DYNAMICS OF EPHEMERAL PONDS AND SUITABILITY FOR IRRIGATION IN THE VRYBURG DISTRICT, SOUTH AFRICA

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DECLARATION

I solemnly declare that the work contained in this thesis is from my own initiative and creation. All the sources, references and assistance have been accordingly acknowledged. Furthermore, I declare that I have not copied any ideas or information without acknowledging the source.

Signed Date

DEDICATION

I dedicate this thesis to my sister Beatrice Krobi Owiredu for her concern, support towards my education, to my wife Doris, for her support and prayers, and my daughters, Akua and Nicky, and my son, Junior, for their interest in my doctoral studies.

ABSTRACT

South Africa is a semi – arid country and most parts of the country, including the study area, are dry due to water scarcity. This situation has adversely affected food security, social and economic development of Vryburg District. During the short rainy season that occurs from October to March, ephemeral ponds form in many places. This pond water is not beneficially utilized and is lost through evaporation and infiltration. The main objective of this study was, therefore, to determine the suitability of the pond water for irrigation.

Goggle Earth was used to identify all ponds in the study area. This was followed by the use of the phase file to map the distribution of the ponds. It was found that the distribution of ponds depended on rainfall intensity, soil characteristics and the nature of the underlying rock. Five ponds were selected for study from 22 originally considered. The criteria used to select the 22 ponds were: proximity to major road, longevity and size of the pond (> 2ha).

ASTER 30-m resolution digital elevation system model (DEM) data were used to extract slope length and height of each selected pond. The DEM was also used to demarcate the catchment area of each selected pond. Furthermore, remote sensing was used to display LULC of the individual pond in the sub catchment from 2004 - 2013. The main land cover classes were woody plants, grass, bare area, built-up area and water. There was an increase in the area covered by woody plants. This was attributed to bush encroachment. Over-grazing was believed to be the reason for reduction of grass cover to create bare areas. Increase in the area covered by water was due to seasonal and daily variability in rainfall. Finally, there was an increase in the size of the built-up area which could be attributed to construction and migration of people to urban areas.

In addition, the relationship between LULC and water quality was investigated. Water samples were collected from the 5 ponds and chemical and biological contaminants were analysed. All the chemical data were within the recommended range specified by DWAF and FAO (Na^+40.5mg/l, K^+ 3.16mg/l, NO_3- 0.45mg/l, Cd 0.03mg/l.) except for cadmium. *Escherichia coli* counts were below the recommended value set by WHO (78 counts/100 ml). The results were combined with land cover change to run multi-linear regression equations to determine the effect of LULC on water quality of pond water. When the R^2value was 0.89,

grass as well as bare area had no effect on nitrate concentration in the pond water. Similarly, ($p<0.58$) grass and bare soil had no effects on electrical conductivity in ephemeral pond water and the R^2 value was 0.78. Furthermore, Na^+ in water did not depend on grass or bare area with R^2value of 0.92. In addition, grass and bare area did not have any impact on cadmium concentration in the pond water ($p<0.85$). In addition only 45% of the data could be accounted for by the equation. Lastly, grass and bare area had significant effects ($p<0.006$) on *E. coli* abundance (R^2=1).

Additionally, the Darcy's equation for infiltration rate, Penman's method for evaporation rate, and the depth of water column were used to model an equation on water balance in the ponds. This was tested in the field and was found that the water in ponds A, C and D could last below 42 days hence was not suitable for irrigation. The water in pond B lasted for50 days and could be used to grow short seas – seasoned crops. The water in pond E lasted for 69 days. The water could be used to grow short – seasoned crops and some vegetables. However, the water from all the ponds could be suitable for irrigation when it is used in the middle of the rainy season. The water can also be used to supplement irrigation during dry spell in the cropping season.

Climatic data such as rainfall, temperature, wind speed and evapo-transpiration were collected and standardized. The standardized Precipitation Index (SPI) was used to standardize the rainfall data. SPI revealed periods of above average (706 mm), average (415 mm) and below average rainfall (234 mm). The results were combined with water depth information and the data from water analysis to develop suitability indices for irrigation. Consequently five regimes were obtained. Ponds A, C and were not suitable for irrigation, C was suitable for irrigation only through soil, water and crop management. Pond D&E were suitable for irrigation due to the greater water depth and good water quality.

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CHAPTER 1

INTRODUCTION

1.1. Background

According to the Council for Scientific and Industrial Research (2012) and Statistics South Africa (2010) irrigation alone uses more than 50% of the total water supply in South Africa. However, this situation does not auger well for the country considering that water is required for other uses such as domestic, urban, mining and industries. According to SA (2010), South Africa water usage is at 82% capacity. Most of the water supply in South Africa comes from rainfall, rivers and dams. Unfortunately, this water resource is not enough for all the water users. .

Agriculture alone consumes more the 50% of water available in South Africa (Statistics South Africa, 2010). Water use in agriculture is characterized by technical and system inefficiency and wastage (Walter *et al*, 2011). This state of affairs cannot be sustainable in the face of a high backlog of 14 million people that lack potable water supply and sanitation (Barradas & Creamer Media, 2011). The consumption of domestic water has risen sharply since 1994. This is due to the implementation of the Reconstruction and Development Programme (RDP).In order to ensure equitable water supply to all South Africans, the government has made efforts to distribute water to the traditionally water-scarce areas. Unfortunately, a lot of water is unaccounted for due to theft and wastage.

South Africa experiences very low amount of rainfall with a mean annual rainfall less than 500 mm (Council for Scientific and Industrial Research, 2012). Rain falls mostly in summer from November to February except for Cape Town that receives its rainfall in winter (May to August). The rainfall occurs in sporadic thunderstorms with very little water being absorbed into the soil. In addition, the greater part of the water is lost through surface evaporation and runoff. Kwazulu-Natal and areas along the eastern coast record an average annual rainfall of 800 mm but this value decreases towards the western parts of the country. Despite the low annual rainfall the country receives, our freshwater resources are threatened by pollution and acid mine drainage

(Fouche & Vlok, 2010; Mathee, 2011). As a result of the low rainfall, the government has embarked on strategies to conserve water. These include the building of dams to supply water for irrigation, mining, industries and domestic uses. Water is also being channeled from Lesotho to the industrial areas of Gauteng. According to Kulkarm (2011) and Knox *et al.* (2013), there has been increasing pressure on governments worldwide to bring about efficiency in irrigation. This will go a long way to make water available for domestic use since irrigation alone consumes more than 50% of the available freshwater in South Africa.

Due to the low annual rainfall the country experiences, it can be regarded as a semi-desert country. Consequently, South Africa can only pursue its sustainable development programme by introducing serious water conservation strategies. These may include reducing water loss, wastage and improving efficiency in water use. Thornton *et al.* (2011) stated that acute water shortages would be experienced in the near future in most of the third world countries to the extent that it will affect food security. As such, careful planning and strategies must be implemented to avert serious effects on livelihoods. Some of the recommendations for water conservation in South Africa include awareness campaigns, reduction of daily water usage, rainwater harvesting and water rescheduling in irrigation (SA, 1998). Furthermore, water conservation pricing is believed to reduce water consumption considerably. This involves rewarding individuals and institutions that reduce their water use and imposing higher rates on others whose water use is not acceptable. Hence, there is the need to look for other sources of water. Some of the alternative sources of water are desalination of seawater, groundwater, diverting of water from other countries and rainwater harvesting. Desalination could be a possible option. SA (2013) added that by the year 2030 desalination could contribute to 10% of the total urban water supply. Desalination is currently taking place in Durban and Port Elizabeth. Nevertheless, desalination for agriculture can be costly. Bhausaheb *et al.* (2011), therefore, recommended reverse and forward osmosis method to save cost. Besides, water will have to be transported over long distances. Hence, consideration could be given to groundwater.

Groundwater is a useful resource for domestic water and ecosystems (Ghanem & Samhan, 2012). For example, in South Africa it is used to irrigate about 24% of the total land area that is under irrigation (Council for Scientific and Industrial Research, 2010). However, the quality and quantity of groundwater are influenced by human and natural factors (Jiang *et al.,* 2009). It can also be contaminated with bacteria and heavy metals (Taghipour *et al.*, 2012). Gallo *et al.* (2012) stated that climate change would affect the quality and quantity of groundwater. It can, therefore, be inferred that groundwater cannot be a reliable source of water in South Africa and consideration can be given to importation of water from big rivers such as the Congo River. The river is clean and every year millions of metric tons flow to the Atlantic Ocean. Nevertheless, the costs of diversion can be very high. Therefore, one of the cheapest and easily available sources of water that may be useful to the small-scale farmer in South Africa is the use of ephemeral ponds for irrigation.

Ephemeral ponds are small temporary ponds that are formed due to runoff. The rate at which ephemeral ponds form and their longevity depends on climate, vegetation type and the nature of the watershed (Jocque *et al.,* 2010). In addition, they are characterized by temporarily variable volumes, surface areas, pH and temperature, low conductivity and are prone to regular changes in environmental conditions and pollution. Net flows occur between pond surface water and subsurface groundwater in response to both regional and local groundwater flow (Mansell *et a*l., 2000). Leonard *et al.* (2012) stated that ponds are usually over looked but they are of significance to humans and the environment. They serve as habitats to a variety of plants and animals that are threatened. Although the ponds are useful to certain organisms, they are temporary and when they dry up the organisms perish or migrate to other habitats.

1.2. Problem Statement

Vryburg District is located in the North West province of South Africa. It is rural, and characterized by low economic activities, high unemployment and poverty. The main agricultural activity is pastoral farming. The animals graze and browse on the grass and shrubs that grow during the short rainy season from October to March. Communal grazing is usually practised and this results in high stocking rate, over-grazing and poor veldt quality (Fyn & O'Connor, 2000) Furthermore, production per herd is low. Community members buy most of their foodstuffs from supermarkets or street vendors who bring them from other districts. The area is generally dry with average annual rainfall of 410 mm. Also the area experiences high temperatures ranging between 18.7°C and 32.5°C. Securing crop production from rain fed agriculture is impossible; hence agriculture is mostly sustained by irrigation. Due to the low retention capacity of the ponds they can only be used to irrigate small-scale agriculture such as growing vegetables and field crops.

In the arid and semi-arid environments such as the study area, the amount, timing and distribution of rainfall is irregular but water and access to it is a key factor in production (SA, 2015). Meanwhile, during the rainy season a lot of water collects in the ephemeral ponds and it is lost through evapo-transpiration and infiltration. The aim of the study is to explore the dynamics of the pond to improve their quality and quantity for irrigation. Due to the short retention capacity of the pond they could be used for small scale agriculture such as such growing of vegetables and field crops (maize, peanut and soybeans). Thus, use of irrigation would significantly improve and raise the level of production and consequently the livelihood outcomes; which cannot be in isolation of other livelihood assets.

Climate change will have serious consequences on agricultural production (Stevanovic *et al.*, 2016; Thornton *et al.*, 2011). Nevertheless, the effects will be more pronounced in Sub-Sahara Africa. The decrease in production will affect food security and result in malnutrition, especially in rural areas. The effects will be due to low and unreliable rainfall resulting in poor harvests from small-scale subsistence farming. Therefore, alternative sources of water need to be explored. Ephemeral ponds are formed as a result of runoff and can last as long as six months. These ponds are not utilized by humans, except for the fact that a few herdsmen use them to water their animals. Most of the water from these ponds is lost to surface evaporation and infiltration.

It is envisaged that the findings of the study will reveal the possible uses of the ponds and help mitigate the water challenges in South Africa. In addition, the use of ephemeral ponds will contribute to food security and reduction of poverty in rural areas. There is also a research gap with regard to the use of ephemeral ponds for irrigation. This may be due to the abundance of water in Europe and North America resulting in less attention being given to the possible contributions of ephemeral ponds. The research will, therefore, be useful for arid and semi-arid countries like South Africa.

1.3. Justification of the Study

Most rural communities, including the study area in South Africa, experience serious water shortages. This has affected food security and wellbeing of rural communities. Meanwhile during the short rainy season of October to March, ephemeral ponds form but the water is lost through infiltration and evaporation. It is believed that the water can be used for small – scale irrigation to produce vegetables and field crops such as maize, sorghum, and groundnuts. This can improve food production and food quality in rural communities. Excess foodstuffs can be sold and serve as a source of income to the people.

In addition, the Department of Agriculture Forestry and Fisheries (DAFF) has initiated vegetable production projects in the study area. The main source of water for these projects is groundwater, which could be saline with negative effects on crop production. This study will therefore, provide useful information that can be used by DAFF to achieve food sufficiency in the area. The research findings can also be useful to the Department of Health, Department of Social Services and NGOs that conduct similar projects in the province. Finally, the study will provide useful baseline data to academics who are interested in research into the uses of ephemeral ponds.

1.4. Research Purpose

The purpose of the study is to analyse the suitability of ephemeral ponds for irrigation in Vryburg District.

1.5. Research Objectives

- To map the spatial distribution of ephemeral ponds in the study area
- To determine their sizes, volume and lifespan
- To distinguish between land use/ land cover dynamics around the ponds
- To determine water quality in the ponds for irrigation
- To model water flow dynamics about pond quantity using climatic data

- To develop suitability thresholds/indices for water in ephemeral ponds for irrigation

1.6. Research Questions

Is it possible to map the spatial distribution of ephemeral ponds in the study area?

