since it is essential for the respiration of all aerobic organisms and hence critical to the survival and wellbeing of the aquatic ecosystem (DWA, 1996).

Therefore, this study will determine the extent to which the agriculture activities within the Grootdraai Dam Catchment is contributing to this cause and hence integrate all this information to enable the problem to be tackled in a more holistic way by all concerned stakeholders.

2.2 WATER POLLUTION DUE TO AGRICULTURAL ACTIVITIES

In the 1970s Canada and the USA undertook a program of non- point source identification and control for the Great Lakes Basin. Pollution from Land Use Activities Reference Groups (PLUARG) did an analysis of data from rivers within the Great Lakes, at both field and plot levels. They found out that among non-point sources agriculture is a major source of pollution (US-EPA, 1994). Pollution from Land Use Activities Reference Groups (PLUARG) is of the opinion that despite billions of dollars spent on point source control measures, further point source control cannot achieve any major additional changes in the improvement of water quality, unless significant control over non-point sources of pollution are addressed effectively.

The United States of America produces national statistics on water quality impairment by point and non-point sources regularly. In 1986 US- EPA reported that 65 % of assessed river miles in the USA were impacted by non-point sources (US–EPA, 1996). Then in 1994 the organisation identified agriculture as the leading cause of water quality impairment of rivers and lakes in the USA, (US–EPA, 1994).

Of the major pollutants recorded in the rivers of the USA that include sediments, nutrients like nitrates and phosphates, pesticides occupied the first four categories and all of them are significantly associated with agricultural practices as shown in table 2.1.

Table 1.6: Leading sources of water impairment in the USA

Rank	*Rivers*	*Lakes*	*Estuarine*
1	Municipal point source	Agriculture	Municipal point source
2	Urban runoff	Urban runoff	Urban runoff
3	Resource extraction	Hydrological modification	Agriculture
4	Industrial point source	Municipal point source	Industrial
5		On site waste water	Mining

Source: US –EPA, 1994).

To date more than 330 million acres of agricultural land produce abundant supply of food. In 2000 the national water quality inventory reported that agricultural non–point source pollution, (NPS) was a leading source of water quality impacts on surveyed rivers and lakes and the second largest source of pollution to wetlands in the USA (EPA, 2013).

This is largely due to poorly located or managed feeding operations, overgrazing, ploughing too often or at the wrong time. It was also due to excessive or improper use or poorly timed application of fertilizers and pesticides.

In The Netherlands irrigable land accounted for approximately 29% of the utilized agricultural area (UAA) in 1995 (Pierre *et al*., 2013). Environmental problems associated with the use of water by agriculture constitute a significant part of the UAA in Europe (Pierre *et al*., 2013). Water contamination by nitrates is a major cause of concern associated with agriculture. This is because of the fact that nitrates are highly soluble. The Netherlands reported a substantial amount of contamination of ground water by nitrates, (FAO, 1996). In The Netherlands agricultural non–point source accounted for 71% of nitrogen load generated within the country (FAO, 1996). Between 1992 and 1996 over 65% of the rivers in the European Union had average annual concentrations exceeding 1mgN/L, (Pierre *et al*., 2013). About 15% of these cases were above 7,5mgN/L. The highest concentrations have been recorded in Northwest Europe where agriculture is particularly intensive (Pierre *et al*., 2013).

Agriculture is responsible for 60 % of the total riverine flux of nitrogen to the North Sea and 25% of the total phosphorous loading. In Czechoslovakia it was reported that agriculture contributes 48% of the pollutants of surface waters (FAO, 1996). Norway and Finland reported a significant eutrophication of surface waters arising from agricultural non–point source pollution. The extensive use of large quantities of nitrogen and phosphorous fertilizers is thought to be responsible for the proliferation of algae in the Adriatic and similar information has been recorded in the Danish coastal waters (FAO, 1996). Danish statistics indicated that manure contributes at least 50% of the leaching of inorganic nitrogen (FAO, 1996).

A study by FAO reported that 50% of the shallow ground water wells supplying over one million rural residents in Lithuania are not fit for human consumption because of a wide range of pollutants like pesticides and nitrates (FAO, 1994). The ECE, (1992) calculations indicated that livestock wastes accounted for approximately 30% of the total phosphorous load to the European inland waters, rest of the agriculture accounting for further 17%.

A study by Ryding (1986) demonstrated how lakes which were not affected by industrial or municipal point sources underwent long term change in nutrient status as a result of agricultural activities in the watershed. Between 1973 and 1981 the nutrient status of Lake Oren in Sweden increased from 1000mg/m3 for total nitrogen and from 10mg/m3 to 45mg/m3 for total phosphorous. Lake transparency declined from 6.2m to 2,6m and increased algal blooms.

In South Africa about 12 % of the landmass is arable land (Blaine, 2013). About 1.5% of this landmass is under irrigation producing 30 % of the country's crops (Blaine, 2013). Vast land has been altered for crop production, resulting in an increase of nutrient laden runoff which is causing high concentrations of nitrates and phosphates into water systems. Excessive amounts of nutrients are delivered from cultivated land to streams especially in areas with poor land management practices (Jackson *et al*., 1986; Carpenter et al., 1998, Vadas *et al*., 2008; Diebel *et al*., 2009). According to Stone et al. (2003) non-point source (NPS) pollution from agriculture may occur when nutrients are applied at rates greater than crops can utilize or when timing of nutrient applications occurs in close proximity to heavy rains. High concentrations of nutrients in water cause algal blooms and eutrophication, degrading aquatic ecosystems and impair water use by humans and other uses (Sharpley *et al*., 1994; USEPA, 2000). Inappropriate agriculture practices intensify erosion processes raising sediment input into water sources reducing water levels of reservoirs. Increased sediment loads make drinking water treatment more difficult while also affecting fish and macro-invertebrates. As a result agricultural runoff is impacting negatively on the water resources of South Africa (Burger & Nel, 2008; CSIR, 2010).

2.3 EFFLUENT CHARACTERISTICS AND WATER QUALITY

2.3.1 Plant Nutrients

Plants require food in the form of macro and micro-nutrients for their growth and development (Uchinda. 2000). For the effective utilisation of these nutrients optimum conditions must be maintained. Macro nutrients are those that are essential to plant growth and development and are needed in large quantities. These include elements like nitrogen, phosphorous and potassium among others. Micro-nutrients are those that are needed by the plants in minute quantities, however, they also play a vital role in plant growth and development. Some of these micro–nutrients include copper, magnesium, and zinc, among others.

2.3.2 Nitrogen

Nitrogen is one of the nutrients that are very essential to plant growth and development. It exists in various soluble forms namely ammonium, nitrate, nitrites and urea (NRMED, 1996). Nitrogen that is formed by biological nitrogen fixation within the roots not used by the plant is released into the soil and converted into nitrate–nitrogen as roots die (Daniel*, et al*., 2007). Nitrogen is present in the soil in many different forms like gas (N_2); as various oxides of nitrogen, such as nitrate (NO_3) and nitrite (NO_2); and as ammonia (NH_3), amines (formed from ammonia), or ammonium (NH_4). Organic matter is a major storage area for nitrogen. In fact, in most soils, more than 95% of the nitrogen is present in the form of organic matter, (Daniel*, et al*., 2007). Figure 2.1 shows the nitrogen cycle.

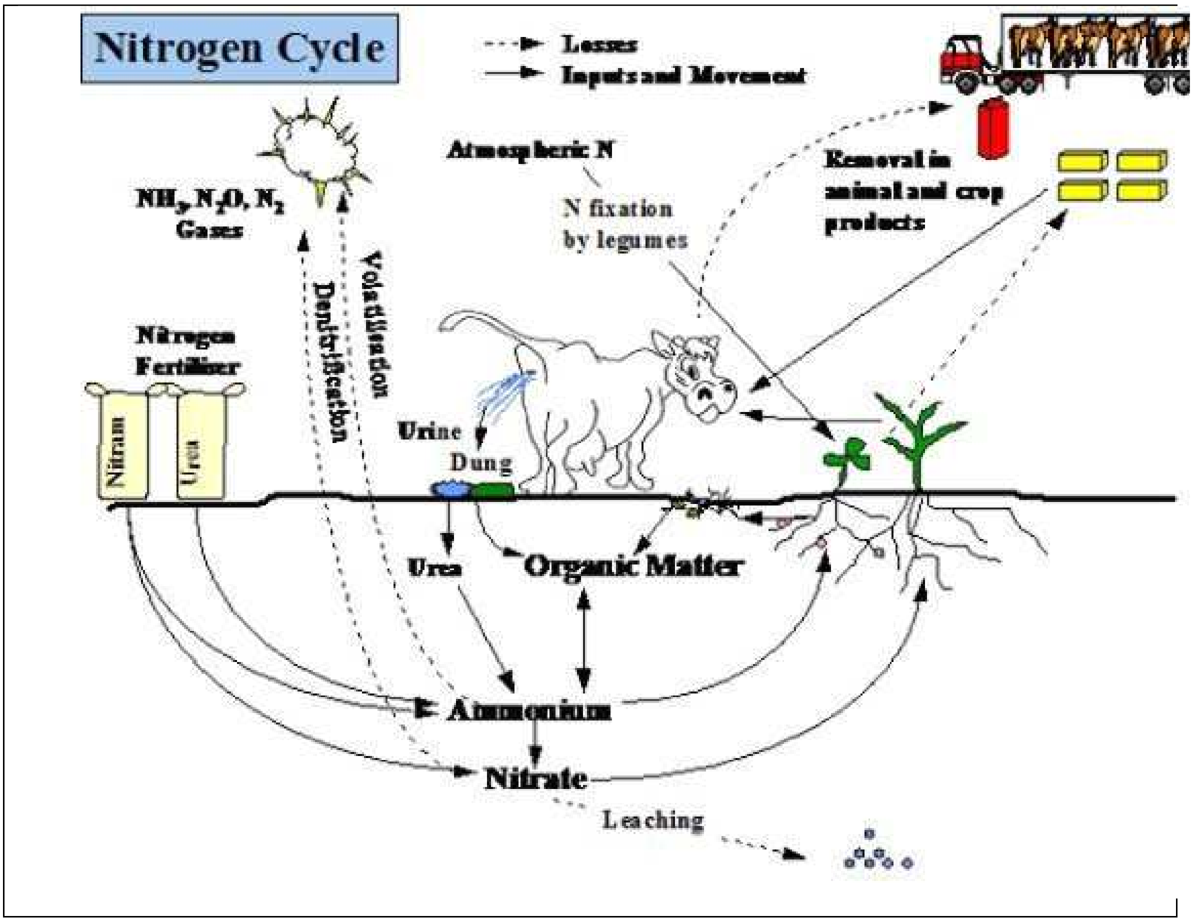

Figure: 1.5: The Nitrogen cycle
(*Source: Uchinda, 2000*)

Nitrogen plays a major role in plant metabolism as it mixes with carbon, hydrogen and oxygen to create amino acids which act as building blocks for protein synthesis, which promotes plant growth (Uchinda, 2000). It is also needed to hasten crop maturity and promote fruit and seed development in plants (Tucker, 1999). Farmers apply nitrogenous fertilisers to increase yields to meet the demand of the ever growing population (Lory, 1999). However, not all the nitrogen is used up by plants as some is absorbed and attached to soils and moved with the soil to water bodies during erosion. Ammonia and nitrates are soluble and hence are mobilised through the soil profile to groundwater during rainy periods by the process of leaching (NRMED, 1996).

2.3.3 Phosphorous

The other macro-nutrient required by plants is phosphorus, which also exists in various forms in the soil. These include apatite phosphorus (AP), non-apatite inorganic phosphorus (NAIP), and organic phosphorus (OP) and dissolved soluble reactive ortho-phosphorus (SRP) (Lory, 1999). Figure 2.2 shows phosphorus cycle.