Is it possible to determine the sizes, volume and lifespan?

Is it possible to distinguish between land use/ land cover dynamics around the ponds?

What pond water quality is suitable for irrigation?

What water flow dynamics model can be developed about pond water quantity using climatic data?

What suitability thresholds/ indices can be developed for water in ephemeral ponds for irrigation?

1.7. Description of the Study Area

Vryburg District consists of many local municipalities that have been shown in Figure 1.

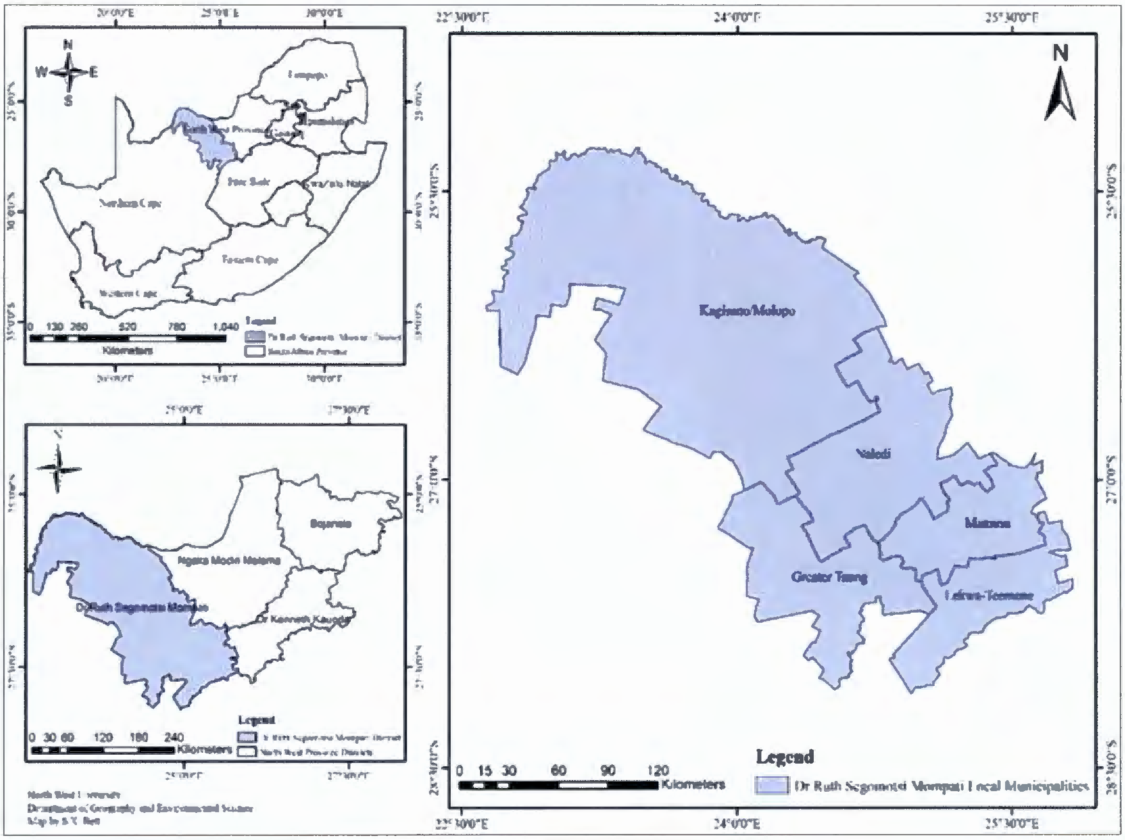

Figure 1: Map of Vryburg District

The study area is Vryburg District, a municipal district found in the North West province of South Africa. The area is located between 25° 16' 0^{S} -28° 6'0S and 22° 38' 0 E -26° 14' 0^{E}.

1.7.1 Environmental settings

Climate

The district is semi-arid and records a mean annual rainfall of 410mm. It experiences summer rainfall mainly from October to March and sometimes extends to April the following year. Rainfall is sporadic and sometimes it is accompanied by hail storm. Consequently dry land farming is not feasible except in the eastern part of the district where the annual rainfall is slightly higher, however, irrigation farming is practiced in Taung (SA, 2010). The mean day and night temperature in summer is 33°C and 18°C respectively. Winter is cool, with the mean day and night temperature being 19°C and 0°C respectively. The relative humidity is between 64%-66%

in February and about 28%-32% in July. Frost occurrence is a regular feature, between 31-60 days in winter. Also the rate of evaporation exceeds that of precipitation in the district (SA, 2015).

Geology

With regard to slope the area is flat with an average gradient of 15%. This may affect water volume in the ponds. Nonetheless in Magopela area next to Taung shows a steep slope. The geology of the area is also important to the study. The dominant rock is dolomite and it is responsible for the formation of underground water. Around Taung and Christiana areas the main rock type consists of a mixture of dolomite and andersite. In and around Vryburg, andesite, which is an intrusive igneous rock, dominates. Delareyville and its surroundings have rocks consisting of a mixture of siltstone, andesite and tillite. The eastern part of Ganyesa is dominated by tillite and then changes to dolomite and siltstone to the west (SA, 2010).

Soil type

Taung area consists of deep yellow apedal soil of depth between 0.45-0.75m. In addition, the southern part of Taung has red apedal soil with poor structure resulting in poor crop production. The western part of Vryburg is made of soils that are shallow, apedal, alkaline with poor structure. Moreover the presence of clay hampers crop production. Clay soil has a large bulk density that prevents infiltration, aeration and root development. Towards the eastern part of Vryburg, the soil is deep but it is not suitable for arable farming (SA, 2010). Vryburg area on the whole is not suitable for crop farming. The underlying soil consists of Glenrose and Mispah soil (SA, 2010). The soil is shallow, and the parent material is close to the soil surface. Hence the area has low agricultural potential. However, around Ganyesa; the soil is suitable for arable farming since there is red apedal soil, which is deep (Walmsley & Walmsley, 2002). But the western side consists of red, yellow and shallow soil. Rainfall and soil characteristics determine land use pattern in an area.

Land cover and vegetation

The major land use activities include beef farming; game farming while maize and vegetables are cultivated to a limited extent. Mucina and Rutherford (2016) describe the vegetation around

Taung as Ghaap Plateau Vaalos veld and South Kimberley Thornveld. The vegetation is of poor quality therefore, the area Taung Irrigation is used for grazing for cattle, sheep and goats. Areas situated at the Scheme produce field crops. The same veldt conditions are found from Vryburg, Delareyville to Schweitzer Reneke. Due to slightly higher rainfall around Schweitzer Reneke, there is an increase in crop farming activities. The same vegetation type is observed from Vryburg to Ganyesa. Whilst the eastern area is used for grazing, the veldt conditions in the western part of Ganyesa are poor similar to that of Stella-Mahikeng Bushveld. Groundwater is used as the main source of irrigation. Commercial activities and moderate settlements are found in a few towns such as Vryburg, Bloemoff, Taung, Delareyville and Schweitzer Reneke. The dominant biome is grassland savannah consisting of Kalahari Thornveld and shrub Bushveld vegetation (Warmsley & Warmsley, 2002). Agriculture is regarded as the major land use with mix crop farming like barley, wheat, sunflower and nuts.

1.8. Conceptual Framework

In rural communities food security and welfare of the people depend on, among other things, the availability of water. Ephemeral ponds could be one of the sources of water for small scale – irrigation. But the suitability of the pond water for irrigation is linked to water quality, longevity and rainfall.

The quality of water for irrigation is determined by its physical, chemical and microbiological standards. The quality is also influenced by natural and anthropogenic factors. Groundwater interactions with pond water and erosion of rocks due to rainfall determine the quality of pond water. In addition human activities such as mining, industries farming, development and municipal waste affect pond water quality.

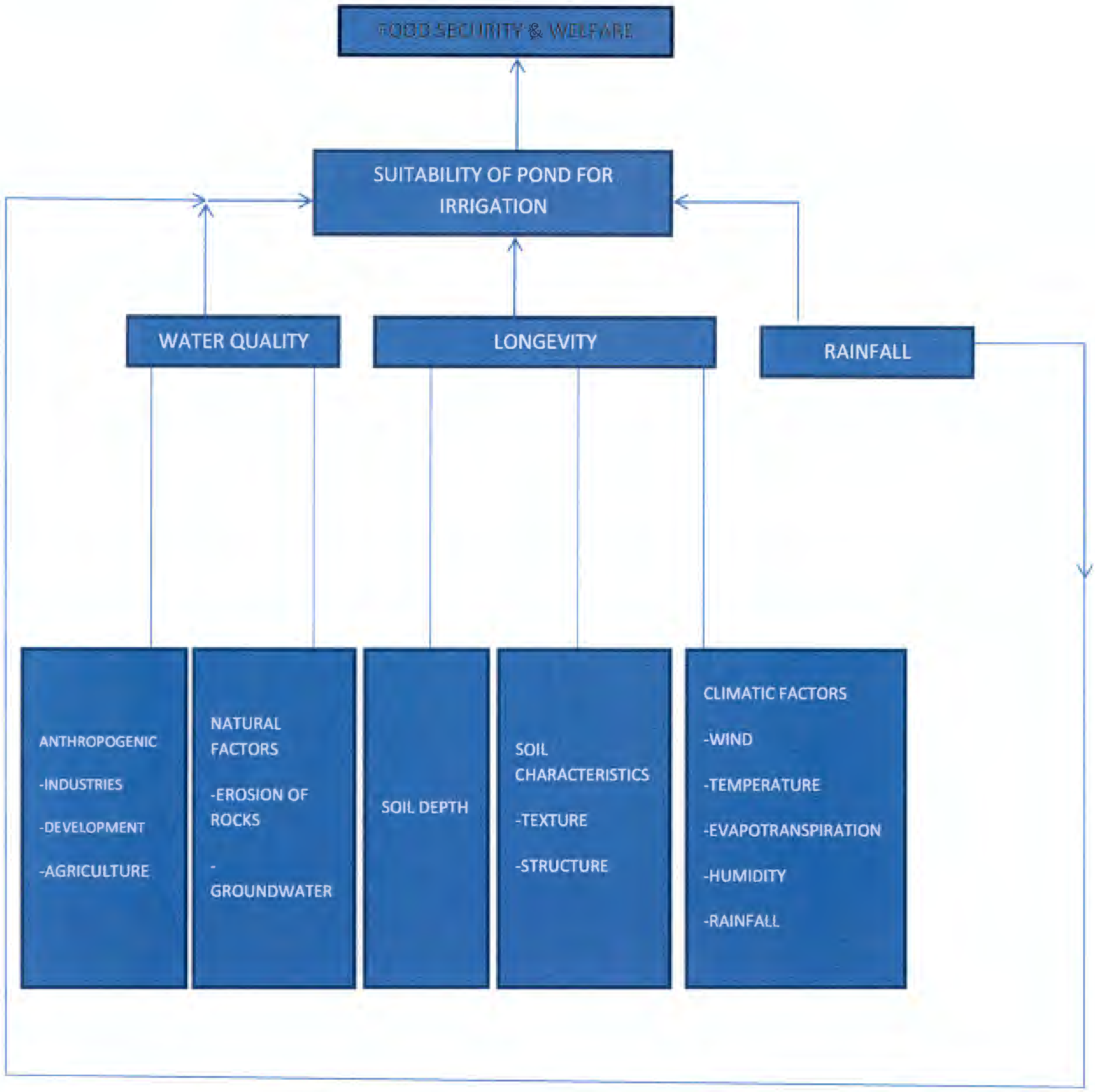

Figure 2: Conceptual framework of suitability of ephemeral pond water for irrigation

Longevity of a pond for irrigation depends on the depth of the water column, soil characteristics and climatic factors such as evapo-transpiration and wind. The quantity of rainfall, intensity and duration are some of the climatic factors that influence longevity of a pond. These factors can also affect the quality of water in the ponds. For example, temperature is an important water quality parameter because it determines the physical and chemical properties of water and thus the rate of chemical and biological reactions. It determines the solubility of certain toxic chemical elements in water. Consequently, temperature governs other parameters such as compound toxicity, conductivity, salinity oxidation reduction potential, and pH and water density (Jocque *et al.,* 2010). In addition, the study area experiences acute water shortages that are caused by both natural and human factors. These include climate change and climate variability, population growth and over extraction of groundwater.

1.8.1 Rainfall amount

The area experiences frequent drought. This problem is accentuated by the effects of climate change, which is epitomized by prolonged droughts and flooding (Winters, 2012). Droughts have severe effects on domestic and agricultural water use. During this period, crop failure is frequent resulting in poor harvests. Moreover, a lack of water and grazing causes a lot of mortality among livestock.

1.8.2 Population growth

Another factor that causes water scarcity in the study area is increase in human population. Over the last few years there has been a gradual increase in population in the Vryburg District. The district recorded a population growth rate of 0.7 from 1996-2001; 0.8 from 2001-2011 (Statistics South Africa, 2012). Consequently there is a high demand for water. But the existing water infrastructure has not been extended to cater for this increase in population thus compounding the water scarcity problem. This has resulted in poor water availability for domestic and agricultural use. This point is sustained by the work of Raditloaneng (2012); who stated that water infrastructure development is skewed towards cities and urban areas more than rural communities. Nevertheless it is the poor who suffer more as a result of increasing water scarcity (Winters, 2012).

1.8.3 Over- extraction of groundwater

Due to the lack of water, rural people resort to extraction of groundwater water for domestic and livestock use and for watering animals. This has resulted in the lowering of the water table. Besides, in some places, the geological formation results in saline water which is unsuitable for growing crops or watering animals. In some instances, the water is hard and can have human health implications.

1.8.4 Effects of water scarcity on the study area and solutions

The problem of water scarcity has affected social and economic activities in the study area. During the dry season; grazing, fodder and water for domestic animals are scarce. Consequently economic activities are low and have resulted in unemployment, lack of income and poor food security. The community, therefore, has to analyse the causes of water scarcity and come up with suitable solutions to address the problem. This can improve their livelihoods and welfare. Some of the alternatives available are: reduction in water use, rainwater harvesting and the use of grey water. But one of the easily available water is from ephemeral ponds. The ponds form during the short rainy season but, the water is not put into any economic use until it dries up. This water can be used for small – scale irrigation to grow crops such as maize and vegetables. This can improve food security and provide employment for people.

1.9. Scope of the Study

The study was restricted only to Vryburg District. Physical, chemical and microbiological water analysis was done and results were compared with the Department of Water Affairs Water Quality Guidelines, World Health Organisation and Food and Agricultural Organisation Water Quality Guidelines for Agricultural Use to determine the suitability of the water for irrigation. The land use land cover change study was from 2004 to 2013. With regard to climatic data, only readings for rainfall, temperature, humidity and wind speed and wind direction were taken for the period 1983 to 2013.

Ephemeral ponds and water bodies that form part of wetlands were considered in the study. Measurements were limited to location, depth of the ponds, area and slope around the ponds.

1.10. Ethics of the Study

Observation of ethical issues is of paramount importance with regard to quantitative studies. Permission was obtained from farm owners and local municipalities that own the selected ponds. Assistants and workers that were involved in the study were informed about the risks associated with the study and participation in the study was voluntary. The assistant that collected the water samples wore an overall and wellington boots. In addition water samples were collected a few metres away from the edges of the ponds to prevent drowning.

The selection of technicians for water microbiological and chemical analyses was done by the heads of departments of Sedibeng Water and the Chemistry Department of North-West University (NWU), Mafikeng Campus. The technicians are well-trained and experienced. When doing the analyses, they wore overalls, gloves, helmets, goggles, and boots to protect them against spillage, exposure to chemicals, obnoxious flame and gases. Fire extinguishers were in place to put off any accidental flame. In addition special containers were available to collect chemical waste and were properly secured to prevent leakage and exposure to people. Also ambulances were available to take injured people immediately to hospital.

1.11. Reliability and Validity of Measurement

Reliability and validity of data are important to quantitative studies. The reliability of an instrument is the consistency with which it can measure what it is supposed to measure when the characteristic has not changed. While validity is the extent to which the instrument can measure what it is intended to measure (Leedy & Ormrod, 2012).

1.10.1 Reliability of data

Google Earth was used to display all the ponds in the district. Based on the basis of their sizes, proximity to road and longevity certain ponds were identified. Random sampling was used to select five ponds for the study. It was believed that those ponds were representative of the ponds in the study area. Sampling containers were washed and disinfected to prevent contamination of samples. In addition water sampling was done 30 cm below the surface and in the middle of the ponds to prevent any outside interference that could affect the quality of the ponds.

With regard to microbiological analysis, water samples were kept under cold conditions making use of ice cubes. The analyses were completed within 24 hours to prevent microbial growth. The instruments that were used for chemical analysis were pre – tested in the laboratory before taking field measurements. This ensured the accuracy of the measurements.

1.10.2 Validity of data

As stated above, random sampling was used to select five ponds for the study. It was believed they were representative of all the ponds in the area. Water analysis data were replicated twice so as to determine the accuracy of the results. The mean was calculated for all the water analysis data. This was followed by analysis of variance (ANOVA). This determined how the actual values deviated from the mean. The mean values from water analysis data were compared with the literature values from the Department of Water Affairs and Forestry. Certain constituents in water correlated with one another. Correlation analysis was used to determine relationships between variables.

1.12. Outline of the Thesis

Chapter 1: Introduction

This chapter consists of introduction, statement of the problem, the study area, objectives and the importance of the study.

Chapter 2: Literature Review

Literature review chapter comprises discussion, evaluations and conclusion on research, academic work and reports already done by researchers on ephemeral ponds, water quality guidelines, GIS and the methodology.

Chapter 3: Distribution of Ephemeral Ponds and LULC Dynamics around the Ponds

This chapter provides a broad discussion of the distribution of ephemeral ponds and LULC around them from 2004-2013 including accuracy assessment of maps that were generated

Chapter 4: Land Use Land Cover Change on Ephemeral Pond Water Quality

The chapter includes the analyses of chemical and biological data and their comparison with DWAF, FAO and WHO Water Quality Guidelines to determine their suitability for irrigation. It also involves the combination of land cover change data and the water analysis data to model multi-linear equations to determine the effects of LULC on pond water quality.

Chapter 5: The Use of Climatic Data to Model Water Balance of the Ponds

The chapter involves a comprehensive discussion of standardized climatic data, the development of a mathematical model and the subsequent determination of water balance in the various ponds modeling results and conclusion will be drawn based on the hypothesis formulated.

Chapter 6: Development of Suitability Indices for Ephemeral Pond

It embodies the use of standardized rainfall data, water quality parameters and water depths to develop suitability threshold/indices for the pond water. It also includes the contribution of the research to academic work and society.

Chapter 7: Conclusion and Recommendation

The last chapter provides a summary of the findings of the research, suggestions and areas for further research.

CHAPTER 2

LITERATURE REVIEW

The literature review section provides a discussion about world water status and the challenges of water resources in semi-arid environments in an era of water scarcity and water security. An overview of mapping ephemeral ponds and concepts on the utilisation of ephemeral pond water are discussed. This is followed by analyses of water in the ponds and the fundamental issues relating to quality and quantity.

2.1 Introduction

Water is the most abundant resource occupying about 97% of the earth (Vaux, 2012; Gleick, 2013). However, about 90% is sea water, which is of little importance to human development. The situation is accentuated by the fact that most of the water is in the form of ice and some is located in the atmosphere. Moreover, the little water that is available is unevenly distributed. Regions such as Europe and North America experience high rainfall, whereas Australia, South Africa, North Africa and some parts of South America register low amount of rainfall. The problem is compounded by the effect of climate change and climate variability (Vaux, 2012). There has been sporadic rainfall in parts of Asia and North America whereas certain parts of the world experience severe droughts. Bartuska *et al.* (2012) stated that by the year 2025, two thirds of the world's population will experience water stress, which may be due to several factors including climate change and anthropogenic activities (Manzoor, 2013). Sub-Saharan Africa is one of the regions in the world that may have problems with water stress (Liu, et al. 2013). The next paragraphs will discuss some of the factors which increase water stress at global, regional and local level.

According to Schulte (2014) water stress can be defined as the lack of water to satisfy human and ecological demand. It was further explained that it includes water scarcity, its quality, environmental function and accessibility. This can result in reduced water quantity and quality of fresh water resources.

2.1.1 Climate change and water stress

It is widely believed that climate change is the main cause of water stress and the effects are more pronounced in areas around the equator (Morrison *et al.*, 2009). It was added that there is a strong correlation between climate change and recent climatic and environmental events such as droughts, floods, poor water quality and quantity (dwindling water table) (Bates *et al.,* 2008).

According to Bates *et al.* (2008) drought reduces water quantity in water bodies, soil and plants. Reduction of water quantity has a negative effect on agriculture. Compounding the situation is the increase in the rate of evapo-transpiration more especially in arid and semi – arid regions (Zakar *et al.,* 2012). This will result in food security problems. Most of the people in these areas practice rain – fed farming and any reduction in rainfall will reduce food production and agriculture which employs about 60% of the labour force in general; may cause job losses and reduced export (Sasson, 2012). In addition, droughts may have severe effects on the formation and the longevity of water especially in ephemeral ponds. During drought years, most ponds will not have water or the water in the ponds will not last for a long time due to rapid evaporation rate. Consequently the salt content of the pond may rise and the pond water will not be suitable for irrigation (Erickson *et al.,* 2010). Nonetheless, developing countries can reduce the negative effects of drought by storing more rain water, building of dams and the construction of check banks (NBR, 2013).

An equally significant aspect that affects water stress is flood. Bates *et al.* (2008) linked flooding to climate change based on the fact that flood damage in recent times is rapid and outstrips population and economic growth. Hence global warming is a contributory factor to flood. This assertion is too general and requires more studies to confirm it. However, NBR (2013) concluded that the general rise in global temperatures causes rapid melting of glaciers resulting in some rivers bursting their banks. This will eventually cause water stress in areas that depend on river water for social and economic development. The effect will be more severe in areas where there is intensive land use such as commercial agriculture, urbanization and industrial activities. Despite the negative effect of flooding and subsequent runoff, ephemeral ponds which occupy low topographical positions in the catchment area will be filled with water. The amount of water in the pond can sustain crop growth for a long time. Therefore different kinds of crops can be grown by using the pond water.

It is also widely believed that climate change can affect the level of groundwater. This is due to the fact that droughts and high evapo-transpiration rate associated with global warming put pressure on agriculture. Hence farmers are compelled to extract water from underground (NBR, 2013). But this assertion was discounted by Bates *et al.* (2008) who argued that groundwater extraction would create a hydraulic gradient in the soil and accelerate infiltration rate of water to replenish groundwater.

Furthermore, high temperatures due to global warming are associated with poor water quality (O' Regan *et al.*, 2014). During floods; sediments, pollutants and bacteria enter lakes, rivers and dams (Whitehead *et al.,* 2015). These reduce water quality and may pose health hazards to people who use the fresh water directly without treatment (Peterson & Posmer, 2010).

2.1.2 The effects of high temperatures on water quantity

Climate change has an effect on water quality. Nevertheless high temperatures can also affect the quantity of water resources. Weinberg (2010) made certain observations on the effects of climate change on the water resources in Bolivia. Weinberg (2010) added that the Chacaltaya glacier that supplied water to La Paz disappeared in 2009 and could cause water shortages in the city. Secondly, in a space of fifty years the water level of Lake Titicaca dropped to 0.8 m, its lowest level. Lastly the length of the rainy season near La Pas has been reduced from six months to three. And all these were attributed to increase in regional temperatures.

The same points were sustained by Al-Ansari *et al.* (2014). The Inter – governmental Panel studied discharges into two rivers; Tigris and Euphrates in Iraq and also summer and winter rainfall trends. It was reported that there was a large decrease of discharges into the rivers, which have been predicted to dry up by 2040. Moreover, it was predicted that there would be a drastic reduction in rainfall especially in summer. It was, therefore, concluded that proper management strategies must be put in place to prevent water stress in future. This assertion can also be applied to ephemeral ponds because high temperatures can reduce the longevity of the pond water.

2.1.3 Anthropogenic factors influencing water stress

Recent studies suggest that anthropogenic factors can cause water stress (Zakar *et al.,* 2012). Notably among them are population growth, urbanization and agriculture. Increase in population will put more pressure on water resources (NBR, 2013). As a result water use per person will reduce. Hence governments must look for alternative sources of water such as desalination of water and rainwater harvesting. The effects of water shortages may be more severe in urban areas due to rural urban migration (Winters, 2012)

Another significant factor that is worth considering is the effects of urbanization on water stress. According to Ahiablame *et al.* (2012) the increase in the population of the city of Lome in Togo over the last few years has put pressure on water resources. Some of the stress includes water shortages, inadequate management of water resources, and increase in water cost. This point is also supported by the work of Muzondi (2014) in Harare, Zimbabwe. Over the period of thirty years the population of the city doubled, driven by the quest for better opportunities in urban areas. It has resulted in the breakdown of water infrastructures, poor management of equipment and sewerage facilities. Consequently water resources and the environment have been polluted.

It can be inferred from the above discussion that urbanization can put more stress on ephemeral pond water in cities. The lack of water availability will force urban residents to put pressure on the use of ephemeral pond water (Adibola *et al.,* 2012).

2.2 Adaptation to water scarcity

Access to enough and clean water is essential to all families and communities. It promotes social and economic development. In rural communities it sustains agriculture, improves food security and provides income to households. Nevertheless, there are 850 million rural people worldwide that do not have access to water (United Nations World Water Assessment Programme, 2015). The greater parts of Africa including the study area, experience water scarcity. The proceeding section discusses the adaptive theory and how it has been applied in different countries to improve water scarcity.

Adaptation to water scarcity can be likened to the Theory of Cognitive Adaptation that was first put forward by Walter Johnson. It describes how people cope with traumatic events. It also describes the way people recover from any adverse experience. Furthermore, during the rebuilding process resources are acquired internally.