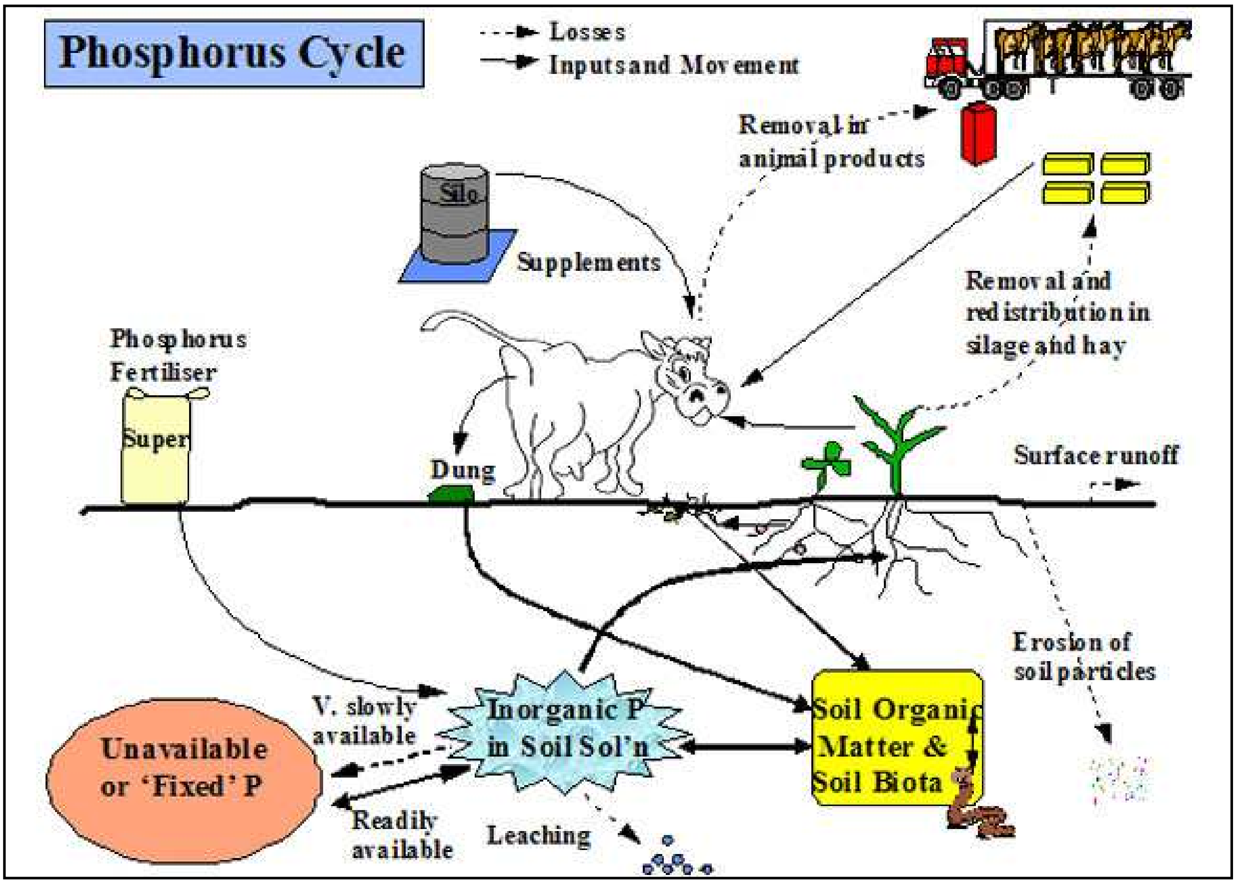

Figure 1.6: The Phosphorus Cycle
Source: Uchinda, 2000

Phosphorus plays a vital role in plant production. It is a constituent of nucleic acids (RNA and DNA), phospholipids and Coenzymes (Tucker, 1999). It is also known to activate Co-Enzymes for amino acid formation and also plays a major role in energy transfer and storage as ADP and ATP (Uchinda, 2000). Phosphorus can be absorbed into soil particles and be transported as erosion material to surface water (Lory, 1999).

The presence of both nitrates and phosphates in water bodies results in the degradation of water quality. This normally is achieved through the process of eutrophication. This results in increased algal growth, reduced water clarity, odour and bad taste of water and water treatment problems (Lory, 1999). Increased algal growth may lead to reduced oxygen levels in water, thus leading to fish death and ecological balance deficiencies of the river system.

2.3.4 Pesticides

Pesticide is a composite term used to define all chemicals intended to prevent, destroy or repel pests and pathogens (NRMED, 1996). In agriculture these include insecticides for insects, herbicides to control weeds, fungicides for fungi and rodenticides for controlling rodents.

Irrigation requires the modification of land and the hydrological regime which creates a habitat that is conducive to breeding insects, e.g. mosquitoes which act as vectors for diseases such as malaria. The continuous application of excess fertiliser may also trigger the exponential growth of weeds. This in turn then requires the use of large volumes of pesticides to control weeds as the insects may drastically reduce the yield if left uncontrolled. These pesticides may find their way into surface water and groundwater through surface water runoff or leaching respectively, depending on the soil properties and the slope, type of pesticide used and the timing of the application.

The introduction of pesticides in groundwater or surface water results in the contamination of water, which may travel far from the original sources. This may result in increased water treatment costs. Besides these pesticides are toxic and may cause death to aquatic life.

Chapter 3

3 RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

The study aims to estimate the contribution of agricultural activities to the poor water quality of the Vaal River, and to explore the current agricultural capacity, competence and knowledge on the use and application of fertiliser. Hence in this chapter the research design and methods that were used during this research are discussed. The relevance of the chosen design and methods is also highlighted. The first section describes the research design while the second section outlines the methods that were employed during the study.

3.2 RESEARCH DESIGN

This section discusses the two designs that were selected for this particular study. Each aim or objective had its own appropriate design best suited for it. The two major designs that were employed in this study are the ex- post factor research design and the survey design.

3.2.1 Ex-post factor research

To determine the correlation between agriculture effluent and its contribution to poor water quality in the Grootdraai Dam the ex-post factor research design was selected. This design is defined as research in which the independent variable or variables have already occurred and in which the researcher starts with observation of the dependent variable or variables. The independent variables are then studied in retrospect for their possible relations to and effects on the dependent variable or variables (Kerlinger, 1964).

This research design can be used to substitute a true experimental research (Simon & Goes, 2013). Ex-post factor research design can be used to test hypothesis about cause and effect or correlation relationships. This design shares some basic logic of inquiry with experimental design.

It is characterised by:

- Explanation of a consequence based on antecedent conditions
- Determination of the influence of a variable on another variable.
- Testing a claim using statistics hypothesis testing techniques.

- Uses data already collected, but not necessarily amassed for research purpose. However this method has its limitations which include:
- Non randomization assigned to treatment hence there could be inherent confound in the variables studied.
- Sample cannot be considered random hence generalisation of the findings is limited
- Little information about any drop outs from the treatment is known (Simon & Goes 2013).

The advantage in using this research design in this study is that the data was already collected and hence obtaining permission to conduct the study was less involved (Simon & Goes, 2013). This constituted secondary data which is described as data or information that was gathered by someone or institutions for other purposes than the one currently being considered for (MacCaston, 2005). As such the information had already been collected by the Department of Water Affairs.

3.2.2 Survey design

To explore the current agricultural capacity, competence and commitment of farmers to achieve compliance with the environmental legislation the cross–sectional survey design was chosen. A survey design is defined as the assessment of the current status, opinions, beliefs and attitudes by questionnaires or interviews from a known population (McMillan & Schumacher, 2001). According to McMillan and Schumacher (2001), a survey design involves the selection of the samples of the respondents first before administering questionnaires or conducting interviews

The cross–sectional survey design involves the collection of data at a point in time from a sample selected to represent a larger population. The choice of this specific design was informed by the choice of data that needed to be collected from the population group. In this type of design there was a great potential to generalise to a larger population as an appropriate sampling design was implemented (Mouton, 2001). Insufficient depth and insider perspective may have led to criticism of “surface level” analysis according to Mouton, (2001).

3.3 METHODOLOGY

For this research the predominant methodology adopted was quantitative methodology. Quantitative methodology is regarded as a process that is systematic and objective in its ways of using numerical data from only a selected subgroup of a universe to generalise the findings to the universe that is being studied (Maree & Peterson, 2013).

3.4 SOURCES OF DATA

3.4.1 Laboratory analysis

Water samples from the Grootdraai Dam were collected and analysed by the Department of Water Affairs (DWA). The parameters analysed were pH, Nitrates ($N0_3$-N) and Nitrites (NO_2-N) for Nitrogen and Phosphorus for agricultural nutrients and turbidity. These parameters were analysed for water samples.

3.4.2 Rainfall and discharge data

Rainfall and temperature data was obtained from the South African Weather Services (Appendix 9 and 10) respectively. Discharge data was collected from DWA. The data was used to analyse and correlate water hydrological regime and concentration of agriculture nutrients on the Grootdraai Dam.

3.4.3 Maps

The map showing the location of the Grootdraai Dam Catchment and the Vaal River shown in Figure 3 was created from datasets obtained from National Geo-Spatial Information (NGI). The landuse/cover map was derived from the National Land Cover 2000 data set developed by the Satellite Application Centre (SAC) of The Council for Scientific and industrial Research (CSIR, 2003). A map of the area of the basin and landuse of the catchment was also developed from data obtained from the National Geo-Spatial Information (NGI). The datasets were very useful sources of information for the analysis of agricultural non-point source pollution.

3.4.4 Observation

A systematic observation method was chosen to record the behavioural patterns of algal blooms within the Grootdraai Dam and its two tributaries. A structured observation method was chosen. Monthly observations were made on the Vaal River (mainstream) and two of its tributaries (T1 and T2). The parameters that were observed were (a) the presence or absence of algal blooms, and (b) the quantity or amount of algal blooms.

The amount of algal blooms was divided into three categories which are:

- Minimum growth.
- Medium growth
- Maximum growth

This was done to enable the classification of the occurrence of any algal blooms observed. During each time photographs were taken of the sampled areas for observation (Figures 4.4-4.9). The photographs were used as evidence and for correlating rainfall pattern and algal bloom in the major stream and the two tributaries.

3.4.5 Questionnaires and personal interview

An interview is described as a two–way conversation in which an interviewer asks questions to the participant so as to obtain required information on a desired subject (Nieuwenhuis, 2013). An interview is therefore a useful technique in providing data that cannot be obtained through observations such as opinions and beliefs.

For this study questionnaires were administered to 16 farmers (Appendix 1 and 2), to determine the type of land use is predominant, and establish the types of fertilisers used by farmers and the knowledge farmers have on the use of fertilisers. Through random sampling, a sample of 16 commercial farmers was selected for interviewing. The commercial farmers were selected and interviewed at the Agricultural Auction Centre where all commercial farmers meet every Friday.

A questionnaire was also administered to the Lekwa Municipality Water Department management, (Appendix 4). In this case no sampling method was applied as management was the target group for interviewing. Data on the state of affairs of the Vaal River, frequency and parameters are tested for as well as monitoring instruments for monitoring farmers operations along the Vaal River was collected.

A questionnaire was administered to the local people of Standerton, (Appendix 3). A sample of 30 residents drawn from the high and low density areas was selected by using a random sampling method. Data on the quality of water supplied by the Lekwa Local Municipality and their understanding of water quality was collected. Interviews with local residents was conducted to establish the opinion of residents on the quality of water and to assess their awareness of causes of water pollution.

3.5 DATA ANALYSIS PROCEDURE

The selection of data analysis method is a key factor in achieving the aim and objectives of the study (Johnson & Gray, 2010). In this study, the constant comparison method was used. According to (Cohen *et al*., 2007), this method allows for the comparison of indicators, categories and theories that have been developed with primary data to achieve a perfect fit between categories and data.

3.5.1 Quantitative analysis

Data obtained from DWA was analysed quantitatively. Correlation methods were used to establish the relationship between rainfall within the catchment and the concentration of agriculture nutrients in the Grootdraai Dam. A student t-test was used to determine the significance between the means of the first and second decades for both nitrogen and phosphorus. Descriptive statistics such percentages were used to analyse information obtained from survey questionnaires and frequency of fertilizer application. Graphical and tabulation methods were also used to summarise data.

3.6 TRUSTWORTHINESS

Credibility is used in qualitative research to refer to the correspondence between what the participants said and how interviewer portrays their points of view. In this particular study the credibility of the interviews was evaluated by employing various methods which includes consistency checks or stakeholder checks, comparison with previous research on similar topic and independent coding as suggested by (Thomas, 2003).

Consistency checks involved providing the opportunities for stakeholders, like farmers, participants and the Lekwa Local Municipality to comment on the categories, interpretations and conclusions made. This process of engagement was a continuous process meaning that it was done at each and every stage throughout the study. It eliminated any irregularities that arose during the study.

An independent coding method, which involved giving an independent coder the research objectives and the raw data that was used to create categories to create his own codes, was done as suggested by (Thomas, 2003). These were then compared to the one done to establish if there was any inconsistency.

3.7 ETHICAL CONSIDERATION

During the data collection process it was of paramount importance to get an in-depth account of the phenomenon which required that participants should be free to express their experience. This required a mutual understanding between the researcher and the participants. Creswell (2012) suggested that this could be achieved by informed consent entered into between the participant and the researcher, voluntary participation, right to privacy, respect towards all the participants and confidentiality. Before data collection an ethical clearance certificate was obtained from the University of South Africa. Once cleared, permission was granted by the Lekwa Local Municipality to conduct the research. The purpose of the research was clearly explained to the participants. Confidentiality contracts were designed and entered into with the participants to ensure that whatever information obtained was protected. Consent forms were also designed and sighed by the participants as proof of their consent to be interviewed.

It was explicitly explained to the participants of their rights to take part or refuse or even pull-out at any time if they felt uncomfortable to continue with the interview. All participants were treated equally and with due respect they deserved. All the information obtained was treated confidentially and anonymity was guaranteed.

3.8 LIMITATIONS OF STUDY

There were some gaps on the data that was obtained from DWA. Data was not consistent in the collection of samples and consequent analysis was not uniform. There were months without or with incomplete data, hence this made it difficult to calculate the means for each year.

Data for pesticides analysis was not readily available from DWA. Hence the only information obtained was from the survey from farmers on the frequency and application of pesticides.

Chapter 4

4 DATA ANALYSIS AND RESULTS

4.1 INTRODUCTION

To further substantiate the physical-chemical properties of water in the Vaal River within the study area and their possible causes a survey was carried out on the local residents of Standerton, the Department of Water Affairs in Lekwa Municipality and the local farmers. The survey was based on a number of parameters that could affect the physical-chemical properties of the quality of water such as type of farming, types of fertilisers used and their frequency of use and any control measures implemented on their use. The legislation that governs the protection of the environment and water resources within the study area was also implored. Therefore, this chapter presents and analyses all the findings in this regard.

4.2 FOUL SMELL ON WATER SUPPLIED BY LEKWA MUNICIPALITY

Residents were asked if they had at any point in time detected any foul smell from the tap water supplied by Lekwa Municipality. The results of that survey indicated that 80% of the sample population confirmed having detected a foul smell on tap water and 20% did not detect any foul smell on the tap water.

Furthermore the sample population was asked to give an opinion on the quality of water supplied by the municipality. About 54% of the sample population rated the water as of poor quality while 17% rated the water as of good quality and 29% was unsure if the water was of poor quality or not.

On the observation of green algae in any section of the Vaal River within the study area 57% of the sample population confirmed having observed green algae growing in the river while 43% had not observed any form of algal growth within the Vaal River at any point in time. About 51% of the population confirmed having observed dead aquatic animals such as fish within the Vaal River while 49% did not observe any dead organisms at all.

The Lekwa Municipality water department acknowledged that the quality of water in the Vaal River was generally deteriorating. However the reason given for the poor water quality was a dysfunctional or poor sewer treatment quality works. The Lekwa water department pointed out that nutrient testing and analysis of Phosphorus and Nitrogen was not done or carried out by Lekwa Municipality and as such the municipality was not responsible for any such tests and analysis on the Vaal River in the study area.

Questions on the environmental legislation governing farmers operations along the Vaal River catchment area were not answered by the Department of Water Affairs and the same was done for the questions on any visits paid to farmers to monitor and ensure compliance.

4.3 TYPE OF FARMING IN THE GROOTDRAAI DAM CATCHMENT

Agriculture has many sub-sectors such as animal husbandry, crop farming, horticulture and etc. Most farmers in the Grootdraai Dam Catchment practice mixed farming that is they practise both crop farming and animal husbandry. Mixed farmers constituted 56% of the sample population. About 31 % of the farmers in the study area practice animal husbandry only while 13 % are limited to plant or crop production as indicated in table 4.1 which shows the types and percentage representative of agriculture types practiced in within the study area.

Table 4.1: Types of agriculture practiced in the catchment

Type of farming	*Frequency*	*(%)*
Animal husbandry	5	31
Crop farming	2	13
Mixed farming	9	56

4.4 DISTANCE OF FARMS FROM THE VAAL RIVER

In a survey conducted to determine the distance of farms from the river it was established that about 56% of the commercial farms in the study area are located very close to the water bodies, within a distance of 0 to 5km from the river. This information is also supported by the visual observations made during the study period. Figures 4.1 and 4.2 show how close some farms are to water bodies.

The distance between the farmlands and water-bodies has been gradually reduced as can be appreciated in Figures 4.1 and 4.2. This could be caused by the need to produce more food to meet the demands of the ever increasing population hence leading to the gradual destruction of buffer zones.

Figure 4.1 Shows how close farms are to the Vaal River in Standerton area
(Photo taken in February 2014)

Figure 4.2: The non-existence of buffer zones in some farms in Standerton
(Photo taken in February 2014)

However 31% of the commercial farms are within the 5km to 10km distance from the river. About 13% of the farms are located within the 10km to 15km distance from the river as indicated in the Table 4.2. However there are two tributaries that pass through those farms and join the Vaal River within the study area.

Table 4.2: Average distance of farms from the Vaal River within the catchment

Distance of farm from river (km)	*Frequency*	*(%)*
0 to 5	9	56
5 to 10	5	31
10 to 15	2	13
Over 15	0	0

4.5 TYPE OF FERTILISER USED BY FARMERS IN STANDERTON

Farmers use a wide variety of fertilisers to enhance plant or crop production. However most of the farmers that were sampled were unable to give the exact name of the type of fertiliser that they use in their farms. Instead they used the packaging to describe the type of fertiliser they use. Figure 4.3 indicates the type and frequency of the fertiliser used. Figure 4.3 also shows that the most commonly used fertiliser is Sasol KN and Sasol 434. This information was also verified with fertiliser retail store AFGRI in Standerton, who confirmed through their sales records that Sasol KN and Sasol 434 fertilisers had the highest sales per month. Figure 4.3 shows that most sampled farmers prefer to use Sasol KN and Sasol 434.

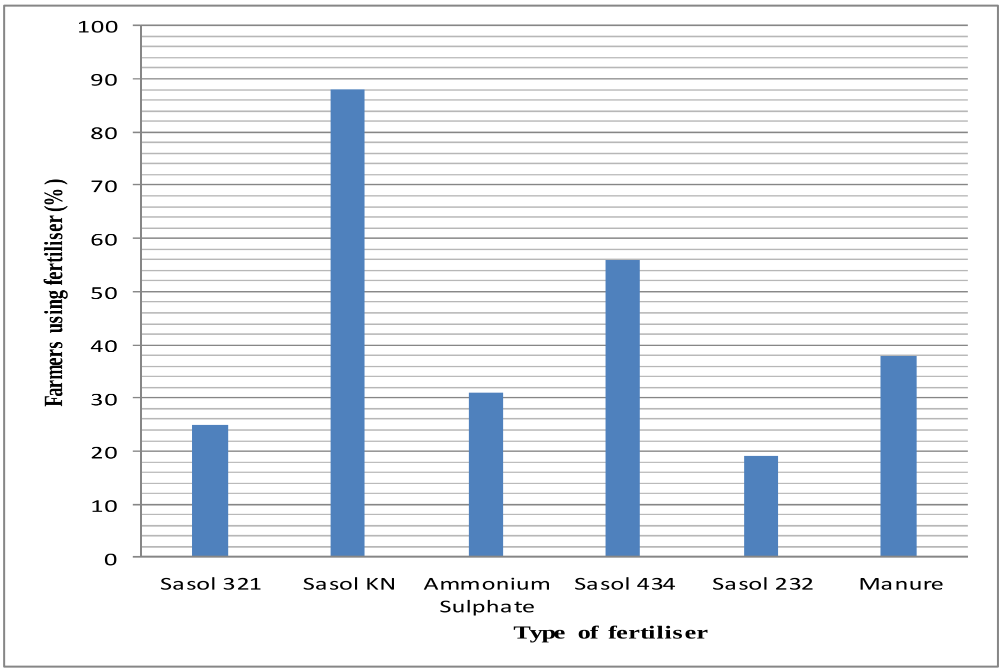

Figure 4.3: Fertiliser used by farmers in the Grootdraai Dam Catchment in 2013

An analysis of the contents of each fertiliser was done to establish the amount of nitrogen and phosphorus is contained in each type of fertiliser. Table 4.3 indicates the amount of nitrogen and phosphorus used in the study area.

Table 4.3: Amount of N and P in different fertilisers used by farmers in the catchment

Name of fertiliser	*Amount of Nitrogen (g/kg)*	*Amount of Phosphorus g/kg*
Sasol 321	125	83
Sasol KN	280	-
Ammonium Sulphate	210	-
Sasol 434	120	90
Sasol 232	63	94
Manure		-

Table 4.3 also indicates that almost all fertilisers contain both nitrogen and phosphorus. Sasol KN however has the highest amount of nitrogen content of 280g/kg while Sasol 232 has the highest content of phosphorous of 94g/kg.

4.6 AMOUNT OF FERTILISER APPLIED PER HECTARE

Farmers seemed to have different amounts of fertiliser they apply per hectare. About 50 % of the sampled farmers apply between 0 to 100kg of fertiliser per hectare, twice every farming season as shown in Table 4.4. 12.5% of the farmers use between 100 to 200kg of fertiliser per farming season. The same percentage of 12.5% is used for the range of between 200 and 300kg and over >300kg per hectare every farming season.

Table 4.4: Average amount of fertiliser applied by farmers per hectare

Amount of fertiliser applied per ha (kg)	*Frequency*	*(%)*
0-100	8	56
100-200	2	12.5
200-300	2	12.5
Over 300	2	12.5

4.7 DURATION OF APPLICATION OF FERTILISER ON FARMS

About 31% of the commercial farmers in the study area have been applying fertiliser for between 0 to 5 years. These are generally young farmers who have recently taken over their family farms.

Meanwhile, 25% of the farmers have been using fertiliser for the period ranging from 5 to 10 years. About 19% of these farmers have been using fertilisers on their farms for a period ranging from 10 to 15 years, while 6.25% have used fertilisers for more than 15 years. However there is a 19% that does not use any form of fertiliser at all as shown in Table 4.5.

Table 4.5: Average time of fertiliser application by farmers

Duration of fertiliser application (years)	*Frequency*	*(%)*
0-5	5	31
5-10	4	25
10-15	3	19
Over 15	1	6
Non application	3	19

4.8 KNOWLEDGE OF FERTILISER APPLICATION

About 19% of the farmers sampled did not have sufficient knowledge on the application requirements or fertiliser specifications, while another 19% of the farmers were not sure of the application methods and quantities. Bearing this in mind it can be stated that approximately 38% of the farmers do not have sufficient knowledge on the application of fertilisers, like how much to apply per hectare, time of application and frequency of application. However, 62% of the sampled farmers have sufficient knowledge on the application of fertilisers as shown in Table 4.6.

Table 4.6: Knowledge of fertiliser application among farmers in 2013

Knowledge of fertiliser application	***Frequency***	***%***
Insufficient	3	19
Sufficient	10	62
Not sure	3	19

4.9 OBSERVATION OF THE VAAL RIVER AND ITS TRIBUTARIES

During the duration of the study the Vaal River and two tributaries that join the Vaal River within the study area were observed for any presence of algal blooms or algal growth and the colour of water.

The results indicate that on Tributary 1 (T1) there was hardly any algal bloom that was observed during the first two months. However, from March to June 2013 there were algal blooms that started showing up. During the months of July to December 2013 there was an abundance of algal activity that was observed as indicated by the two figures below. Figure 4.4 shows algal activity taken in March 2013 while figure 4.5 shows algal activity taken in November 2012.

Figure 4.4: Algal activity observed at T1
(*Photo taken in March 2013*)

Figure 4.5: Algal activity observed at T1
(*Photo taken in November 2012*)

Figure 4.7: Algal activity observed at T2
(*Photo taken in October 2013*)

Figure 4.6: Algal activity observed at T2
(*Photo taken in March 2013*)

On Tributary 2 (T2) an almost similar trend to T1 was observed. During the months of January to March there was little algal growth observed as shown in Figure 4.6. During the months of April to August there was a general increment on algal bloom appearance while the months of September to December had the most abundant appearance. Figures 4.6 and 4.7 also show algal activity during March and October 2013 respectively, taken from T2.

Figure 4.8: Algal activity in the main channel
(*Photo taken in October 2013*)

Figure 4.9: Algal Activity in Main channel
(*Photo taken in April 2013*)

On the main river (Vaal River) the trend was almost the same with that of T1 and T2. There were very little algal blooms that were observed during the first three months and a moderate algal growth pattern was observed during the months of April to July as shown in Figure 4.8.

.However from the months of August to December there was an abundant appearance of algal activity observed as shown in Figure 4.9 taken from the Vaal River in October 2013. As can be observed the entire water body is covered by algal blooms in this section of the Vaal River.

4.10 PHOSPHORUS IN WATER

The data collected from DWA was divided into decades for analysis. During the first decade from 1988 to 1997 phosphorus concentration in the water was dropping during the first three years from a concentration of 0.086mg/l in 1988 to 0.052mg/l in 1990. However in 1991 there was a drastic increase to 0.086mg/l. Thereafter, the concentration of P in the water remained fairly constant. 1996 saw a sharp increase in the concentration of dissolved P of 0.095mg/l. The average concentration measured during this period was 0.0688mg/l. Figure 4.10 indicates the different concentrations of dissolved phosphorus recorded in the water during this decade.

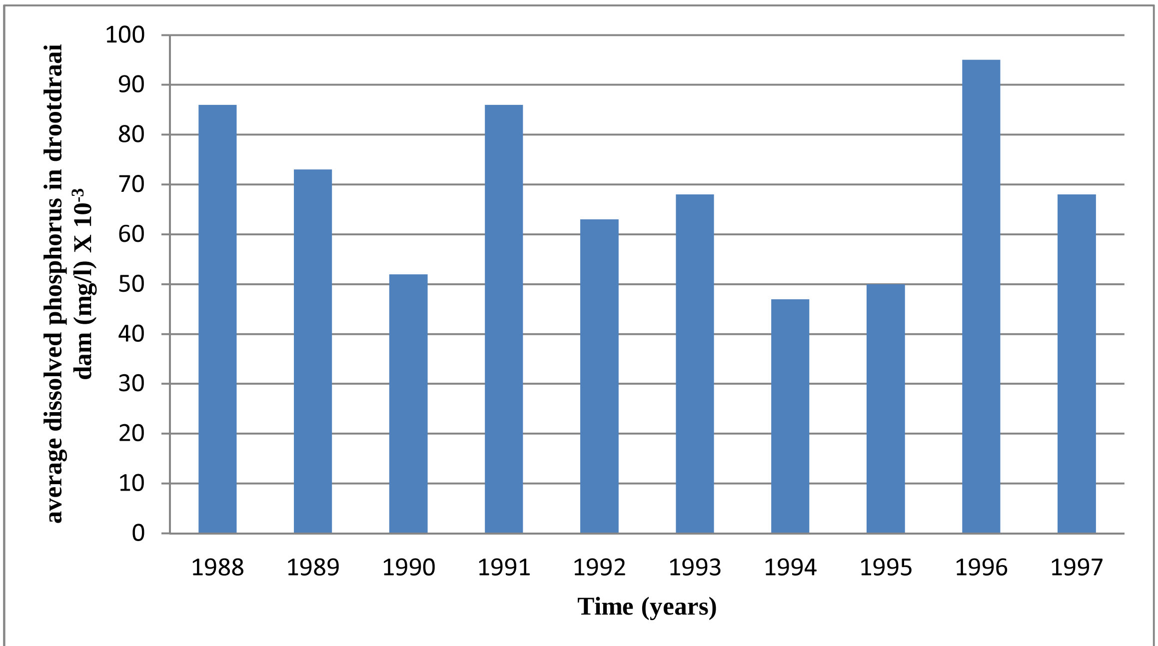

Figure 4.10: The average annual dissolved phosphorous in the Grootdraai Dam for the period 1988 to 1997

In the second decade stretching from 1998 to 2007 dissolved phosphorus concentration was fairly consistent to the first decade. The highest values of dissolved P concentration of 0.163mg/l was recorded in the years 2001 and 2007, 0.164mg/l while the list amount of 0.047mg/l was recorded in 2005. Figure 4.11 indicates the different concentrations of dissolved Phosphorus in water during the 1988-2007 decade. In the year 2000 there was no data available for the whole year and hence it was not possible to calculate any mean concentration.