According to United Nations Environmental Programme (2013) adaptation is what is done to manage or to survive to the effect of something. The Millenium Development Goals (MDGS) rather explained adaptation as changing existing policies and practices so as to avoid any negative impact. It also puts the government in the forefront of adaptation in society. However, small communities should also play a leading role in adaptation since they are directly affected by any negative changes in their environment.

Adaptation is, therefore, important in every society when it faces scarcity of resources such as energy and water. The scarcity can negatively influence development activities. And it has to be done swiftly to avert serious consequences in societies. According to United Nations Environmental Programme (2013) during the process of adaptation all sectors of institutions and levels of governance including stakeholders must be involved.

With regard to water, it is imperative to discuss the dynamics of water management. Adaptation to water scarcity involves the supply and the demand management of water. Supply management involves all the possible sources of water and how they can be harnessed for use by humans. This includes harvesting of rainwater, building of dams and storage of runoff for later use. Other sources are the use of groundwater, reuse of wastewater, seawater desalination and inter basin transfers (FAO, 2012).

2.2.1. Supply management of water

Rainwater harvesting and the groundwater abstraction are relevant at the household level among small communities. They require less capital and low technology inputs. In the Woreda watershed, in Ethiopia, rainwater harvesting and runoff farming proved successful for domestic use, growing of vegetables and for watering animals; as well as improving income of farmers (Amha, 2006). At the community level runoff can be directed to small reservoirs for community projects such as vegetable growing and serving as watering points for domestic animal and also for game farming. Groundwater is a common source of water in rural areas. About 2.5 million people globally depend on ground water for domestic and agricultural use (ISARM, 2009). But over abstraction can result in its depletion and affect base flow to rivers and other water bodies (United Nations World Water Assessment Programme, 2015).

Wastewater is used in some water stressed countries such as Israel and Tunisia. This requires proper disinfection techniques or it can contaminate the soil and crops. Hence its use in irrigation is restricted to the growing of field crops and the avoidance of the use of sprinkler irrigation (Jhansi& Mishra, 2013)

2.2.2 Demand management of water

Having discussed the supply management of water resources, it is reasonable to mention also the demand management. Bartuska *et al.* (2012) stated that by the year 2025, the world will be experiencing acute water shortages. FAO (2012) also identified population growth, changes in consumption patterns and services, urbanization and climate change as the factors that cause water scarcity. Since water resources are over stretched, the current usage of water has to be managed properly. Demand management involves water allocation, efficiency in water use, increase in crop production and selection. It also involves educating people about water conservation and the growing of crops that require less water (UNEP, 2013).

Many regions and countries around the world experience water stress. Some of these countries have been able to develop policies and strategies to adapt to water scarcity. The section below discusses regions and countries that have applied the theory to water stress. It is then followed by the description of the conditions in the study area and how the communities can adapt to water stress

Jordan is one of the driest countries in the world (Turton *et al.*, 2003). The rainfall pattern is variable which ranges from 200 mm – 630 mm annually. However there is a high demand for water for agriculture. The main sources of water are rainfall and the River Jordan. Unfortunately, the water from the river is shared by many countries such as Israel, Syria, Lebanon the West Bank and Egypt. This situation leaves little water available for Jordan for its social economic and agricultural development programmes. In addition, the cost of irrigation is high in the country. Hence about 90% of the cultivated land is rain fed and the remainder lacks water for cultivation (Turton *et al.*, 2003).

In spite of the low water availability, the country has formulated strategies to counteract the situation. The capacities of major dams have been increased coupled with the construction of new dams to store more water for irrigation and domestic use. There have been improvements in the use of drip irrigation to conserve water in agriculture. New cultivars of citrus and bananas are being introduced to replace the existing ones that require more water.

Israel and Palestine have also developed strategies and policies to adapt to water scarcity. These areas experience serious water deficit with water demand outstripping water supply. This has compelled the government in the Gaza strip to continuously extract groundwater to the extent that the water becomes saline due to seawater contamination. The salinity of the water affects the quality of citrus and other tree crops. As regards the West Bank, the rainfall ranges from 600mm to 800mm per annum to as low as 200 mm per annum in the eastern part of the Jordan Valley. The water quality is impaired due to contamination from agriculture and industries. The contaminants include nitrates, fuels, heavy metals and other compounds from organic sources (Turton *et al.*, 2003).

Due to limited water supply and poor water quality the government has embarked on measure to improve the situation. About 25% of the water used for irrigation comes from treated sewerage; but this water may not be suitable to irrigate fruit crops and vegetables (El-Zanfaly, 2015). Seawater desalination is also done on a limited level since the cost involved is high. In order to reduce the cost of desalination, solar energy technology must be introduced (United Nations World Water Assessment Program, 2015). Moreover, runoff and wastewater are directed and stored and treated for later use. In addition during storm events excess water is collected into reservoir that is later used. This practice can be useful in the study area since runoff and storm water flow during the rainy season.

South Africa is also another country that experiences water scarcity. The greater part of South Africa is dry, recording an average annual rainfall of less than 500 mm (Council for Scientific and Industrial Research, 2012). According to Asmal (1998), only 8% of the rainfall is available at the surface. In addition, most of its rivers are temporary hence water cannot be used for irrigation throughout the year. The situation is accentuated by low reserves of groundwater (Turton, 2003).

Some measures have, therefore, been taken to arrest the situation. Firstly the New Water Act of 1998 was promulgated to regulate water use. The riparian water policy was repealed and was replaced by equitable distribution of water. But this has not been achieved yet. It also specified equitable distribution of water resources with special consideration to rural areas and peri-urban communities. Nonetheless water infrastructure is more concentrated in urban areas (Raditloaneng, 2012). Hence many rural communities experience serious water shortages. Also water is transferred from the Mountain Kingdom of Lesotho to Gauteng, the industrial province of South Africa. This is achieved through a system of dams and tunnels that connect to the Vaal River in South Africa. The establishment of the Catchment Management Agencies is still in the planning stage. In addition, the allocation of reserves to water bodies to preserve aquatic organisms was given a special attention.

Zimbabwe on the other hand experiences high rainfall ranging from 337 mm to 1110 mm per annum (Mazvimavi, 2010). Nevertheless there is an annual variability in rainfall pattern. Hence total dependence on rainfall causes losses in production. The rainfall season is short; it starts from November and ends in March. Nevertheless the country is endowed with groundwater reserves. This water can be suitable for small-scale farming. In addition there are many dams that supply about 90% of the total surface water. This water is used for agriculture and domestic purposes in cities and urban areas. Sometimes during drought periods food production and grazing are affected.

Zimbabwe depends mainly on rainfall and surface water sources for its development. These water sources are not sustainable and may result in water scarcity in the face of climate change, population growth and an increase in consumption pattern (United Nations World Assessment Programme, 2015). With respect to water demand management, not much has been done regarding water conservation and the use of appropriate crops that tolerate drought.

In Egypt, UNEP (2013) recommended adaptation strategies such as improving agriculture by growing high yielding crops and changing existing varieties that can adapt to water stress. The demand management must include education about water conservation.

2.2.3 Environmental conditions in the study area and adaptation to water stress

Vryburg District is a dry area, which records low mean annual rainfall below 400 mm (Warmsley & Warmsley, 2002). The short rainfall season, which runs from October to March, is usually irregular and sometimes accompanied by hail and thunderstorms. Hence less water enters the soil. The bulk of the rain water ends up in streams and rivers through runoff. The situation is accentuated by high evapo-transpiration and high temperatures that contribute to water stress in the environment as well as the soil. The lack of water has affected both the economic and social life of the residents in the study area. Unemployment rate is very high and has contributed to idleness, crimes and migration to urban areas. Lack of job opportunities has resulted in poor incomes among the people. Poverty is therefore endemic; all these have resulted in poor food security (O'Farrel *et al.,* 2009).

With regard to agriculture, it is limited to livestock grazing. Crop production is virtually absent due to the low amount of rainfall and its distribution (O'Farrell *et al.,* 2009). The common livestock raised are mainly cattle and goats. The grazing consists of grasses and thorny bushes. Owing to the low amount of rainfall the yield from the veldt is low. This is translated into poor growth of animals, low maturity mass and as well as high mortality rate during drought periods. Incomes and profits from the sales of animals are therefore low.

Water stress has effects on agriculture and domestic water use. Firstly, there is poor water infrastructure in the study area. Hence many people do not have access to potable water. Consequently there are acute water shortages especially in remote villages. Groundwater is the main source of water for people in the rural areas (SA, 2015). Sometimes the water becomes salty and unsuitable for domestic use or for watering animals. The communities in the study area therefore need to come up with measures to adapt to the conditions of water scarcity. Firstly there should be proper education programs about water scarcity and how they can conserve water. There should be educated about rainwater harvesting. Water must be stored in tanks above ground and underground and in dams (Ahma, 2006). Runoff water should be directed into storage tanks for community use. This can be used to cultivate crops or for animal watering.

Moreover, ephemeral ponds form in the study area and pond water can last up to four months after the end of the rainy season. It can be useful to irrigate vegetables and some field crops.

Vegetables are a good source of vitamins and minerals and can improve the health and vitality of the people in the study area. Maize, sorghum, peanut can be cultivated easily with the use of the pond water. Maize is a staple crop in South Africa; it is the main source of carbohydrate of people in the study area. The stem and leaves that remain after harvesting can be used to provide fodder for farm animals. GMO crops and drought tolerant cultivars can be grown. Fodder can be scarce during the dry seasons. Ephemeral pond water can be used to cultivate fodder. Crops can be cut and conserved to be fed animals during the dry season. With respect to grazing animals only hardy and drought tolerant ones must be reared. They may include the Africander, Nguni and Brahma. They are able to withstand water stress, harsh temperatures and poor grazing. Moreover farmers must stockpile feed in summer when it is abundant.

There are many countries in the world that experience water scarcity. Some of these countries have devised strategies and programs to make water available for use. These include supply and demand management of water. The strategies adopted by the various countries depend on availability of the water resources, technology and finance. These strategies must be assessed and the ones that are suitable for the study area may be adopted.

Water scarcity is experienced in many states and it is attributed to population growth, increased in demand and climate change. However communities and states must develop programmes and strategies to adapt to water scarcity. These include supply and demand management of water. In rural communities, rainwater harvesting, the use of runoff water and groundwater are recommended. In addition crop productivity must be improved through the selection of high yielding crops and drought tolerant cultivars. In the study area, ephemeral ponds form during the rainy seasons and the water can be used to augment water shortages. Hence all available water including ephemeral ponds should be utilized for human use only.

2.3 The uses of ephemeral ponds

Ephemeral ponds have multiple uses which include the support for aquatic organisms, domestic and irrigation purposes.

2.3.1 The use of ephemeral ponds for ecosystem functioning.

The main function of ephemeral ponds is to support aquatic ecosystems and to maintain biodiversity (Calhoun *et al*., 2014). They serve as habitats for a variety of organisms including insects, crustaceans, amphibians and migratory birds (Hoverman, 2012). Unfortunately, some of the species are threatened; hence, there is an enormous pressure from biologists, ecologists and environmental groups to protect these organisms through the management of the ponds (Hoverman, 2012). Calhoun *et al.* (2014) stated that the management of the ponds poses challenges due to their locations on private land and poor implementation of legislation governing protection of such water bodies. Similarly, in South Africa and the study area in particular, most of the ponds are owned by private individuals. Securing the pond for communal irrigation and controlling land use around the ponds may cause conflicts among stakeholders.

2.3.2 Domestic use of ephemeral ponds

Ephemeral ponds are abundant in tropical savannah and in most rural areas they are used for domestic purpose including drinking, washing, doing house chores and bathing (Zongo and Boussim, 2015). Also in some coastal areas such as Bangladesh, small isolated wetlands (ponds) are used for drinking, cooking, bathing and washing (Rabbani *et al.,* 2013). The domestic use of ephemeral pond water conflicts with its use for irrigation. The pond water is usually contaminated with bacteria and algae (Bates *et al*., 2008; Zongo & Boussim, 2015). This may cause illnesses to people who use the water for drinking, washing and for other domestic purposes (Rabbani *et a*l., 2013). Hence pond water may not be suitable for domestic use without treatment. The micro-organisms in water hardly affect field crops and other crops that are not eaten raw when the water is used for irrigation.

2.3.3 The use of ephemeral pond water for irrigation

Ephemeral ponds can be used for irrigation and they form part of wetlands in general including other water bodies such as vernal pond, bogs, mangrove, temporary pools and seasonal wetlands (Thomas *et al.,* 2010). In addition pans, wadis cisterns playas are also considered as wetlands.

Some wetlands have been used for agricultural production (McInnes *et al.,* 2013). They include ephemeral ponds, wadis in the Middle East and cisterns. Rabbani *et al.* (2013) conducted a study to assess the effects of climate change on small ponds in coastal areas of Bangladesh and found that more than 20% of the rural communities depended on the pond water for home gardening and irrigation. Despite the poor sampling procedure, it can also be argued that the use of ephemeral pond water for irrigation in the study area can improve the livelihoods of rural households based on the experience in Bangladesh. It was also stated that the wetland ponds were affected by extreme weather events such as seawater rise and the consequence intrusion into the coastal ponds. Inland ponds such as ephemeral ponds in the study can also be affected by floods and droughts and may impact on the water quality of ponds.