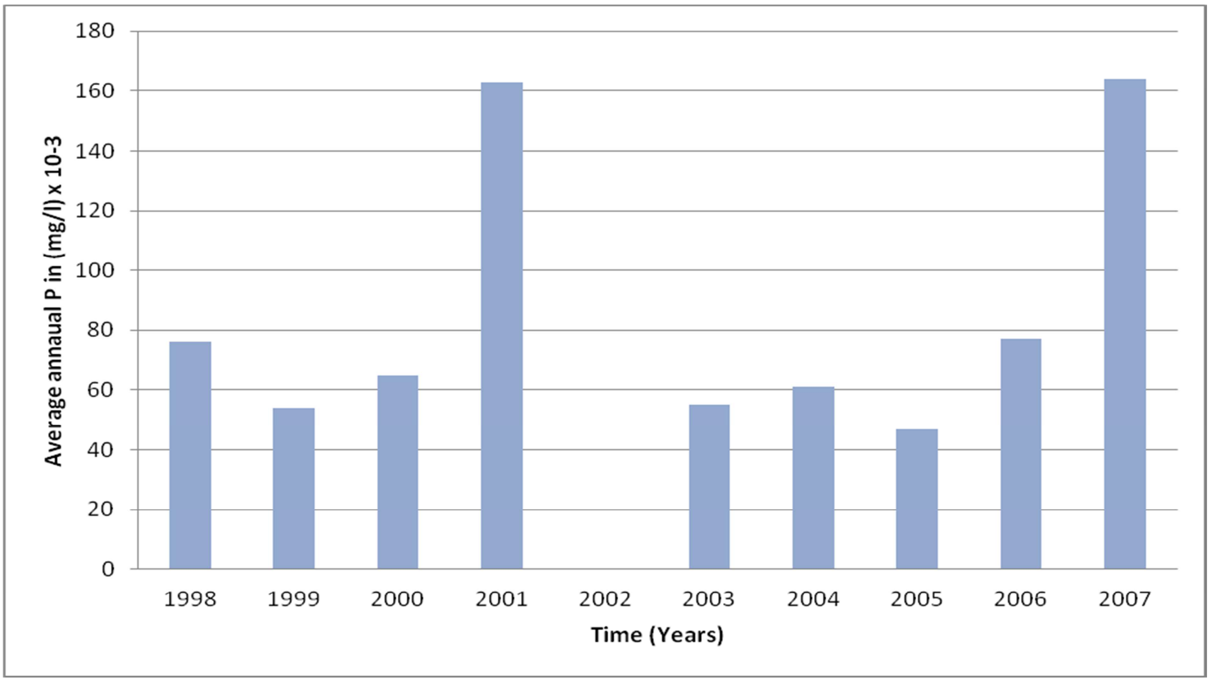

Figure 4.11: The average annual dissolved P in the Grootdraai dam for the period 1998 to 2007

The mean concentration measured during this period was 0.0847mg/l. A t- test was performed on the two sets of data to establish if the difference in the means of the two sets of data was significant or not. The results obtained from that t-test and the level of confidence is shown in Table 4.7.

Table 4.7: Student t- test for Phosphorous

	Phosphorus conc: mg/l Decade 1(1988-1997)	*Phosphorus conc: mg/l Decade 2(1998-2007)*	*Phosphorus values squared Decade 1(1988-1997)*	*Phosphorus values squared Decade 2(1998-2007)*
	0.086	0.076	0.007396	0.005776
	0.073	0.054	0.005329	0.002916
	0.052	0.065	0.002704	0.004225
	0.086	0.163	0.007396	0.026569
	0.063	0.055	0.003969	0.003025
	0.068	0.061	0.004624	0.003721
	0.047	0.047	0.002209	0.002209
	0.050	0.077	0.0025	0.005929
	0.095	0.164	0.009025	0.026896
	0.068	0.085	0.004624	0.007225
Sum	0.688	0.847		
Mean	0.0688	0.0847		
Correction factor (CF)	0.047334	0.0717409		
Sum of squares			0.049776	0.088491
Standard error (SE)	0.005491	0.01438024		
Pooled error	0.009936			
Standard error of difference (SED)	0.004443514			
t- value calculated	3.578249			
Table t value	2.1			

Table 4.7 indicates that the calculated t-value of 2.823 is greater than the t-value from the table of 2.1 at 5% confidence level. This shows that the difference between the means of the two sets of data is significant meaning that the difference is not merely by chance but it could be due to a gradual deposit of P into the water from a source within the area. It can therefore be argued through this t test that there has been a gradual increase in the concentration of P in the Grootdraai Dam over the years.

According to DWA (1996a) water quality guide lines the concentrations of P recorded are way above the permissible concentration of 0.03mg/l-0.05mg/l. Therefore, the P concentrations in the Vaal River are classified as unacceptable according to the Vaal River Barrage in stream water quality guidelines as shown in the Table 4.8.

Table 4.8: DWA water guidelines for Phosphorus (mg/l)

Use	*Permissible Phosphorous (mg/l)*
Domestic use	none
Aquatic ecosystem	0.05
Recreational	none

Source: Estie (2007)

Furthermore an average monthly analysis of phosphorus concentration was done. It was noted that the concentration of P is generally higher in the months from November (0.0866mg/l) to February (0.106mg/l). During the months from March to July it decreases gently reaching the lowest concentrations of 0.068mg/l in July. There is also an unexpected peak in August where the concentration rises to 0.092mg/l. Between June and July farmers apply fertilisers on their winter crops. During this time the temperatures in the study area begin to increase as spring approaches as shown in (Appendix 10). The peak in August could be as a result of cultivation of winter crops where farmers also apply fertilisers and pesticides. The irrigation practiced during this dry season causes the washing away of nutrients and pesticides into water-bodies. Also the volume of water in water-bodies decreases during the dry season due to high rates of evaporation, increasing pollutant concentration in river. Figure 4.12 shows how the average monthly concentration of phosphorous varied.

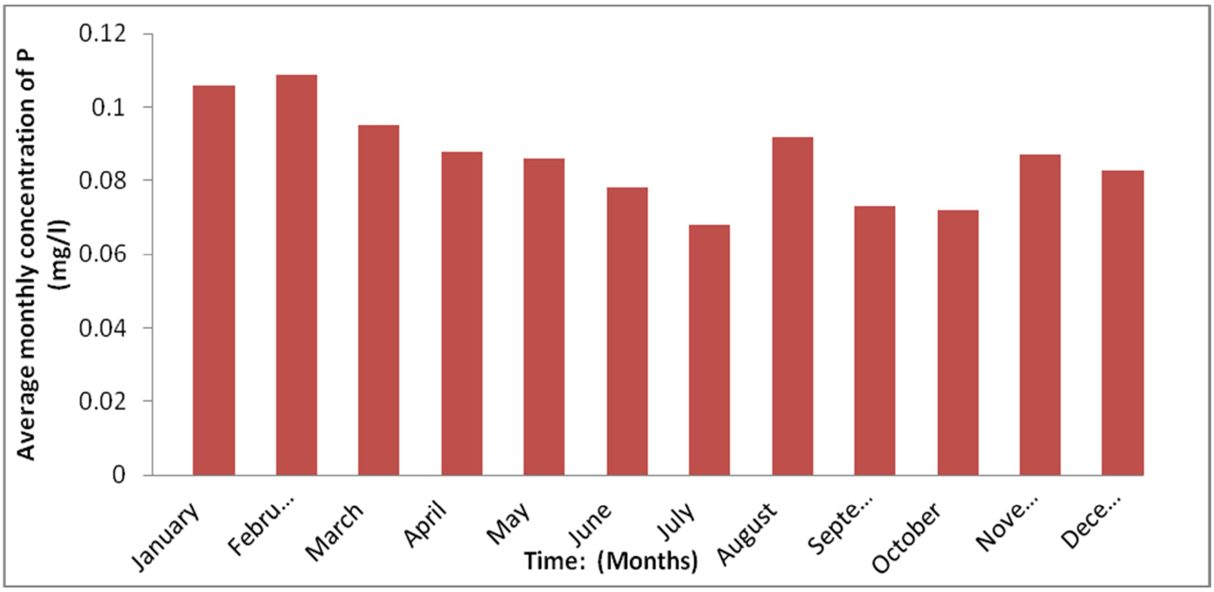

Figure 4.12: Average monthly concentration of P in the Vaal River.

4.11 NITRATE IN THE WATER

The data for nitrates concentration, just like that for phosphorus was collected from the DWA for the period 1988 to 2007 and also divided into two decades for easier analysis.

During the first decade the dissolved nitrate concentration detected in water had the highest value of 1.221mg/l in 1988. However between the years 1989 to 1996 the dissolved nitrate concentration was slowly decreasing from 0.938mg/l in 1989 to 0.730mg/l in 1994. The nitrate concentration dissolved in water started increasing steadily to 1.071mg/l recorded in 1996 and 1997 as shown in Figure 4.13.

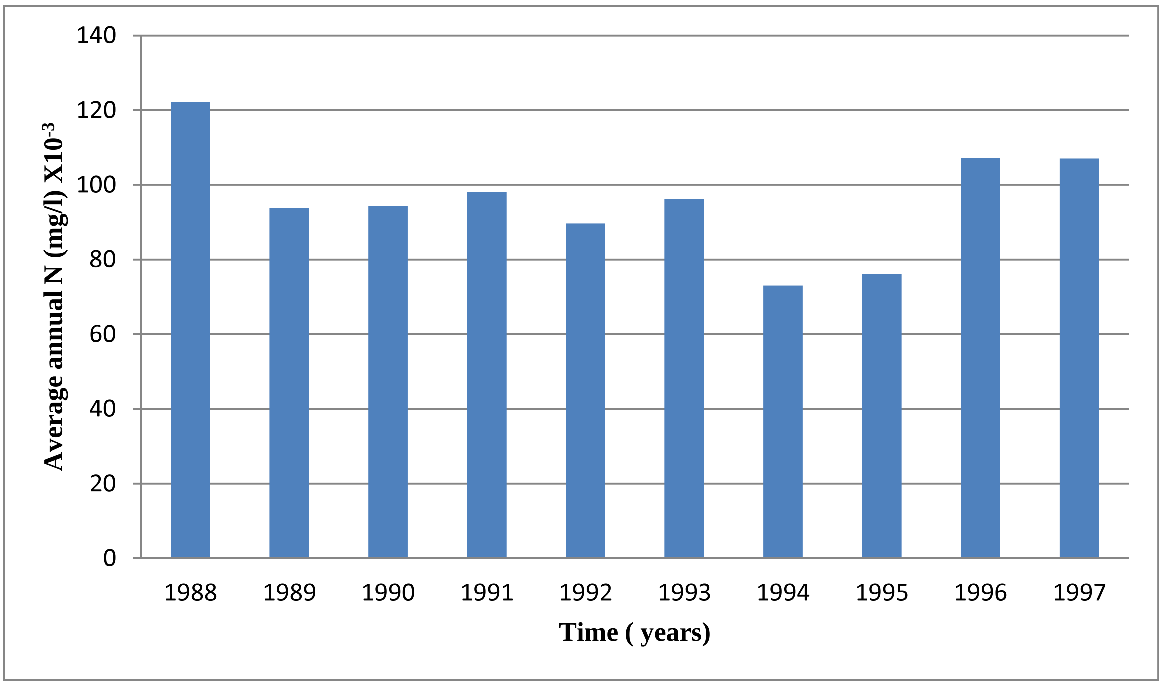

Figure 4.13: Average dissolved N in the Grootdraai dam in the period 1988 to 1997

In the second decade there was no specific pattern shown by the dissolved nitrate concentration in the water. However from 1998 there was a steady increment from 0.756mg/l in 1999 to 1.844mg/l in 2001. Then there was a downward trend until 2006 where 0.727mg/l was recorded. In 2007 another high reading of 1.792 mg/l was recorded as shown in Figure 4.14. . In the year 2000 there was no data available for the whole year and hence it was not possible to calculate any mean concentration.

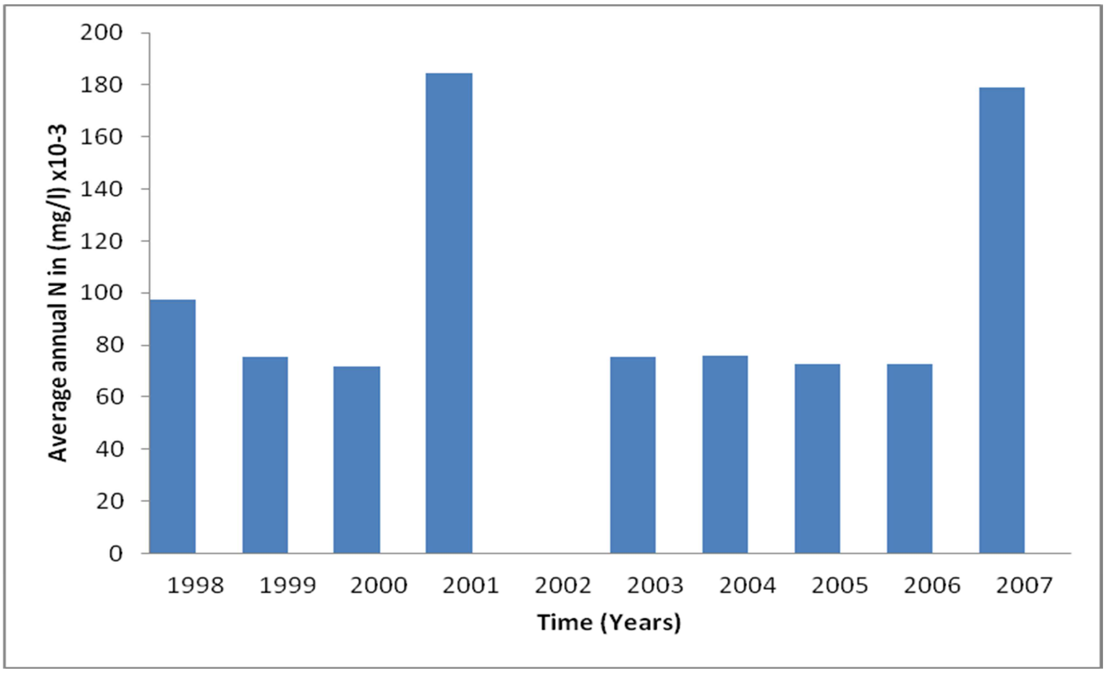

Figure 4.14: Average annual dissolved N in the Grootdraai dam in the period 1998 to 2007

The mean for the dissolved nitrate concentration in water for the first decade was calculated to be 0.9576mg/l while the mean for the second decade was 1.004mg/l. There is a clear difference between the two means for the two decades. However, a student t test was performed on the 2 set of data, to determine if the difference between the two means is significant or not. The results obtained from that test and the level of confidence is shown in Table 4.9.

Table 4.9: Student t- test for Nitrates

	Nitrogen conc: mg/l Decade 1(1988-1997)	*Nitrogen conc: mg/l Decade 2(1998-2007)*	*Nitrogen values squared Decade 1(1988-1997)*	*Nitrogen values squared Decade 2(1998-2007)*
	1.221	0.976	1.490841	0.952576
	0.938	0.756	0.879844	0.571536
	0.943	0.720	0.889249	0.5184
	0.981	1.844	0.962361	3.400336
	0.897	0.755	0.804609	0.570025
	0.962	0.761	0.925444	0.579121
	0.730	0.726	0.5329	0.527076
	0.761	0.727	0.579121	0.528529
	1.072	1.792	1.149184	3.211264
	1.071	0.983	1.147041	0.966289
Sum	9.576	10.04		
Mean	0956	1.004		
Correction factor (CF)	9.1699776	10.08016		
Sum of squares			9.360594	11.825152
Standard error (SE)	0.0485107	0.146775717		
Pooled error	0.097643213			
Standard error of difference (SED)	0.043667372			
t- value calculated	1.0625782			
Table t value	2.1			

The t-value of 2.1 shown in Table 4.9 is greater than the calculated t-value which is 1.06. This means that the difference between the two means is not significant although both values are relatively high. Table 4.10 indicates the DWA water guidelines for nitrates.

Table 4.10: DWA water guidelines for Nitrates

Use	*Permissible nitrates (mg/l)*
Domestic use	< 6 mg/l
Aquatic ecosystem	< 0.5 mg/l
Recreational	No guidelines

Source: Estie (2007)

According to the DWA guidelines given in Table 4.10 it is evident that the concentration of nitrates is above the permissible levels for aquatic ecosystems. This could be owed to the properties of nitrates. Nitrates are highly soluble in water and as such large quantities may be found in soils and in water. According to Michael *et al* (1992), there are four possible causes of nitrogen pollution. The first being pollution through soil erosion resulting in sediment deposition off the fields of origin. The second being nitrogen pollution from fertiliser application, that result in runoff deposited directly in surface water courses, and volatilisation losses at the time of application.

A further analysis of the average monthly concentration showed that the concentration of nitrates was rather higher during January, 0.733mg/l to April, 0.0836mg/l. Then the concentration begins a downwards trend until it reaches 0.523mg/l in July. However there is a peak in August of 0.740mg/l which is difficult to explain. Between June and July farmers apply fertiliser on their winter crop. During this time the temperatures in the catchment begin to increase as spring approaches as shown in (Appendix 10).

The peak in August could be as a result of the cultivation of winter crops where farmers also apply crop nutrients and pesticides. The irrigation practiced during this dry season may cause the washing away of agricultural nutrients and pesticides into water-bodies. Also the volume of water in water-bodies decreases during the dry season due to high rates of evaporation, increasing pollutant concentration in rivers. From October to December the concentration begins a gentle ascent as shown in Figure 4.15.

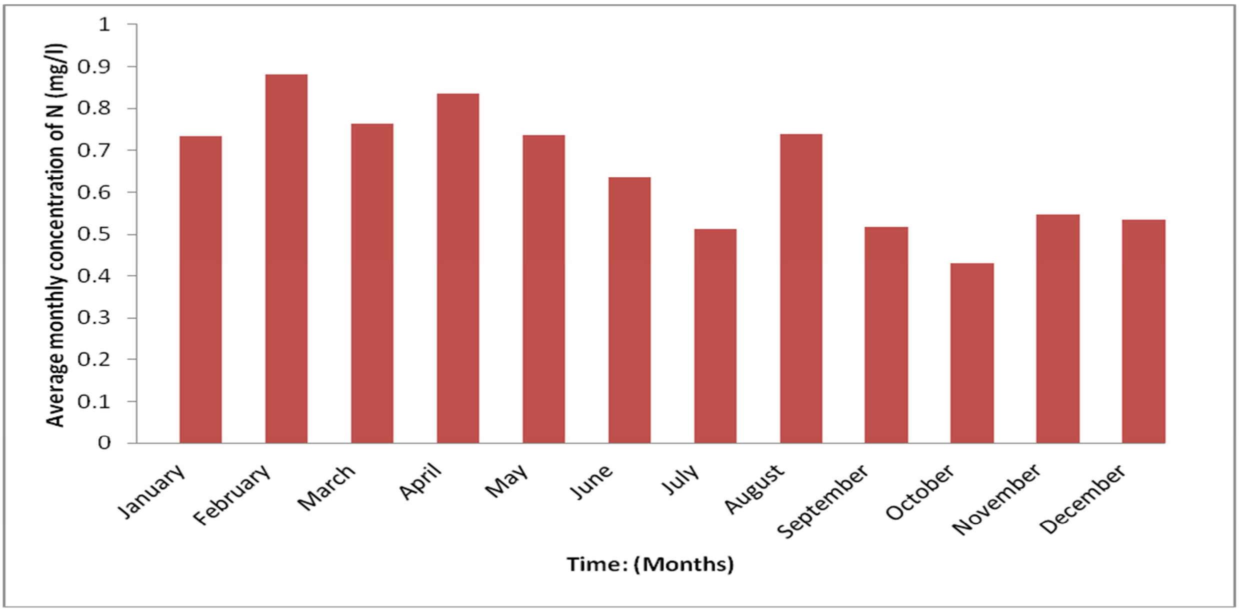

Figure 4.15: Average monthly concentration of N in the Grootdraai dam

4.12 PH IN THE WATER

The pH data recorded from Grootdraai Dam was obtained from the DWA. It was determined here as one of the parameters that could be used to reflect the acidity and alkalinity of the water in the Grootdraai Dam. Acidic or alkaline conditions may have a severe effect on the aquatic system. In this study the pH conditions were used to assess the extent of pollution in the water in relation to the fertilizer use within the study area.

In the Grootdraai Dam the pH of the water is slightly alkaline. For the purpose of this study an average pH for a particular year was calculated. The results indicated that in 2010 a minimum mean value of 7.30 was recorded. Meanwhile the highest mean pH value of 7.97 was recorded in 2013. Generally the mean pH values of the water in the Grootdraai Dam were between pH 7.70 and pH 7.92 during the rest of the period, from 2004 to 2013, as shown in the Figure 4.16.

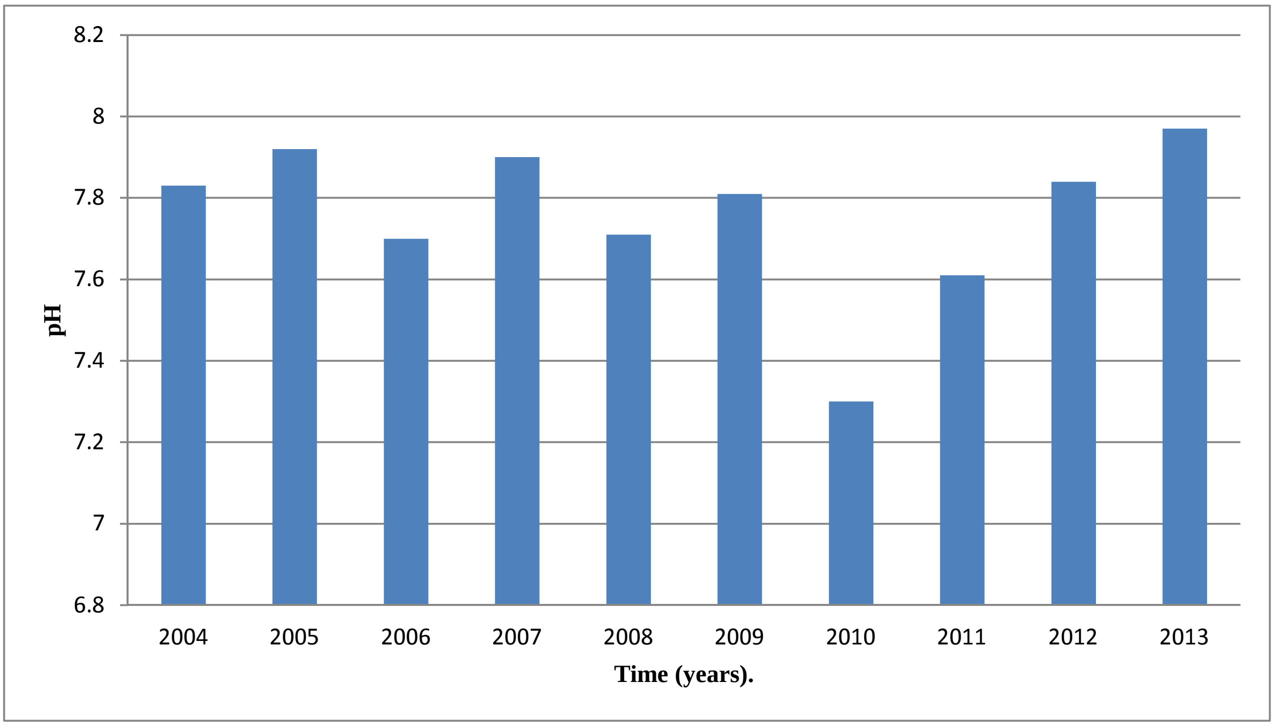

Figure 4.16: Average yearly pH in the Grootdraai dam

4.13 RUNOFF AND NUTRIENT DYNAMICS

According to FAO (2013) the use of P and N in South Africa is 1.86 and 4.27 tons per 100 Ha of cultivated land, respectively, and the fertiliser uptake by crops is 49.21 Kg/Ha. The total N and P applied in each quaternary basin is calculated by multiplying the area of cultivated land of a quaternary basin by the quantity of the nutrient under consideration.

Table 4.11 shows the total nutrients used in the quaternary basins of the GDC. The sum of nutrients used in quaternary basins gives the total nutrients used per annum in the whole GDC. Table 4.11 also shows the excess N and P that are not removed from the soil by crops and are washed away by runoff water per Ha of each cultivated land in each quaternary basin. The excess nutrients are calculated by subtracting the crop nutrient uptake from the total nutrient applied.