Mukherjee and Gupta (2011) conducted another study to assess the profitability of wastewater irrigation from East Calcutta Wetlands on rice with that of groundwater. It was found that using wastewater to irrigate rice was more profitable than that of groundwater irrigation. Nevertheless the profitability kept on reducing with increasing levels of pollutants such as chromium, lead and mercury. Regression analysis was used to assess the profitability of the enterprise. Profitability was the dependent variable while price per kilogramme of rice, level of pollutants and input costs were used as the independent variables. The average profit per unit of output (Rs/kg) was 3.09 while the one for groundwater irrigation was 0.40. It was concluded that the increased profitability was attributed to the presence of nutrients in wastewater that contributed to higher yield from wastewater irrigation. However, profitability was reducing gradually due to toxicity of heavy metals in water. Ephemeral ponds receive their water from runoff and it may contain sediments, nutrients and pollutants (Morrison *et al.,* 2009) which may impact on the profitability of crop production.

2.4. Mapping of ephemeral ponds.

Ephemeral ponds are useful for domestic and irrigation purposes. In order to make effective use of the ponds, mapping the extent and spatial distribution of these ponds is imperative. The dimensions of the ponds also determine the volume of water that can occupy them. Various methods and techniques have been employed to identify the locations, characteristics and the physical conditions of the ponds. The manual techniques of collecting data about natural and man – made features and subsequent mapping has been there since time immemorial. However they are without difficulties and limitations (Reed & Ritz, 2004). The methods are usually expensive and require a long time to obtain the output. With respect to aerial photography it is characterized by poor accuracy and repeatability (Wu *et al.*, 2009).

Consequently, geospatial mapping technology has been introduced to take care of the disadvantages and limitations associated with the field technology of mapping. One of the new mapping technologies is thematic mapping. Data can be collected instantly and linked to processing devices and stored in a data base. Parts of the data or the whole can be extracted and analysed in different ways. It can, therefore, be inferred that conducting ground survey to collect information regarding water parameters is too expensive and time – consuming and thus impracticable (Lathrop *et al.,* 2004).

Muster *et al.* (2012) were able to identify all the water ponds in three Arctic Tundra wetlands with the use of Landsat-5 TM at 30- m and the MODIS water at 250 resolutions. In addition the sub pixel divisions of the water cover were shown. This is a very effective method of mapping water bodies since resolutions alone are not effective enough to identify small water bodies (Muster *et al.,* 2012). However, the images should have been compared with primary data sources such as topographical maps and existing information to determine the accuracy of the data (Sreenivasulu *et al.*, 2013).

The approach was similar to the study conducted by Qiusheng *et al.* (2009) in Massachusetts. A combination of tools and primary data were used to determine potential woodland pools. Information about potential and current woodland vernal pools was obtained for the study area from a data base. A Stochastic Depression Tool from a Whitebox was employed to map depressions on the topography using Digital Elevation Model (DEM). This was followed by the Monte Carlo approach to map depression shapes from (DEM) error. In addition, LiDAR DEM was used to isolate other depressions in urban areas from those occurring in forests, grassland and wetlands. The Normalised Difference Water Index (NDWI) was employed to determine water features from that of the soil. The results were then compared with the database of the National Heritage and Endagered Species Programmme. The results showed 2.25 – 6.0% accuracy assessment and a proxy omission rate of 82% with variations in the positions of the pools. However, the methodology may be useful in determining the positions of ephemeral ponds in the study area especially measuring pond depth and area for such measurements determine the longevity of the pond water.

2.4.1 Area measurements of ephemeral ponds

The area of land cover can be determined by the use of satellite image which is then processed to map the different land cover characteristics. The scale of the map can be used to calculate the area of the land cover (Sreenivasulu *et al.,* 2013). This method of calculating area is only appropriate for large land cover size therefore in the case of small ephemeral ponds; the pixel method will be more appropriate (Begum & Nessa, 2013). The method is useful for measuring small ponds less than one hectare; those ponds are more likely to be formed in the study area.

In another study, Liu *et al.* (2015) made use of Landsat TM/ ETM ortho-rectified images to map supra glacial lakes on debris covered glaciers in the Khan Tengri Tumor Mountains. Images used were from 1990 to 2011. Firstly the boundaries were adapted manually from GLIMS dataset and the band ratio method was used to map the boundaries. Finally the outlines of the lakes were extracted by using ENVI object based feature extraction module. The spatial resolution was 30 m^2 for distribution and mapping of lakes. Also the uncertainty in measurement was fixed at 0.5 pixel. The results showed a lot of differences between mean area of lakes and years. Also there was a positive correlation between area of lakes and total liquid precipitation (R^2= 0.50). But the mean area decreased with an increase in average air temperature.

2. 5 Factors that influence pond water quantity

Having mentioned the methods used to measure the area of ponds; it is also worthy to discuss the factors that affect the quantity of water in the ponds. The quantity of water in ephemeral pond is a critical consideration that determines its suitability for irrigation in relation to precipitation, slope length, soil characteristics and evapo-transpiration.

Pomeroy *et al.* (2010) studied the hydrological characteristics of wetlands in the Canadian Prairies and identified precipitation, runoff, groundwater recharge, evapo-transpiration and saturated flow as the factors that affect wetland water balance. Precipitation is the main source of water for ephemeral ponds (Owen & Horton, 2013). A study was conducted to monitor the water in the basins of over 200 ponds in Montana Prairie from 1980 - 2007. It was concluded that during drought periods, only 20% of the basins had water in the specific month when monitoring was done yearly. But during average rainfall years, about 50% of the basins had water. Similarly, Thomas *et al.* (2010) observed that the number of vernal ponds and their water level are associated with season and precipitation. Fewer ponds and low water levels occur during dry, warm years. Conversely more ponds and higher water levels are observed during periods of high precipitation.

The slope around a pond is also an important factor that can influence pond water quantity. According to Bharati (2013) slope increases the amount of runoff and the amount of water that collects in ponds. This is due to the fact that little time is allowed for infiltration. But when the slope is gentle, the flow rate is reduced hence more time will be available for infiltration and percolation. It is the slope length and steepness that affect the water quantity in a pond. When the slope length is extensive, more runoff will reach the pond to increase its size and volume (Menconi & Grohmann, 2013).

The level of the water table also affects the discharge of water from ponds. Thomas *et al.* (2010) studied vernal ponds in Michigan and found that they are common in areas with high water table, fine textured soil or where the topsoil is underlined with bedrock. When the water table is close to the surface the soil is completely saturated hence water discharge from ponds is zero. The groundwater level can go down due to base-flow of water into rivers, streams, lakes and the sea (Pomeroy *et al.*, 2010).

Ephemeral ponds can lose water through saturated flow to adjacent land. This happens due to the creation of hydraulic gradient. When the soil is dry due to high temperature the lateral movement is fast and this affects the lifetime of the ponds. According to Collins (2012) the extent of soil drainage has a profound effect on wetland development. Hence the determination of infiltration rate of a pond is essential for it affects its water balance. This is mainly influenced by soil characteristics, water table recharge and vadose region below the pond. Racz *et al.* (2011) studied infiltration rates from artificially managed recharged pond in California and observed that about 98% of water loss was due to infiltration. The absence of horizontal saturated flow resulted in the creation of high hydraulic gradient and fast downward movement of water in the soil. Conversely, infiltration rate has a positive correlation with water volume (Racz *et al.*, 2011). When the volume of water is high, the hydraulic gradient increases hence the fast rate of infiltration. Conversely in arid regions, reduced water quantity in ponds may be due to surface evaporation (Erickson, 2010). This can result in low infiltration rate.

Besides saturated flow of water to adjacent land, evapo-transpiration is a major factor whereby water is lost from ponds. Evapo-transpiration is a major factor that affects water budget in ponds. Hauwert and Sharp (2014) measured the recharge over a karst aquifer and established that about 70% of annual precipitation is lost into the atmosphere due to evapo-transpiration. The effect of evaporation is more pronounced in hot, arid and semi-arid regions. In these areas, albedo is more severe resulting in high temperature during the day and low relative humidity. The absence of trees results in high wind speed. These factors contribute to high evapo-transpiration rate. Randerson *et al.* (2012) measured annual evapo-transpiration rates on a variety of wetlands and observed a wide variation among the wetlands (40-1500 mm/year).This shows that climatic difference affect evapo-transpiration rate. In addition, seasonal differences affect the rate of evapo-transpiration with summer recording the highest rate. In winter evapo-transpiration rate is very low (Pomeroy *et al.,* 2010). Evapo-transpiration is influenced by radiation, convection, water vapour and the opening of stomatal pores. Nevertheless, in winter all the processes are hampered due to reduced intensity of solar radiation and rainfall.

Evapo-transpiration has been identified as the main cause of water loss from ponds (Gulliver *et al.*, 2010). It therefore has to be managed to make ephemeral ponds useful for small scale farm irrigation. The main methods of reducing evapo-transpiration on water bodies are mechanical and chemical. Mechanical method refers to covering the water surface with a material to block ultra violet radiation from reaching the water surface. This method reduces the vapour pressure of the water surface hence low evaporation rate.

Sahoo *et al.* (2012) identified Bowen Ratio Energy Budget (BREB), Priestley Taylor and Bruin – Keijman Model as the best method to measure evaporation from farm ponds compared to class A pan evaporimeter. A study was conducted by Sahoo *et al.* (2012) to compare the rate of evaporation between two similar farm ponds under the same environmental condition. An experimental farm pond was covered with a biological canopy whilst the control had no treatment. It was found that the control pond experienced a higher daily evaporation rate (1.18 mm) more than the experimental farm pond. It was concluded that the mechanical method was more effective in reducing evapo-transpiration rate. Also the biological method is more permanent than the chemical method. In addition, it has proven to be effective in reducing evaporation on farm ponds (Sahoo *et al.*, 2012).

There are different types of chemicals that are used to retard the rate of evaporation from water surfaces. Some are a mixture or emulsion and alcohol to reduce evaporation, whilst others make water molecules bond tightly together or to thicken it (Craig *et al.,* 2005). The chemical method may not be expensive but it is temporary and may not be suitable under strong windy conditions. The efficiency of three chemical compounds for evaporation reduction was analysed under different environmental conditions such as wind speed and solar radiation. The chemical compounds were steary alcohol, ethylene glycol and mono octadecyl ether (Elvira *et a*l., 2013). It was found that all the three compounds were effective in reducing evaporationt rate from 13% to 17%. However, at higher temperatures and wind speed greater than 3 m/s the efficiency of the chemicals reduced drastically. It, therefore, implies that the use of chemicals to control evaporation is affected by environmental conditions.

2.6. Maximising water quantity of ephemeral ponds

Infiltration and evaporation are some of the factors that affect water volume in a pond. One of the measures to improve the quantity of water in an ephemeral pond is the maximization of runoff into the pond whilst reducing evaporation rates. Runoff is determined by factors such as soil characteristics, vegetation precipitation, slope, drainage of the area and antecedent moisture condition (AL–Ansari *et al.*, 2013). These factors are physical and cannot be controlled by humans. Nevertheless, engineering work such as excavation of ponds and lining them with impervious material can improve their capacity. Moreover, the building of check banks and the use of stone dykes can direct more runoff into the ponds (Al Zayed *et al.*, 2013). The practice of runoff farming has not only improved yields of crop and pastures in North Africa, Middle East and Pakistan but has abated crop failure (Prinz & Malik, 2011). It was added that the most suitable area for runoff farming is when the rainfall regime is between 300 – 600 mm per annum. The study area also falls within the regime of low rainfall. It records a mean annual rainfall below

400 mm. Having considered the factors that affect the quantity of water in ephemeral ponds, it is also reasonable to consider land use land cover change on the quality of ephemeral ponds.

2.7. Effects of land use and land cover change on ephemeral ponds

Land use land cover change affects water quantity and quality of all water bodies (Johnbosco and Nnaji, 2011; Gallo *et al.*, 2012; Huang *et al.*, 2013). In order to determine the effect of land use land cover change on wetlands, advanced tools have been developed to measure the change. Adeoye (2012) made use of Landsat Imageries, GIS and topographical maps to monitor land use land cover change of Lokoja, a confluence town in Nigeria from 1986, 2001, to 2006. A great change in forest cover and reduction in water area was observed while bare soil and settlement increased drastically. It was concluded that the destruction of vegetation was due to urbanization. Furthermore it was suggested that planners and policy makers should consider the conservation of natural resources when considering development projects. A similar study was conducted on the Himalayan wetlands in India to determine the impact of land use and land cover change from 1986, 1995 to 2005. The wetland area decreased more than 50% from 1986 to 2005. In addition, there was a reduction in natural vegetation, but agricultural land, and settlements increased tremendously. This was attributed to the conversion of wetland into agricultural fields. The decrease in the vegetation cover was due to population pressure. The increase in agricultural activities resulted in the siltation and pollution of the wetlands.