Table 4.11: Excess nutrients washed away from cultivated area of each basin per annum

Basin	*Runoff (1000 m^3/km^2)*	*Area (Km^2)*	*Cultivated land Ha*	*Runoff on cultivated land (000 m^3)*	*Total N use Kg/Ha*	*Total P use Kg/Ha*	*Excess N (Kg/Ha)*	*Excess P (Kg/Ha)*
C11A	75.53	720.26	13468	10172.38	57508.36	25050.48	57459.15	25001.27
C11F	60.38	930.59	26410	15946.36	112770.7	49122.6	112721.49	49073.39
C11H	73.12	1105.19	41130	30074.26	175625.1	76501.8	175575.89	76452.59
C11B	65.84	535.32	9688	6378.58	41367.76	18019.68	41318.55	17970.47
C11G	44.57	432.42	14100	6284.37	60207	26226	60157.79	26176.79
C11K	59.68	340.81	14702	8774.15	62777.54	27345.72	62728.33	27296.51
C11E	62.68	1156.41	31557	19779.93	134748.39	58696.02	134699.18	58646.81
C11J	53.02	1002.45	27121	14379.55	115806.67	50445.06	115757.46	50395.85
C11D	64.58	372.19	7104	4587.76	30334.08	13213.44	30284.87	13164.23
C11L	58.73	948.98	38555	22643.35	164629.85	71712.3	164580.64	71663.09
C11C	91.84	449.27	6691	6145.01	28570.57	12445.26	28521.36	12396.05
Total					**984346**	**428778.4**	**983804.7**	**428237.1**

Using the excess nutrient of each quaternary basin, shown in Table 4.11, the total nutrients that are finally washed away by runoff water in the particular quaternary basin is calculated by multiplying the area of cultivated land of the basin by the excess nutrient (as shown in Equation 4.1) and the results are shown in Table 4.12.

$$N_{pol} = A_c \times N_{ex}, \qquad [4.1]$$

where, N_{pol} is total nutrients washed by runoff, A_c is area of cultivated land in a basin and N_{ex} is the excess nutrient

Table 4.12 also shows the total dissolved nutrients in runoff water in each basin, which is obtained by dividing the total nutrient washed away by the annual runoff that flows over the cultivated land of each basin. The dissolved nutrients washed away by runoff water per annum in each quaternary basin are given in Table 4.12, as well as the total for the whole catchment.

Table 4.12: Total dissolved nutrient washed away by runoff from cultivated lands annually

Total N washed away (ton)	*Total P washed away (ton)*	*Dissolved N in Runoff (t/m3)*	*Dissolved P in runoff (t/m3)*	*Dissolved N in runoff (mg/l)*	*Dissolved P in runoff (mg/l)*
773859.83	336717.1	0.08	0.03	7607.46	3310.11
2976974.6	1296028.2	0.19	0.08	18668.68	8127.42
7221436.4	3144495	0.24	0.1	24012.02	10455.77
400294.11	174097.91	0.06	0.03	6275.6	2729.41
848224.84	369092.74	0.13	0.06	13497.37	5873.19
922231.91	401313.29	0.11	0.05	10510.78	4573.81
4250702	1850717.4	0.21	0.09	21489.98	9356.54
3139458.1	1366785.9	0.22	0.1	21832.8	9505.07
215143.72	93518.69	0.05	0.02	4689.52	2038.44
6345406.6	2762970.4	0.28	0.12	28023.27	12202.13
190836.42	82941.97	0.03	0.01	3105.55	1349.75
Total				**159713**	**69521.64**

The average yearly nutrients in the Grootdraai Dam are calculated from measured N and P quantities found in the water of the dam. The yearly N and P averages are calculated from measured data for a period of 20 years, as shown in Table 4.13. The yearly nutrient averages were used to calculate the average annual nutrients in the Grootdraai Dam as shown in Table 4.13. Average annual P measured in the Grootdraai Dam are calculated at 0.077 mg/l and yet the permissible limit for P in water is 0.005 mg/l. Average annual N measured in the dam are 0.981 mg/l, yet the permissible limit is 0.040 mg/l. Therefore, agriculture nutrients found in the waters of the Grootdraai are very high, compromising the water quality of the dam, affecting its multiple uses.

Table 4.13: Measured average annual dissolved agricultural nutrients in the Grootdraai Dam (mg/l)

Year	*P (mg/l)*	*N (mg/l)*
1988	0.086	1.221
1989	0.073	0.938
1990	0.052	0.943
1991	0.086	0.981
1992	0.063	0.897
1993	0.068	0.962
1994	0.047	0.730
1995	0.050	0.761
1996	0.095	1.072
1997	0.068	1.071
1998	0.076	0.976
1999	0.054	0.756
2000	0.065	0.720
2001	0.163	1.844
2003	0.055	0.755
2004	0.061	0.761
2005	0.047	0.726
2006	0.077	0.727
2007	0.164	1.792
2008	0.085	0.983
Total	**1.535**	**19.616**
Average	**0.077**	**0.981**

Chapter 5

5 DISCUSSION

5.1 INTRODUCTION

There are a number of important environmental and agronomic factors to be considered in dealing with water pollution. Together these factors in the long run affect the quality of water in rivers, lakes and dams. Some of these factors include climatic conditions, such as the amount of rainfall the area receives, soil properties, type of agriculture practised, type of crops and water management among others. Hence there is a need for a thorough understanding of the interaction of these factors if water pollution can be effectively reduced. In this chapter the results obtained will be discussed and critically analysed.

5.2 AGRICULTURE NUTRIENTS IN WATER

5.2.1 Nitrates

To better understand the dynamics of nitrates in the waters of the Vaal River the data obtained from the DWA was grouped into two decades. The first decade stretches from 1988 to 1997, and the second decade stretching from 1998 to 2007. As explained in section 4.11 the nitrate concentration in the water was generally high, ranging between 0.73mg/l in 1994 and 1.22mg/l in 1998.

The high concentration of nitrates in the Vaal River coincides with two very crucial periods of the cropping season in the commercial farms. Nitrates concentration is high from October to April and this corresponds with the farming season. During this period, commercial farmers start planting and hence it is during this time that they start applying fertilisers to their farms. This could probably be the cause of the observed high trends in the concentration of nitrates. The second event is a climatic one. During this period the study area also experiences a gradual increase in the amount of rain received generally above 70mm from October through to March. Since nitrates are highly soluble in water the probability is very high that not all of the fertiliser applied during this period is absorbed by plants as intended. Some of this fertiliser is probably washed by surface runoff directly into the water, increasing the concentration of nitrates in the water as observed and analysed.

According to Johnson, (1987) plants only use 50–70% of the amount of applied fertiliser. The remainder is either transported by erosion or runoff which could be responsible for the trend observed in the Vaal River.

In normal circumstances where nitrate concentrations are found in permissible levels they are good for plant nutrition and are responsible for a healthy aquatic system. However, in higher concentrations it has the potential to cause tiredness chronic in nature, in extreme cases cyanosis and difficulty to breathe may occur in bottle fed infants (DWAF, 1996g). Higher concentrations of nitrates, together with phosphates may cause nutrient enrichment to water bodies thereby stimulating growth of algae which may be associated to bad odours and poor water taste (DWAF, 1996g).

5.2.2 Phosphorous

Normal level of Phosphorous concentration is necessary for plant and animal growth as it stimulates growth of biota leading to an increase in consumer populations such as fish hence leading to an improvement in the water body's quality of life. However, levels higher/above the tolerable concentration may have detrimental effects on aquatic system, like accelerating algal bloom and water weeds leading to a depletion of available oxygen (DWAF, 1996a). According to Sawyer, (1947) and Vollenweider, (1968) surface water concentrations of inorganic P and total P between 0,01mg/l and 0,02mg/ l are considered critical values above which eutrophication is accelerated. Bearing this in mind the concentration levels recorded in Grootdraai are way higher than the above critical values, making the Vaal River highly prone to eutrophication.

Just like nitrates, higher phosphorous concentrations occur during the period from October to March. This could possibly be as a result of farmers applying two much fertiliser during this period, leading to an increase of these nutrients in the soil. It is during this period when rainfall season begins and according to Sharply *et a*l (1992) export of P in runoff occurs in particulate and dissolved forms eroded during flow events. This constitutes a major proportion of transported form of nutrients from cultivated land. As a result it is highly probable that the higher concentrations observed during the periods of higher rainfall could be as a result of this form of transport.

5.3 FERTILIZER USE

The study has observed that commercial farmers in the study area, the Grootdraai Dam Catchment, use a variety of fertilisers. This use of a variety of fertiliser as shown in Table 9 is an indication that large quantities of fertilizer are being used at Standerton farming community. Figure 9 shows that the most commonly used fertiliser is Sasol KN and Sasol 434. An analysis of the contents of each fertiliser used showed that Sasol KN has the highest content of Nitrogen of 280g/kg, while Sasol434 has 120g/kg. Hence the continued use of these fertilisers could lead to nutrient enrichment of the soils and consequently water bodies.

Fertilisers are applied routinely during the farming season. Most farmers indicated that they apply fertilisers during the beginning of the season, between October and November and then thereafter application is per need. However not all farmers knew which type of fertiliser they were using on their farms. This shows that farmers lack knowledge on the basics of fertiliser application and use. Most of the farmers, about 69%, have been applying fertilisers in their farms for over 5 years. This could probably explain the high concentration levels of nitrogen and phosphorous in the water.

In most of the farms it was observed that application of fertilisers is done by farm workers who are not trained in handling and application of fertilisers. This practice could easily lead to excessive use of fertiliser. There is a lack of agricultural extension workers to visit farms regularly to advice, train and monitor the farm workers or farmers to effectively use fertilisers. In general the farmers rely on different sources of information for information on the use and application of fertilisers.

Excessive use of fertiliser leads to soil and water pollution. This can lead to nutrient enrichment which in turn results in algal blooms. These algal blooms may lead to the depletion of oxygen in the water and consequently causing the death of aquatic organisms. In the Vaal River seasonal algal blooms have been observed although death of aquatic organisms has not been observed. However, if the trend continues the problem of fish death maybe observed soon.

5.4 NEARNESS OF FARMS TO THE RIVER

According to studies conducted by Petersen *et al* (1987) in agricultural areas, buffer zones have almost been eliminated. The determination of the closeness of farms to the Vaal River helped to establish how much of the riparian zone had been destroyed in the study area. Buffer zones help to absorb or retain most of the pollutants from the farmlands. Hence their elimination means that most of the pollutants cannot be retained, entering into the water bodies directly from croplands during and after heavy rains.

In the Grootdraai Dam Catchment 56% of the commercial farms are located between 0–5m from the river as shown in Table 8. This shows that most of the buffer zones in this area have been destroyed, allowing the free flow of pollutants from agriculture fields into the water system.

However levels higher/ above the tolerable concentration have detrimental effects on aquatic system, like accelerating algal blooms and water weeds leading to a depletion of available oxygen (DWAF, 1996a). According to Sawyer, 1947: Volleywieder (1968) surface water concentrations of inorganic P and total P between 0, 01mg/ l and 0,02mg/l are considered critical values above which eutrophication is accelerated. Bearing this in mind the concentration levels recorded in the Grootdraai Dam are way higher than the above critical values making the Vaal River highly prone to eutrophication.

Higher pollutant concentrations occur during the period from October to March; this could possibly be due to farmers applying fertilisers in excess during this period. This leads to an increase of nutrients in the soil which plants cannot absorb. During this time the rainfall season begins and according to Sharply *et al* (1992), export of P in runoff occurs in particulate and dissolved forms eroded, during flow events. This constitutes a major proportion of transport from most cultivated lands. Considering this, it is highly probable that the higher concentrations observed during the periods of higher rainfall could be as a result of this form of transportation of these nutrients. The destruction of the buffer zones in this part could be one of the reasons why the seasonal concentrations of N and P in the water is high during the rainy season and slowly decrease as winter approaches with very low or no rainfall at all.

The destruction of buffer zones in the study area is a cause for concern. One wonders why these buffer zones have been destroyed. Perhaps the only possible reasons could be lack of awareness on the part of farmers on the role these riparian zones play in preventing water pollution or over nourishment of the river system or the need by farmers to increase production to meet the ever increasing population. The other possible reason could be a lack of personnel to enforce laws that protect the environment.

5.5 OBSERVATION OF VAAL RIVER AND ITS TWO TRIBUTARIES

During the study, the Vaal River and two of its tributaries within the study area were monitored for any signs of algal activities. The two tributaries were targeted because they are surrounded by farmlands and enter the Vaal River within the study area meaning whatever pollution they have, will end up in the Vaal River. As can be observed in Figure 4.4, taken in March 2013 these are very little algal blooms that can be seen in the tributary. The same little amount could be observed in Figure 4.6 taken during the same time from the second tributary. The same trend is observed in Figure 4.8 taken from the Vaal River during the same period. It has been established that during this period the concentration of P and N are high in the water. Perhaps during this time the algae start to grow gradually as P and N become readily available.

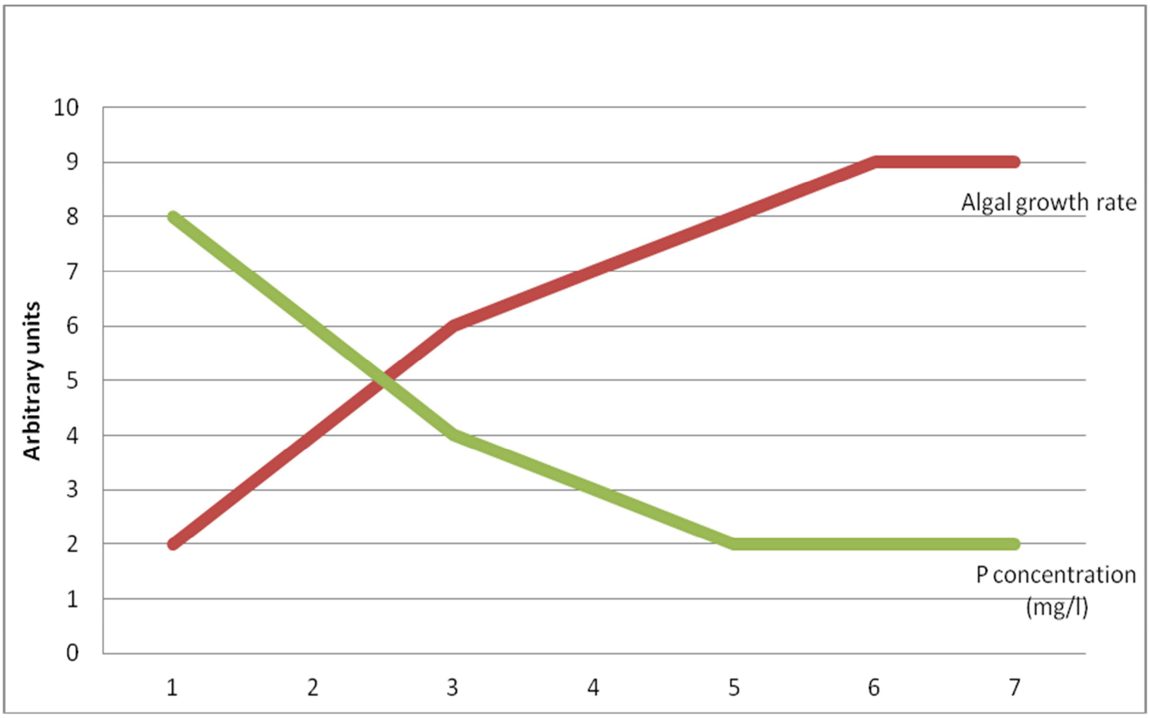

Figure 5.1: Relationship between algal growth rate and the nutrients concentration in the water

The relationship between P and N concentration and growth rate of algae is an inverse one as shown in Figure 5.1. That is to say from January to June the concentration of P and N declines, gradually while during the same period the amount of algal blooms observed in the river seems to increase gradually. This could be because during periods of high concentrations of P and N algae begin to absorb these nutrients which they require for their metabolic processes and growth. Then gradually algae begins to flourish with time, by then as the algae population increases more nutrients are absorbed from the water leading to a steady decline in the concentration of P and N. From August to October the algae population could have possibly reached maximum growth rate and hence begin to die as oxygen is also gradually declining. Figure 23 below shows the relationship that exists between algal growth rate and P and N concentrations. The units used are arbitrary.

It is observed that the nutrients minimum levels correspond with the maximum algal growth rate, meaning that it is during this period that corresponds with the highest population of algae. This means that large amounts of nutrients are absorbed by algae leading to a low concentration in the water. When the algal population begins to decline the levels of the nutrients concentration begin to slowly rise possibly because some algae on their death recycle these nutrients back into the water. This coupled with the beginning of the farming season eventually cause the nutrient levels to increase in the water as has been observed during the study period.

Chapter 6

6 CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

The area around Standerton Town is a very important commercial farming area. Farmers in the area use fertiliser to improve crop yields and pesticides to prevent crop damages. To further boost crop yields, land in the study area has been severely altered for agricultural purposes and buffer zones from water sources have been destroyed to maximize production. This study has estimated the contribution of the agricultural activities to the poor water quality of the Vaal River within the Grootdraai Dam Catchment and their impact on the whole aquatic system. The study has explored the current capacity, competence and commitment of farmers to achieve compliance with the environmental legislation governing water management.

To achieve the objectives of the study a survey was carried out to determine the type and amount of fertiliser used by farmers. The survey was random and captured from fifteen commercial farmers. The distance between the water-bodies and the farmlands was determined through this survey and physical observation. It was established that farmers could be using excess fertiliser as untrained farm workers are the ones charged with the application of fertilisers.

The distance between the farms and water-bodies was also found to be too small and the buffer zones no longer exist. A regular observation of the river was also done to detail any algal bloom activities.

Data collected from the DWA was analysed for nitrates and phosphates concentrations in the water. The data obtained was divided into two decades for analysis. Yearly average concentrations were calculated for the first decade from 1988 to 1997 and then compared to monthly means for the second decade 1998 to 2007. For the nitrates the two values were different and a statistical analysis was done and the difference between the two means found to be statistically insignificant although the concentration of nitrates was high.

For phosphorous the values for the two means were also found to be different and as such a statistical analysis was also done and the difference was found to be statistically significant. All this data was analysed aiming to establish the link between each factor investigated.

Monthly average rainfall for the study area was also analysed and correlated to the occurrence of higher concentrations of agrochemicals in the water. It was established that there is a positive correlation between the months of high rainfall and the months of higher concentrations in the water.

General information on the study area was also obtained through informal interviews with farmers, farm workers and other stakeholders. A survey was also conducted on the general population where a random sampling method was used to select the sample. The survey showed that the water delivered to the general population was of poor quality, producing an unpleasant odour and sometimes muddy.

The data that was collected can be used to create awareness among farmers to control water pollution and promote sustainable use of the natural resources such as water. This is also necessary to create a more sustainable and efficient use of agrochemicals.

6.2 CONCLUSION

From the study the following conclusions can be made:

- Analysis of data from the Vaal River showed that water was polluted by nutrients and phosphates from runoff due to high use of fertilisers. Considering data from DWA, questionnaires and the literature review, it can be concluded that pollution by nutrients (P and N) in the Vaal River is evident as shown by the high concentration of P an N in the water and the observed algal blooms during the period of study.

- The study shows that the Vaal River is actually at a risk of direct pollution from agrochemicals due to unrestricted use of fertilisers. The most frequently used type of fertiliser has higher quantities of N and P and as such higher concentrations of the said nutrients are relatively high.

- The study revealed that the quality of water received by the local population in Standerton is of poor quality as the water produces a foul smell at times. The foul or odour can be attributed to dead algae.

- The study showed that there was a general lack of knowledge on fertiliser application which is responsible for nutrient enrichment.

- The study showed that there is little commitment to achieve compliance as evidenced by the destruction of buffer zones, which help to reduce amount of nutrients directly entering the river by acting as sinks for such nutrients between farmlands and the river.

- Environmental problems are generally related to human activities in the resource exploitation resulting in the degradation of the environment if not exploited responsibly. The problem of poor water quality in the Vaal River are as a result of poor farming methods by both commercial and subsistence farmers, and also of the responsible authority by failing to enforce legislation.

- The conducted survey showed that there are no enough agricultural extension workers to train, monitor and regulate the use of agrochemicals in the study area.

6.3 RECOMMENDATIONS

- Since the study did not do any tests or analysis of pesticides it is recommended that further study be conducted to quantify the effects of pesticides with the study area.

- The DWA together with the department of agriculture should consider deploying extension workers on a regular basis to educate, monitor and enforce regulations related to the pollution and use of agrochemicals.

- Buffer zones should be protected in order to control soil and agricultural nutrients and pesticides from entering water-bodies.

- Farmers should become less dependent on chemical fertilisers. Other forms of fertiliser like green fertilisers should be introduced to reduce the amount of chemicals finding their way into the river. Biological methods should be introduced for pest control. This is a natural way of controlling pests by using their natural enemies referred to as biological control agents. This process involves the rearing and realising natural enemies of those pests which need to be controlled, for example a small wasp can be used to control the corn borer

- There is a great need to increase awareness among farmers towards environmental protection and sustainable water management.

- Farmers could try to prevent the leaching of nutrient after the growing season by increasing the area under autumn/winter green cover.

- The Department of Agriculture and the Department of Water Affairs (DWA) should promote or subsidise better fertiliser application methods and develop new environmentally sound fertilisers and promote regular soil testing.

- Farmers should be educated on the rational nitrogen and phosphorus application which can be calculated on the basis of the crop nitrogen balance taking into account the plant needs of the nutrients.

- The DWA should decentralise the testing and monitoring of water quality to municipal authority so that Municipalities can have direct access to the testing facilities and therefore be responsible for ensuring good water quality management programmes are developed and implemented. This could be achieved by building sound laboratories within each local Department of Water Affairs.

- The DWA should embark on a large scale recruitment and training of personnel to assist in collecting and processing water samples from different points as lack of trained personnel emerged to be one of the major factors contributing to the Lekwa Municipality being unable to collect and process water samples.

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APPENDICES

APPENDIX 1: Questionare for the local farming community of Standerton for the research project (UNISA) to be filled independently (Afrikaans version).

1. Watter tipo boedery spesialiseer jy in?
   Diere veeteelt ☐ Plante veeteelt ☐ Gemengde boerdery ☐

2. Hoe ver is jou plaas van die Vaal Rivier?
   0 km – 5 km ☐ 5 km – 10 km ☐ 10 km – ☐

3. Waar is jou beeste pan, vark hok, vuilrun in verhouding tot die Vaal Rivier?

   0 km – 5 km ☐ 5 km – 10 km ☐ 10 km -15 km ☐

4. Watter tipe kunsmis gebruik jy op jou plaas?

   ....

   ....

5. Hoeveel van hierdie kunsmis doen jy aansoek per boerdery – season per hektaar?

   ....

   ....

6. Vir hoel lank gebruila jy hierdie tipe van die kunsmis?

   ....

7. Hoe gereeld gebruik jy tipe van die kunsmis?

   Elke boerdery seisoen ☐ Ander, spesifiseer ☐

8. Dink u dat , u het genoeg keanis oor die volgende: Hoe om die kunsmis te gebruik

Nie genoeng ☐ Genoeg ☐ Nie seker nie ☐

a. Hoeveel kunsmis te gebruik per hektaar vir verskillende plante.
Nie genoeg ☐ Genoeg ☐ Ni esker n☐

b. Wanneer moet die kunsmis gebruik
Nie genoeg ☐ Geno☐ Ni seker nie☐

9. Hoe het u die inligting van die kunsmis gekry?

....

....

10. Is daar a forum waaria die boere die inligting gekommunikeer?

....

11. Hoe word die inligting aan die boere gekommunikeer?

....

....

12. Hoeveel per week of per maad word die inligting aan hulle gekommunikeer?
....
....

Baie dankie u die vorm gevoltooi.

APPENDIX 2: Questionnaire for the local farming community of Standerton for the research project (University of South Africa) to be filled independently. (English version).

1. What type of farming do you specialise in?

   Animal husbandry ☐ Plant husbandry ☐ Mixed farming ☐

2. How far is your farm from the Vaal River?

   0km – 5km ☐ 5km -- 10km ☐ 10km --- 15km ☐

3. Where is the your : a) cattle pan, b) pig sty, c) foul run in relation to the Vaal River?

   0km – 5km ☐ 5km -- 10km ☐ 10km --- 15km ☐

4. Which type of fertiliser do you use on your farm?

   ....

   ....

5. How much of this fertiliser do you apply per farming season per hectare?

   ....

6. For how long have you been using this type of fertiliser?

   ....

7. How frequent do you use this fertiliser?

   Every farming season ☐ other, specify ☐

8. Do you feel like you have sufficient knowledge on?

   a) How to apply the fertiliser.

   Insufficient ☐ sufficient ☐ Not sure ☐

   b) How much to apply per hectare for different crops

   Insufficient ☐ Sufficient ☐ Not sure ☐

   c) When to apply it.

Insufficient ☐ Sufficient ☐ Not sure ☐

9. How did you acquire such information?

....
....
....

10. Is there a forum where information is communicated to farmers?

....
....
....

11. How is information communicated to farmers?

....
....
....
....
....

12. How often is information communicated to farmers?

....
....
....

Thank you for your co-operation.

APPENDIX 3: Questionnaire for local residents of Standerton on water quality for the research project to be filled independently**.**

1. What is your understanding of water quality?

   ....

   ....

2. Does tap water sometimes have a bad test?

   Yes ☐ No ☐

3. Does tap water sometimes have a foul smell or odour?

   Yes ☐ No ☐

4. What is your opinion of the water quality supplied by the Lekwa municipality?

   Poor ☐ Good ☐ Not sure ☐

5. Have you brought your concerns to knowledge of the relevant authority?

   Yes ☐ No ☐

6. What do you think could be the cause of the state you described above?

   ....

7. Have you at any given time observed any excess of growth of plants in the Vaal River? E.g. Green algae.

   Yes ☐ No ☐

8. Have you at any given time seen any dead aquatic organisms in the river? e.g. fish?

   Yes ☐ No ☐

9. If any, in which section of the river have you observed that?

   ....

10. At what time of year did you observe any of the above? E.g. Month?

....

11. What do you think could be responsible for all this above?

....

12. What do you think could be the solution to all this?

....

APPENDIX 4: Questionnaire for the Lekwa Municipality water authority for the research project to be filled independently.

1. What is the general state of affairs in the Vaal River?

   ....

   ....

   ....

   ....

2. When the last time water was tested for phosphates and nitrates and what was the outcome?

   ....

   ....

   ....

   ....

   ....

3. How often does the municipality carry out these phosphates tests?

   ....

4. What are the parameters used to guide the tests?

   ....

   ....

5. Is it possible to access the results of the previous 20 year tests?

   ....

6. What do you think could be affecting the quality of water in the Vaal River?

   ....

   ....

7. Is there any monitoring instrument on the operation of farmers along the Vaal River?

....

8. Is there any environmental legislation governing farmers operation in such areas?

    ....

9. Are there any visits paid to the farms to ensure compliance with said legislation?

    ....

10. How often are these visits scheduled?

    ....

11. Do you organise any workshops to ensure awareness on river pollution and possible solutions?

    ....

12. How often are these organised?

    ....

APPENDIX 5: The procedure to for t-test

Step 1:

Get the sum of the yields for each decade and then the mean.