It should, however, be noted that not all land use and land cover changes places negative effects on water quality. Forest establishment, planting of fodder and plantation agriculture could rather improve the quality of wetlands. These practices require little use of fertilizers and pesticides hence less pollution of water resources. Moreover, the vegetation cover traps silt and other suspended solids therefore the area and depth covered by water will be reduced.

2.7.1. Effects of agriculture on water quality of ephemeral ponds

Zamani *et al.* (2012) and Chow *et al.* (2011) stated that activities such as intensive agriculture, industries and high concentrations of people tend to pollute water bodies. These pollutants may also influence the quality of ephemeral pond water by virtue of their location in a catchment area. Divya and Belagali (2012) added that chemical fertilizers affect the quality of water hence effective management of fertilizer application in a catchment area has to be done. In addition, good legislation must be introduced by the state to control fertilizer application on farms.

Crop farming and grazing are the main agricultural activities that take place in the study area and can impact on the water quality of the ponds. Pesticides, fertilizers and sediments reach ephemeral ponds through runoff although the extent of the pollution depends on the amount of runoff and drift (Anderson *et* al., 2014). It was stated that the pollutants that normally emanate from agricultural activities may include nitrates, phosphates, organo-phosphate and organo-chlorides. Moreover, Withers *et al.* (2014) stated that high concentrations of phosphorus cause eutrophication of water bodies. Notwithstanding the disadvantages of land use on ponds the study emphasizes that moderate concentrations of nitrates and phosphorus in water may improve crop growth when the water is used for irrigation. Verhoever and Setter (2010) were of the view that wetlands should not be drained for agriculture; but the water can be used for irrigation and the use of pesticides and fertilizers should be discouraged. It was, however, suggested that crop farming and grazing would be more appropriate in South Sahara Africa when wetlands are used for agricultural purposes.

There are conflicting reports about the effects of grazing on the quality of wetlands. Roche *et al.* (2013) studied the relationships between cattle grazing and meadow water quality. Grazing was done next to some meadows whilst in the control experiment grazing there was no grazing. The results showed no significant difference in the levels of nutrients, turbidity and temperature between grazed and non-grazed treatments. Hence it was concluded that livestock grazing had no effects on water quality. Scrimgeor and Kendall (2002) evaluated the effects of intensive livestock rearing on water quality of three streams in Cyprus High grassland plateau in Canada. Lower levels of dissolved oxygen and pH were measured but conductivity, phosphate and turbidity levels were higher at the areas that were grazed compared to the site that had no animals. The varying results of the effect of grazing on wetlands could be attributed to the intensity and the systems of grazing. The former was practicing extensive system of farming whilst the latter was involved in intensive system of ranching hence the different conclusions. Moris and Reich (2013), however stated that careful management can reduce the effects of grazing on wetland water quality.

2.7.2. Impact of urbanisation on pond water quality

Having discussed the effects of agriculture on the quality of ephemeral ponds it is also important to consider the influence of urbanisation on the ponds. Urbanisation is one of the causes of pollution of water bodies (Jayakumar *et al.*, 2013). It was stated that municipal waste may contain *inter alia* suspended solids, pathogens, phosphates and ammonia. Furthermore, the constituents of municipal waste depend on anthropogenic activities and population density in the area. Jayakumar *et al.* (2013) compared the effects of raw storm water with that of biologically treated storm water on the growth of paddy rice in basins. It was concluded from the results of the water quality analysis that urbanization and industries might cause water pollution. The water samples were not replicated hence the validity of the results cannot be guaranteed. The water quality analysis was mainly based on physical parameters with the exception of sulphate, oil and grease. The study could have taken into consideration heavy metals such as lead, cadmium for they are present in effluents from petrol stations, small industries and some household chemicals.

Furthermore leachate from dumping sites and landfills is another source of pollution of water bodies due to urbanization. It may contain a variety of substances such as heavy metals, anions and cations. Nyame *et al.* (2012) investigated the effects of leachate from a landfill site next to an Accra wetland over a six- month period. The measurement of the constituents such as Ca^{++}, Mg^{++}, and TDS exceeded the World Health Organisation (WHO) criteria for effluent discharge into water bodies. But the heavy metals (lead, cadmium, zinc, manganese) and phosphate concentrations were below the recommended limits. It was concluded that the landfill was new hence less effluents got into the wetland. Moreover the WHO criteria for water quality are lax and should be considered alongside other water quality guidelines. Having considered the effects of land use on ephemeral ponds it is also reasonable to look at water quality parameters.

2.8. Water quality parameters for irrigation

The main water quality parameters that affect water for irrigation can be grouped into physical, chemical and microbiological. The study is confined to chemical and microbiological only.

2.8.1 Chemical parameters from in – situ analysis

The chemical data that were measured from in – situ analysis that may affect water for irrigation are hydrogen ion concentrations (pH) and electrical conductivity (EC). In general when the soil pH is < 5 or > 9 it is not suitable for growing crops (Liu & Hanlon, 2012). Under very acidic conditions, certain minerals such as Al^{+++}, Fe^{++}, Mn^{++}, Cu^{++}, Mo, Ni become toxic to crops. Also when the pH exceeds 9, the concentrations of Ca and Mg rise very high and may not be suitable for growing crops. Although extreme pH values are not suitable for growing crops, soil and crop management can ameliorate the situation (DWAF, 1996). Furthermore, total dissolved solids (TDS) are one of the constituents that can affect the water quality for irrigation. TDS is described as the total quantity of elements that are dissolved in water. When a solution contains TDS level higher that 2000 mg/l it is described as saline and can adversely affect crops and soil (WHO, 1984). Adamu (2013) assessed among other things the TDS of a dam and irrigation canals of the Watari Irrigation Project in Nigeria. Water samples were taken from six positions and taken to the laboratories for analysis. This is a good practice to ascertain the reliability of the results. All the values were below the recommended limits for irrigation. It was therefore recommended that the dam water was fit for irrigation. TDS is influenced by geo-chemical characteristic of the area. During rainy seasons TDS concentration increases in water bodies due to dissolution of fertilizers, manure and other chemicals in runoff. It therefore means that there is a great variability in TDS with season (Shabalala *et al.,* 2013).

In another study, Shabalala *et al.* (2013) investigated the variation of water quality with season on the Bonsma Dam in South Africa. It was found that total dissolved solid concentrations were high during the rainy season, while the pH value was low. But all the data met the requirements for irrigation. But during the dry season the water became alkaline and the TDS concentration reduced. Runoff from agricultural activities resulted in raising EC and TDS in the dam. High pH level in the dam during the dry season was attributed to high fertilizer application and dumping of chemicals. It was concluded that agricultural activities affect water quality in a catchment area hence they have to be controlled.

2.8.2. Chemical parameters

Besides the physical parameters, chemical constituents in irrigation water above certain limits can pose serious effect on crops, soil and humans. Notably among them are sodium ions, chlorides and the heavy metals.

High toxicity of sodium ions (Na^{+}) in irrigation water can have serious consequences on soil and crops. Sodium ions dissolve organic substances in the soil and disperse soil particle hence destroys the soil structure. Irrigating crops with saline water causes sodium to accumulate around the root zone of crops. This increases the concentration of the soil solution to the extent that osmosis is affected. It causes drought in the soil and consequently crop growth is impaired (FAO, 2010). For example, Kahlaoui *et al.* (2011) investigated the effects of subsurface irrigation systems together with three tomato cultivar tolerance to salinity. Different concentrations of sodium were applied to the three cultivars at different water requirements of the crop at 100%, 80%, 50%. The results showed variability to the tomato parameters such as leaf area, petiole size, and chlorophyll content. Fruit size was not affected; however, there were differences in sodium, magnesium and calcium contents of the crop. High concentration of sodium and chlorine in irrigation water make it saline and may be harmful to crops (Verwey & Vermuelen, 2011).

Nevertheless sodium chloride concentrations in ponds increase when the water level is low due to evapo-transpiration and percolation (Ochieng *et al.,* 2013; Muyen *et al.*, 2011). During the rainy season when the pond volume is high, toxicity due to sodium chloride concentration will not be detrimental to crops. The study believes that by the time the pond water level reaches its toxicity level the crops might have matured and been harvested. In addition, the effects of high toxicity of sodium on crops are more pronounced on tree crops than annuals (DWAF, 1996).

Ventrella (2012) studied the effect of saline irrigation water on tomato in the Mediterranean region. The treatment of electrical conductivity EC levels of 2.99 ds m^{-1}; 4, 95 ds m^{-1} and 6 dsm^{-1} was applied. The treatment was combined with water requirement to the crop at 100%, 50% and 25% levels. It was found that there was no significant difference in yield between good quality water and saline water, rather the crop quality increased with the use of saline water. However, the study suggested that when average winter rainfall is low, salinity level must be monitored and husbandry practices adapted accordingly. It can therefore be inferred that saline water can be managed and used successfully for irrigation. Singh and Pandor (2012) conducted a similar experiment on mustard using saline water at 7.48dsm^{-1}with good quality water. It was also found that there was no significant reduction in yield of the crop. It was therefore concluded that saline water is useful for supplementary irrigation. The two studies used electrical conductivity to measure salinity; this is the measure of the conductivity of dissolved ions in solution, it is not a true measure of salinity. Specific ion toxicity should have been used to measure salinity such as sodium and chloride ions instead of electrical conductivity or total dissolved solids. Ondrasek *et al* (2011) recommended ways to control salinity by using micro irrigation at short intervals, mulching of the soil, reducing the use of fertilizers and planting genetically modified crops. Ephemeral ponds are subjected to varying saline concentration reaching the highest level when the water volume is low.

Salinity can be controlled to some extent but the presence of certain heavy metals such as cadmium, lead, mercury and arsenic in irrigation water over and above the recommended limit poses a concern to water users. Besides causing reduction in yield and quality of crops, heavy metals can affect the health of humans (Anim *et al.,* 2012). Aweng *et a*l. (2011) assessed the concentrations of aluminum, boron, cadmium, iron, lead, manganese and zinc in irrigation water, soil and some fruits and vegetables. With the exception of boron, cadmium and manganese, all the metal concentrations were within the safe limits of the National Water Standard for Irrigation (INQWS, 2010). With regard to soil and crop, all the metals analysed complied with the recommended limits. Therefore, high concentrations of certain constituents in irrigation water do not mean that the water must be discarded since the absorption of minerals depends on the type of crop or the presence of other constituents in the water. Similarly, Khan *et al.* (2014) determined the concentration of various heavy metals in irrigation water, soil and two crops, canola and spinach by using industrial wastewater. The results confirmed safe limits of all the heavy metals in water, soil and crops except cadmium whose concentration was higher in the crops above WHO recommended criteria. However, cadmium concentration tends to be higher in wastewater and crops hence it has to be monitored regularly (Khan *et al.,* 2014). Although the study used only two crops, results revealed that under conditions of low pH, more heavy metals such as cadmium become available in soil solution and are absorbed by plants (DWAF, 1996).

Anim *et al.* (2012) also conducted a study to determine the effects of heavy metals on lettuce by using sewerage water and a hand dug well as sources of irrigation water. Water, soil and leaf analyses were done using standard procedures. The chemical analysis included inter alia Fe, Mn, Zn, Cu, Pb and Cd. All these elements showed high concentrations in water, soil, and leaves but they did not exceed the limits for WHO criteria except for Cd and Mn. Hence the following conclusions and recommendations were made:

- The presence of heavy metals in vegetables can be harmful to humans
- High concentrations of heavy metals in leaves may be linked to the soil
- High levels of Cd might be due to bioaccumulation
- Leaves tend to accumulate heavy metals more than roots
- Health officials should educate people about health hazards associated with wastewater irrigation

Some of the common anions that can affect crops are chlorides and nitrates. Both are crop nutrients but higher concentrations in water for irrigation can reduce crop quality and yield. For example, a study was conducted on the Watari Irrigation Project on the slope of the Watari River Valley in Kano, Northern Nigeria, to assess the quality of collected irrigated water and the effects on soil. The anions that were analysed included among others Cl^-, HCO_3^- and NO_3^-. Seven water samples were collected from seven sites without any replication. But for the soil analysis seven samples were collected from the sites and each sample was replicated. All the anions were within the recommended limits except one site where the Cl^- concentration was above the safe limits. It was recommended that in spite of the favourable results, water quality monitoring should be done regularly. In addition, agro – chemical and fertilizer application should be managed to avert pollution of the river. However, the water samples should have been replicated to determine the reliability of the data.

In another study by Anim *et al.* (2012) to assess the quality of untreated sewerage water for irrigation in the cultivation of lettuce, high levels of Cl^-, SO_4^{--}, and PO_4^{---} above WHO recommended limits were observed. It was suggested that health workers must educate people about the use of untreated sewerage water for irrigation. In the study area some of the ponds are next to residential areas and the ponds could be affected by sewerage discharges.

2.8.3. Microbiological water quality

The presence of micro – organisms in irrigation water above the recommended limit can contaminate crops such as vegetables and fruits. Subsequently, when they are ingested by humans they can cause problems such as vomiting, diarrhea, and stomach pain. The common micro – organisms that may be present in irrigation water include bacteria, fungi, viruses, and protozoa.