Step 2:

Calculate Correction Factor (CF)

= (Sum for decade 1) ^{2}/number of observations); (Sum for decade 2) ^{2}/number of observations)

= (9.576) ^{2}/10; (10.04) ^{2}/10

Step 3:

Square each value to calculate the Sum of Squares for each decade.

Step 4:

Calculate Standard Error (SE):

= Square root {(Sum of Squares - CF) / (Observations - 1)}

= square root {(9.360594-9.1699776) / (10-1)}; Square root {(11.825152-10.08016) / (10-1)}

Step 5:

We have two Standard Errors. Calculate the pooled SE. Pooled SE = SE1 + SE2 / 2

= (0.048510709 + 0.146775717)/2

Calculate Standard Error of Diff. SED = Pooled SE x {Sq.root (2/No. obs)}

SED = 0.097643213x {Sq.root (2/10)} SED = 0.043667372

Step 7:

Calculate the’t’ value’t’ = Mean Difference / SED

= (1.004-0.9576) / 0.043667372

= 1.062578247

Step 8:

Now we found that calculated’t’ = 1.062578247

Now compare Calculated’t’ value with table’t’ value for 18 df {(10-1) + (10-1)} at 5% probability (table’t’ value = 2.10)

Therefore since t value calculated < t table value then the difference between the two nutrients is not significant.

How to make a decision

Based on the comparison of calculated't' value with the theoretical't' value from the table, we conclude:

1. If the calculated't' value is greater than the theoretical't' value, then the difference between the two treatments is significant. This means the difference is not likely due to chance but more likely due to a real difference between the two treatments.

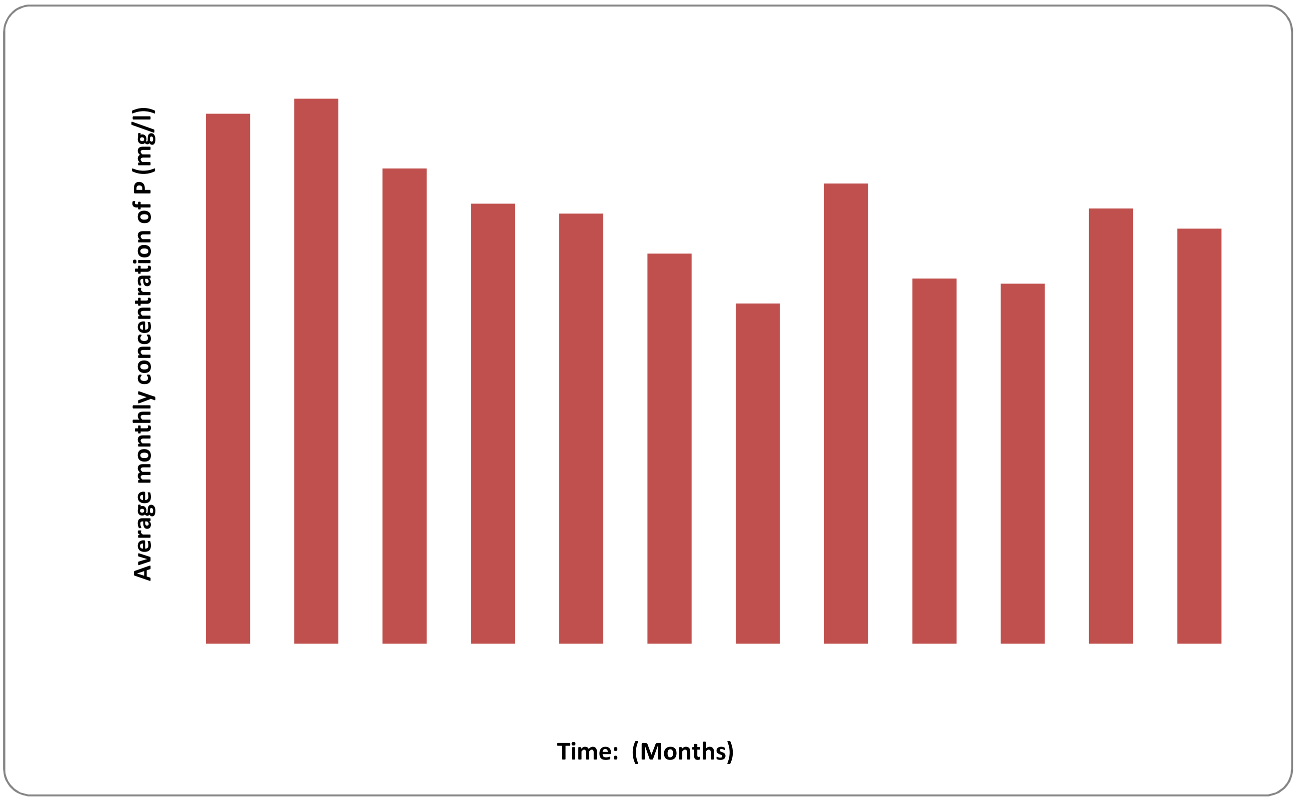
2. If the calculated't' value is less than the theoretical't' value, then the difference between the two treatments is not significant. This means the observed difference is more likely due to chance and we conclude that the two treatments are not different.

APPENDIX 6: T - Test table

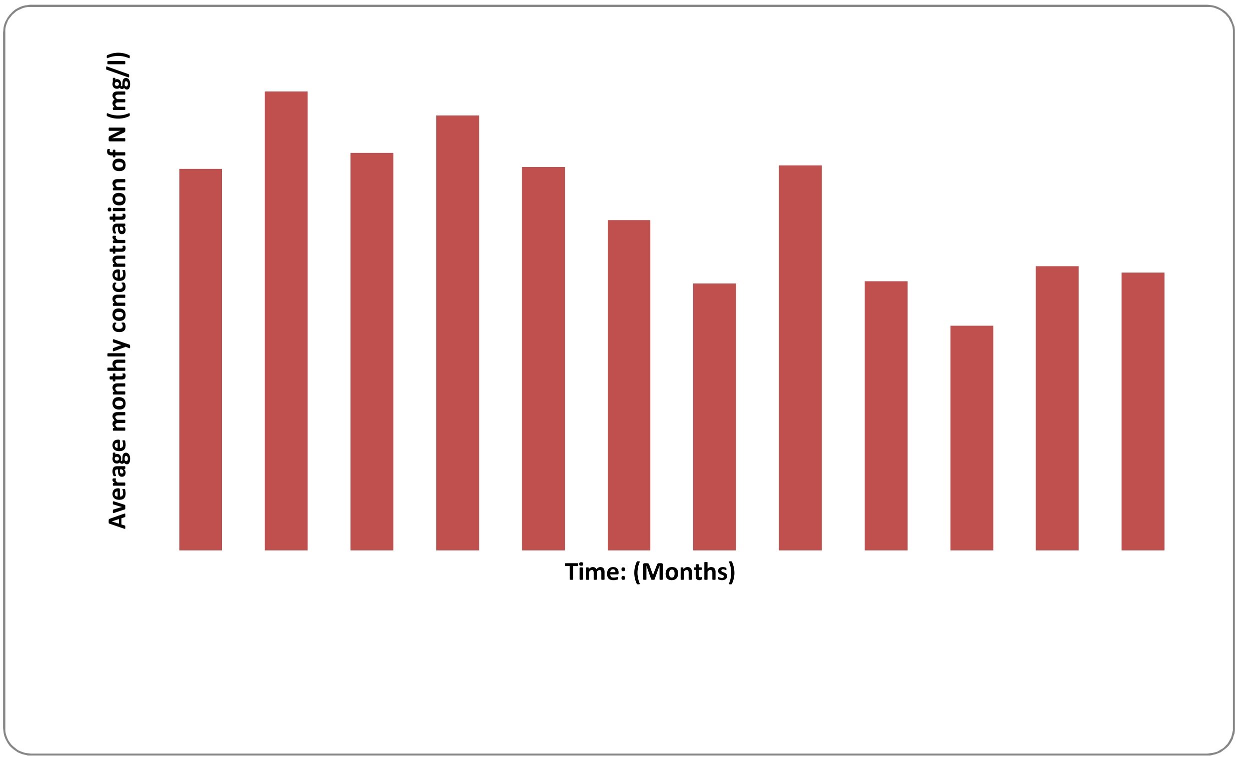
t Table	$t_{.50}$	$t_{.75}$	$t_{.80}$	$t_{.85}$	$t_{.90}$	$t_{.95}$	$t_{.975}$	$t_{.99}$	$t_{.995}$	$t_{.999}$	$t_{.9995}$
cum. Prob											
one tail	0.50	0.25	0.20	0.15	0.10	0.05	0.025	0.01	0.005	0.001	0.0005
two tail	1.00	0.50	0.40	0.30	0.20	0.10	0.05	0.02	0.01	0.002	0.001
df											
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	22.327	31.599
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.208	5.956
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.000	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0.000	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.000	0.695	0.873	1.079	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.000	0.694	0.870	1.076	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.000	0.692	0.868	1.074	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	0.000	0.691	0.866	1.071	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0.000	0.690	0.865	1.069	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.000	0.689	0.863	1.067	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.000	0.688	0.862	1.066	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.000	0.688	0.861	1.064	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0.000	0.687	0.860	1.063	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	0l.000	0.686	0.859	1.061	1.323	1.721	2.080	2.518	2.831	3.527	3.819

22	0.000	0.686	0.858	1.060	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.000	0.685	0.858	1.059	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	0.000	0.685	0.857	1.058	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0.000	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	0.000	0.684	0.856	1.057	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.000	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.000	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.000	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0.000	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	0.000	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0.000	0.679	0.848	1.045	1.296	1.671	2.000	2.390	2.660	3.232	3.460
80	0.000	0.678	0.846	1.043	1.292	1.664	1.990	2.374	2.639	3.195	3.416
100	0.000	0.677	0.845	1.042	1.290	1.660	1.984	2.364	2.626	3.174	3.390
1000	0.000	0.675	0.842	1.037	1.282	1.646	1.962	2.330	2.581	3.098	3.300
z	0.000	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.090	3.291
	0%	50%	60%	70%	80%	90%	95%	98%	99%	99.8%	99.9%
	Confidence Level										

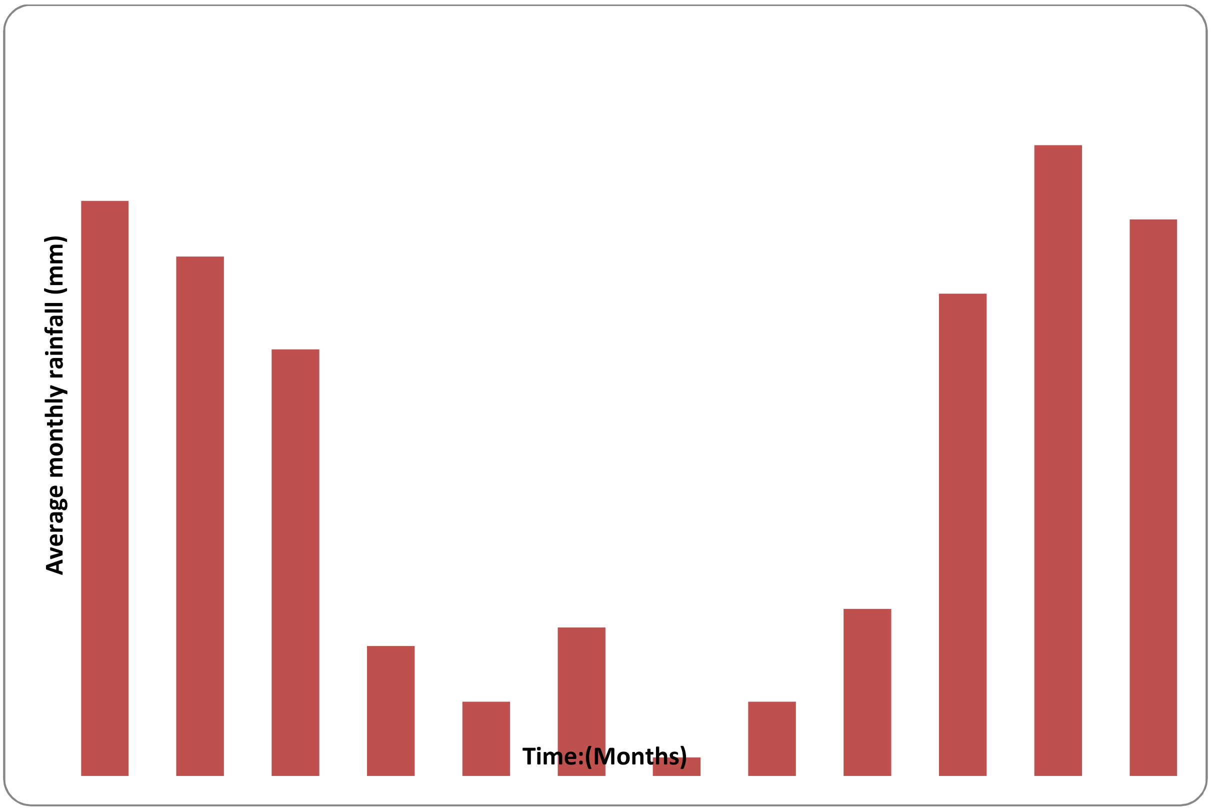
APPENDIX 7: Average monthly concentration of P in the Grootdraai dam



APPENDIX 8: Average monthly concentration of N in the Grootdraai dam



APPENDIX 9: Average monthly rainfall in Standerton



APPENDIX 10: Average monthly temperature in Standerton