Fonseca *et al.* (2012) assessed the survival rate of *E. coli* on selected vegetables through the use of different irrigation methods such as furrow irrigation, sprinkler and sub-surface irrigation. It was observed that the bacteria could survive longer (7days) on vegetables irrigated by sprinkler irrigation. In addition, there was a longer survival rate of the bacteria in soil in winter than summer. It was confirmed that bacteria contamination of fruits and vegetables is more pronounced using sprinkler irrigation than any other method.

A study was conducted by Ijabadeniyi *et al.* (2011) in Mpumalanga in South Africa to determine bacterial quality of irrigated canal water from Loskopdam. Bacteria concentrations were measured from two rivers that supply water to the dam and vegetables were assessed for *E. coli* contamination. The study took place over a period of 12 months. It was found that the level of *E. coli* and faecal coliform was higher than all other pathogen above WHO acceptable limit for irrigation. This goes a long way to confirm the findings of Akrong *et al.* (2012). It was concluded that the rivers in the area could be the possible sources of vegetable contamination. But the type of irrigation method was not mentioned. Another contributory factor for vegetable contamination could be due to the irrigation method applied.

In a similar study, Abakpa *et al.* (2013) assessed the quality of irrigation water such as abattoir wastewater, industrial wastewater, domestic sewerage and non-point source polluted water in Kano, Nigeria. The results showed faecal coliform concentrations were above 1000 cfu/100ml. and above permissible levels by WHO. It was concluded that faecal pollution was a threat to public health and discharges of wastewater into water bodies must be monitored and disinfection of polluted water must be done before using it for irrigation.

2.9. Water Quality Guidelines for Irrigation

There are many guidelines that have been developed for use in irrigation. The common ones are WHO Water Quality Guidelines and European Water Quality Guidelines. All these describe the constituents of water that are suitable for irrigation. Guidelines have been determined for chemical, physical and microbiological parameters. The descriptions range from no degree of restrictions, slight to moderate problems and severe irrigation problems. But the present study l uses the DWAF (1996) and WHO Water Quality Guidelines.

2.9.1 Department of Water Affairs (DWAF) water quality guidelines

The DWAF guidelines were developed for water managers, decision makers connected with the use of water and water users in irrigation. The main purpose was to determine the fitness for use of irrigation water based on the constituents present. The guidelines are more detailed than other international ones. However, they tend to focus more on the chemical parameters with only coliform bacteria described in the guidelines. Coliform bacteria are indicator organisms that give information of water pollution. However, a few specific pathogens such as *Vibrio cholera* should have been included because this is a killer pathogen that can easily contaminate fruits and vegetables and can be transmitted to humans when ingested (Kraft, 2018)

In addition, asbestos can contaminate irrigation water through mining. The fibres can remain on fruits and vegetables that are irrigated by contaminated water. This can cause asbestosis to humans over a long period. Moreover, mercury is a highly toxic substance that can occur in irrigation water and can bio-accumulate in humans through ingestion of fresh fruits and vegetables. In South Africa, due to improper mining and poor environmental management acid mine drainage is formed. The chemical can contaminate water bodies such as groundwater, rivers, dams and ponds. The inclusion of such substances in the present water quality guidelines vis-à-vis irrigation water guidelines is vital for human health. In addition, some of the criteria are described as tentative. This means that there was a disagreement about the criteria and the findings were inconclusive; suggesting further studies, which could provide actual results about the criteria, are required.

2.9.2. World Health Organisation (WHO) water quality guidelines

There are many water quality guidelines developed by WHO which include domestic, aquatic ecosystem and wastewater use. There is no specific guideline for irrigation hence the FAO (1987) guidelines for irrigation is referred to as the WHO Water Quality Guidelines for Domestic Water use. The main aims for the development of the guidelines were to protect public health and to be used as the basis for individual countries to develop their own guidelines. This is a good example for situations, resources and priorities differ from one country to another. The adoption of criteria based on domestic water use is flawed. The effect of constituents on humans is different from that of crops and soil. The FAO guidelines is old and only takes care of parameters such as pH, TDS, Na^{+}, SARS, $CO3^{--}$, $HCO3^{-}$ and coliform bacteria. New studies have revealed the effects of lead, cadmium, Aluminium etc. on the soil, crops and humans through irrigation water. Hence, those constituents must be included in the guidelines. Secondly, the criteria are lax as compared to DWAF or EU guidelines and may not serve their purpose for protecting public health. Thus, the present study made use of both guidelines to augment for the constituents not present in the other guidelines.

CHAPTER 3

DISTRIBUTION OF EPHEMERAL PONDS AND LULC DYNAMICS AROUND THE PONDS

3.1. INTRODUCTION

Ephemeral ponds are formed in all regions of the world. Nevertheless, their distribution and longevity depend on rainfall intensity and soil characteristics of an area. High rainfall contributes to abundance of the ponds, their size and longevity (Owen & Horton, 2013). Moreover, fine, textured soil such as clay reduces the infiltration rate of water in the pond making the water stay longer in the pond. In addition, the underlying rock influences the formation of ponds. Rocks such as dolomite and lime promote the formation of groundwater leaving less water on the surface. Other impervious rocks such as granite reduce the percolation of water and contribute to the formation and the longevity of the pond water. The size and volume of water in the ponds are influenced by slope height and length surrounding the ponds and area of water surface (USGS, 2016). Steep slope accelerates the flow of water into the ponds. But, when the slope is gentle more water seeps into the soil and reduces the amount of water that enters the ponds. Moreover, the slope length surrounding the ponds contributes to the quantity of water that flows into the ponds. This has effects on the area and volume occupied by the water in the ponds.

Ephemeral ponds are located at a lower depression of the catchment area hence they receive water mainly from runoff. In the catchment area, there are many land uses such as grazing, crop farming, mining and built-up areas. These activities affect the quality and quantity of ephemeral pond water. Chemicals, fertilizers and agricultural waste enter the pond through runoff. In addition, some wastes from mining, construction and homes end up in the pond. The wastes and effluent affect the water quality of ephemeral ponds (Jocque *et al.,* 2010). Also the creation of hard surfaces accelerates the flow of water into the ponds and thereby increases the volume of water in the pond.

The conservative method of manual identification of ephemeral ponds and the subsequent mapping is difficult and time consuming. However, over the last few years Remote Sensing and GIS has made it easy to solve the problem. The study therefore made use of Landsat 8 to identify the ponds in the study area, their distribution and LULC.

3.2. Methodology

This section provides a description of the material and methods for collecting data. It, therefore, includes data sources, image processing and change detection.

3.2.1. Design of the Study

The study was quantitative and the design adopted was SIMPLE EX – POST FACTO, which is characterised by cause and effect relationships. Land use affects pond water quality, pond area and water depth. The design was used to investigate the effects of land use on ephemeral pond water characteristics. Data such as depth of pond, climate, land use and land cover change were collected for analysis.

Objectives 1 and 3: *To map the spatial distribution of ephemeral ponds and distinguish between land use/ land cover dynamics around the ponds in the study area.*

Landsat 8 Enhanced Thematic Mapper Plus (ETM^+) was used to collect information about the ponds in the study area. This multi temporal satellite has a resolution of 30 m. It was, therefore, used to map land use land cover change from 2004 to 2013 using Erdas Imagine 2013.

3.2.2. Satellite Data

The traditional method of mapping ponds and water bodies has proved time-consuming and expensive. Hence, this study utilized the shapefile and Landsat remote sensing data to determine the spatial distribution of ephemeral ponds and land cover changes around the ponds.

3.2.2.1 Data sources

Landsat images, level 1G, were obtained from South Africa National Space Agency (SANSA). A strategy for selecting Landsat imagery for development of land cover database for the study area was governed by available multi-temporal images, vegetation phenology and image quality (cloudiness, haze). The data set was derived from Landsat satellite images spanning a 10-year period (2004 to 2013). The North West shapefile was used to show the distribution of the ponds in the study area. Processed, multi-temporal Landsat 8 imagery at 30 m resolution assisted in identifying the location of the ponds and area covered by the ponds in order to determine their capacity for irrigation. This was achieved by means of using supplementary data from a phase file from the Survey Department in South Africa.

3.2.2.2 Selection of ponds

Google Earth was used to display all the ponds in the study area. North West phase file was used to show the distribution of the ponds in the study area. This was followed by the use of Landsat 8 Images that were processed to identify the ponds. Twenty two ponds were then selected based on proximity to road, size of ponds and the longevity of the pond water. Random sampling was then used to select 5 ponds for study. In addition, land use and land cover mapping was done to determine the land uses around the selected ponds. LULC influences pond water quality and quantity.

ASTER 30-m resolution digital elevation model (DEM) data was used to extract slope length and height of each selected pond as these determine the quantity of water that is collected in the pond.

3.2.3 Data analysis

3.2.3.1mage processing

Land cover mapping and subsequent quantitative change detection requires geometric registration between image scenes, and radiometric rectification to adjust for differences in atmospheric conditions, viewing geometry and sensor noise and response (Jensen, 2005; Lillesand *et al.*, 2008).

Geometric corrections

Geometric correction involves a process of minimizing geometric distortions in an image caused by systematic and unsystematic sensor errors. All the images were resampled using the nearest neighbour option and were projected to the Universal Transverse Mercator (UTM) system. The images were registered to South African datum projection system to match them with available in situ vector data.

Radiometric correction

The images were pre-processed by converting the digital numbers to reflectance units (Culf *et al.*, 1995). This correction minimizes variation due to varying solar zenith angles and incident solar radiation. DN values were converted to radiance values (L) using the calibration coefficients "gain" and "bias" supplied in the imagery report file as shown in Equation (1.

$$L_\lambda = (gain * DN) + bias \qquad \textbf{\textit{Equation 1}}$$

where: L_λ =satellite radiance and *DN* is the digital number.

Once radiance values were calculated, the reflectance (ρ) was then calculated for each band as described in Vermote *et al.*(1997). The E_{Sun_λ} values were taken from the Landsat 8 science Data Users Handbook (NASA Goddard Space Flight Centre, 2002).

3.2.3. Image classification

Image classification is the process of assigning the pixels to different classes and usually each pixel is treated as an individual unit composed of values in several spectral bands. In this study, a supervised maximum likelihood classification system was used to extract thematic classes from the images and for which area statistics was generated

3.2.3.1 Land Cover Classification System

Land use and land cover categories were mapped using the classification scheme developed by Thompson (1996) which included grassland, freshwater, cultivated/grazing and built-up-areas.

3.2.3.2 Classification accuracy assessment

Accuracy assessment of land cover mapping is an important step in the process of analysing remote sensing data. In this study, field exercise facilitated the identification of ground reference samples for use in the assessment of the accuracy of classified images. Furthermore, to correlate spectral features of the image with features on the ground, field exercise was conducted during the dry season, corresponding to the time of image acquisition. Thereafter, ground data was compared to data derived from image classification. The ground reference label was paired with the remote sensing-derived label for assignment in the error matrix, (Jensen, 2005). The error matrix showed errors of omission (producer's accuracy) and commission (user's accuracy), overall classification accuracy and a Kappa coefficient. The Kappa coefficient of agreement is a measure of the actual agreement minus chance agreement. The overall classification accuracy is a percentage expressed as the number of correctly classified sample pixels over the total number of sample pixels. This percentage indicated how accurate the classification was with respect to the reference data (Story and Congalton, 1986).

3.2.4. Change detection

Post classification comparison was employed for the 2004 to 2013 images that were independently classified and registered in order to employ the algorithm to determine those pixels with a change after image classification. Quantitative statistics were compiled to determine specific changes between the two images i.e. magnitude and direction of change in each land cover type (Calder, 2002). Tables were drawn for each of the years under study to understand the changes in land use land cover for the years studied.

3.3. Results and Discussions of Remote Sensing and GIS Data

Remote Sensing and GIS are powerful tools to map and collect data about water bodies including ephemeral ponds. The section embodies the display of GIS images in the form of tables, graphs and the discussion thereof. Figure 3 shows the distribution of ephemeral ponds in the study area.

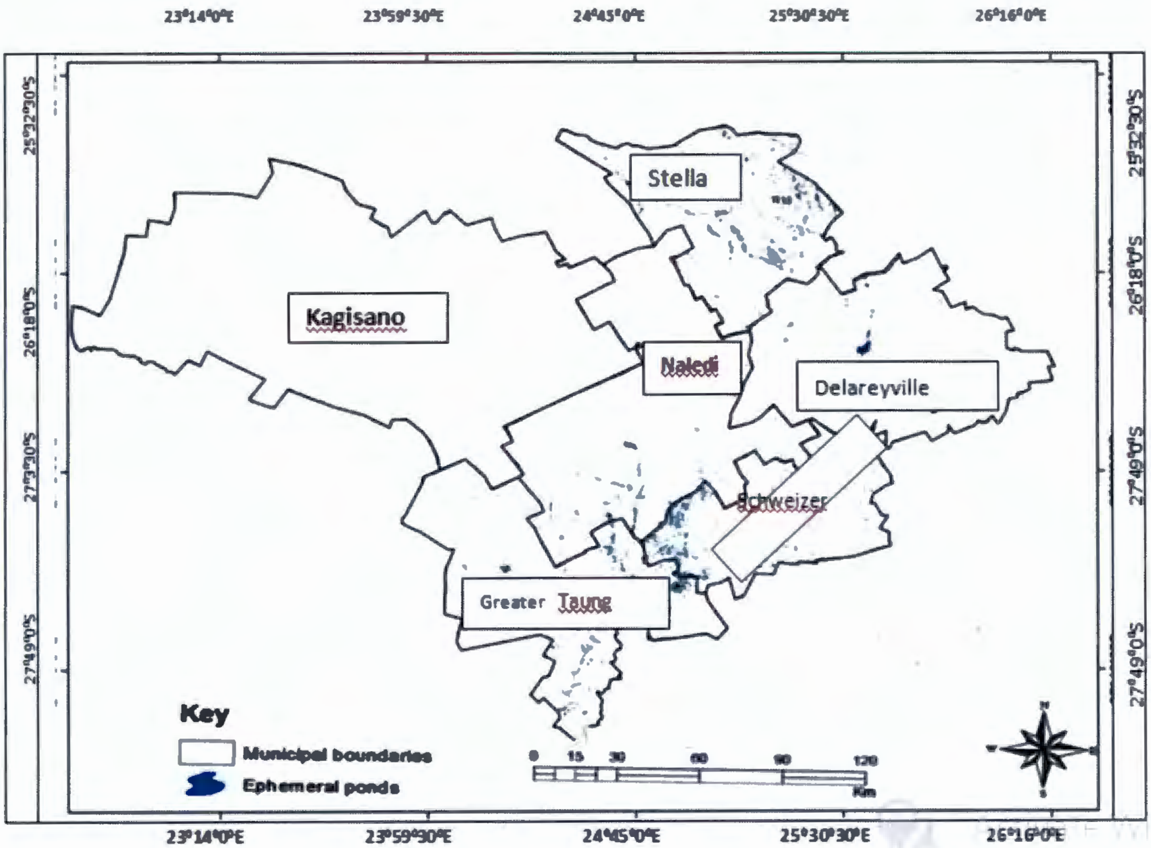

Figure 3: Map showing distributions of ephemeral ponds in the study area

3.3.1 Distribution of ephemeral ponds in the study area

This was made possible by the use of Landsat-8^{TM}+. Muster *et al* (2012) used Landsat 5^{TM} at 30m resolution to identify the water bodies in the Artic Tundra Wetlands. Qiao *et al* (2015) also made use of Landsat TM/ETM ortho-rectified images to map the supra glacier lakes in the Khan Tengri Tumour Mountains.Ephemeral ponds are formed during the rainy season that starts from October and ends in March the following year. The distribution and the number of ponds depend on rainfall intensity and soil characteristics. During periods of high rainfall, more ponds are formed and vary in size from a few square meters to about 20 hectares. The longevity of the ponds also ranges from a few days to about six months. The Kagisano area is virtually devoid of ponds. This is mainly due to the dryness of the place. The area experiences relatively low rainfall.

Furthermore, the underlying rock consists of dolomite and siltstone. Dolomite is responsible for the formation of groundwater hence rainwater infiltrates and accumulates underground. More ponds are formed at Stella, Schweitzer Reneke and its surroundings however, larger ponds are observed around Delareyville. This is due to the high rainfall around those areas and also the surrounding areas have rocks that consist of siltstone, andersite and tillite that store water on the surface. Small ponds form in and around Taung but due to the nature of the underlying rock the water percolates to form groundwater. When rainfall intensity is above average for a particular season, the ponds start filling until they reach their maximum height in February. The longevity of the bigger ponds is prolonged thus could be used for irrigation. The smaller ponds lose their water immediately after the rainy season.

3.3.2 Spatial distribution of ephemeral ponds in the study area

The location of a pond, slope height, length, area covered by the pond and its depth determine the amount of water it can store (USDS, 2016). These parameters affect the capacity of a pond and its subsequent suitability for irrigation. When a pond is located down a steep slope, a lot of water is collected by the slope and runs down quickly to be stored in the pond. This contributes to the volume of water in the pond. The water also spreads over a larger area. In addition, when the slope around a pond extends over a large area, more water moves down and collects in the pond.

Spatial Location of site A, B and C

All the three ponds are situated on a long elevation between Madibogo and Delareyville. Their formation was due to the high rainfall in the area, low water permeability and the nature of the underlying rock. Figure 4 shows the spatial location of the ponds.

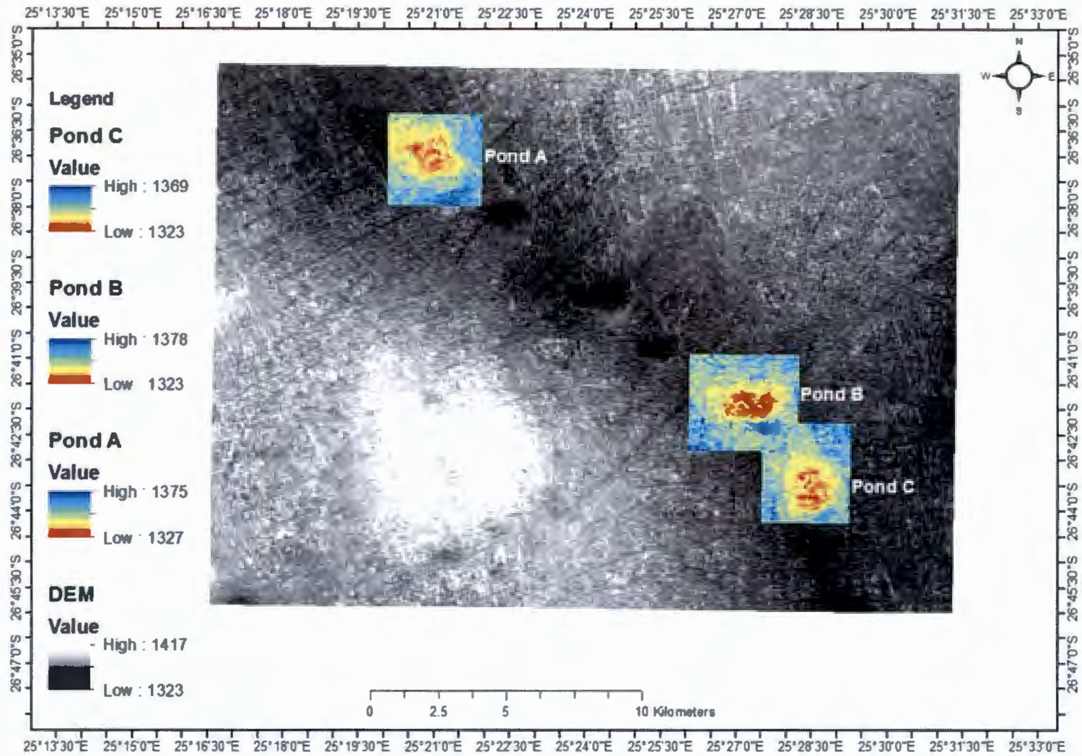

Figure 4: Map of sites A, B and C showing spatial location

Pond A is situated between Delareyville and Madibogo on Latitude 26° 24' 31.86"E and Longitude 25° '10' 37.41"S. The water occupied an area of 37.17ha. The water depth at 2014 was 1.620 m. The highest point on the slope is 1365 m with an average slope height of 13.61m above the water surface. It is bordered by a long slope that also contributes to the amount of water that collects in it. Due to the low soil permeability the water remains in the pond for long. The water can be used to irrigate crops such as vegetables and cereals. The growing of these crops can improve food security in the surrounding villages. In addition the vegetables can be sold at Delareyville, Madibogo and the surrounding villages to provide cash to the farmers. Rabbani *et al* (2013) studied the effects of climate change on some rural, coastal pond villages in Bangladesh. It was observed that about 20% of the rural communities use the water for home gardening and irrigation.

Pond B is located at Delareyville on Latitude 26° 41' 5.97"S and Longitude 25° 27' 41.43"E. The highest point on the slope is 1387m. The average slope height is 18.25 m. The pond covered an area of 50.58 ha with a maximum depth of 2.540m in 2014. The extensive slope coupled with the height assist in the flow of runoff into the pond. During periods of average and above average rainfall, a lot of water fills the pond. Consequently it may be suitable to grow a variety of crops such as vegetables, cereals and fodder. In the study area most of the farmers are herdsmen. During the period of drought, fodder becomes scarce and expensive. It adversely results in poor growth and high mortality of the livestock. Thus farmers could use the pond water to irrigate crops such as lucerne, oats and maize. These can be cut and stored as fodder for farm animals. The fodder will improve the conditions of farm animals and also serve as a source of income for the farmers.

Pond C is also located next to Delareyville along Schweitzer Reneke road. Its geographical location is Latitude 26° 41' 5.97"S and Longitude 25° 27' 41.43"E. It is bordered by a steep slope at the north western part of the pond. The highest point on the slope is 1351 m with an average slope height of 7.7m. The steep nature of the slope assists in the flow of runoff into the pond. In 2014, when measurements were taken the water covered an area of 17.64 ha and a maximum depth of 2.260 m was recorded. When the amount of rainfall is high, the longevity of the water increases and this could be suitable to grow short-seasoned crops such as vegetables and cereals.

Spatial location of site D

The pond can be found between Pudimoe and Dryharts along Taung, Vryburg road. It is located on Latitude 27° 24' 1.17"S and Longitude 24° 43' 2.14"E. The highest point on the DEM is 1264 m and the lowest is 1077m. The average slope height is 39.5 m. The shade of brown colour indicates the dry pond. In 2014, the height of the water column was 0.450 m.

The location of pond D is represented by Figure 5

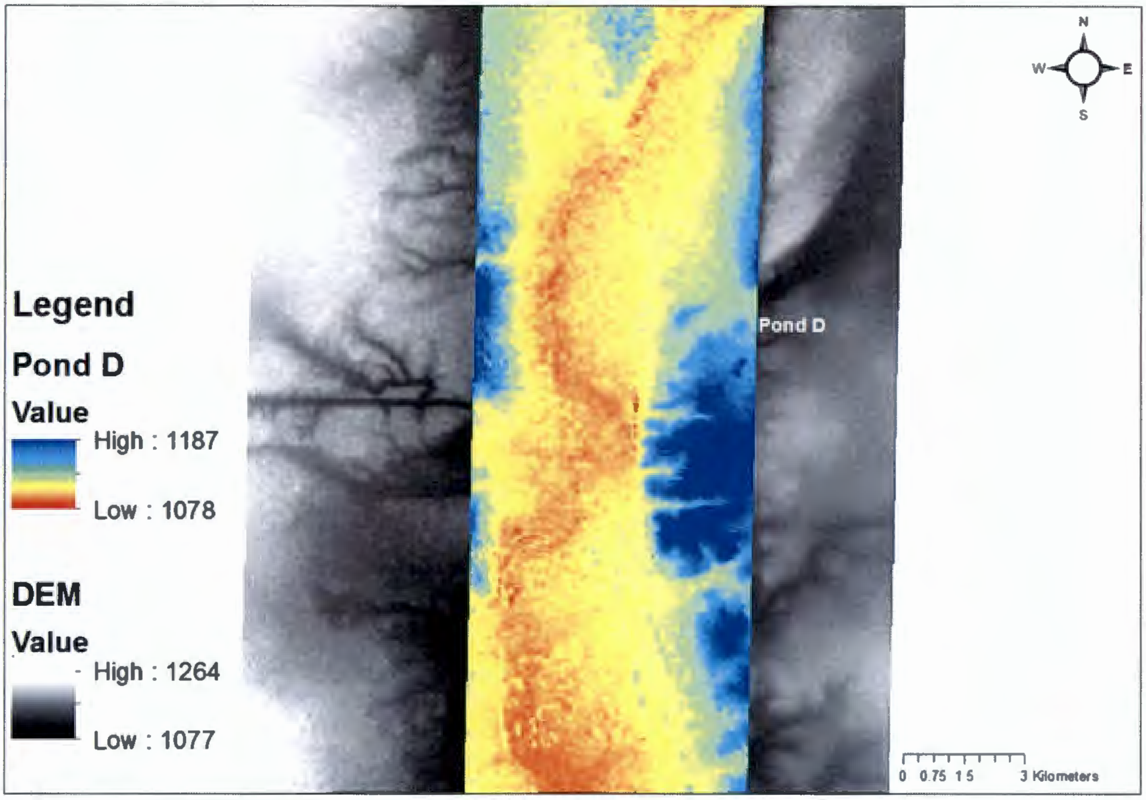

Figure 5: Map of site D showing spatial location

Runoff from the north western slope enters a small stream hence the low water capacity of the pond. The low depth and small area covered by water during the rainy season render the pond unsuitable for irrigation.

Spatial location of site E

Figure 6 represents the spatial location of pond E. The pond can be found along Vryburg, Setlagole road next to Stella Junction. It is located at Latitude 26° 32' 52.29"S and Longitude 24° 52' 28.38"E. It is bordered by a long slope of the highest point of 1356.86 m. In 2014, the water covered an area of 61.20ha and a depth of 2.150 m.

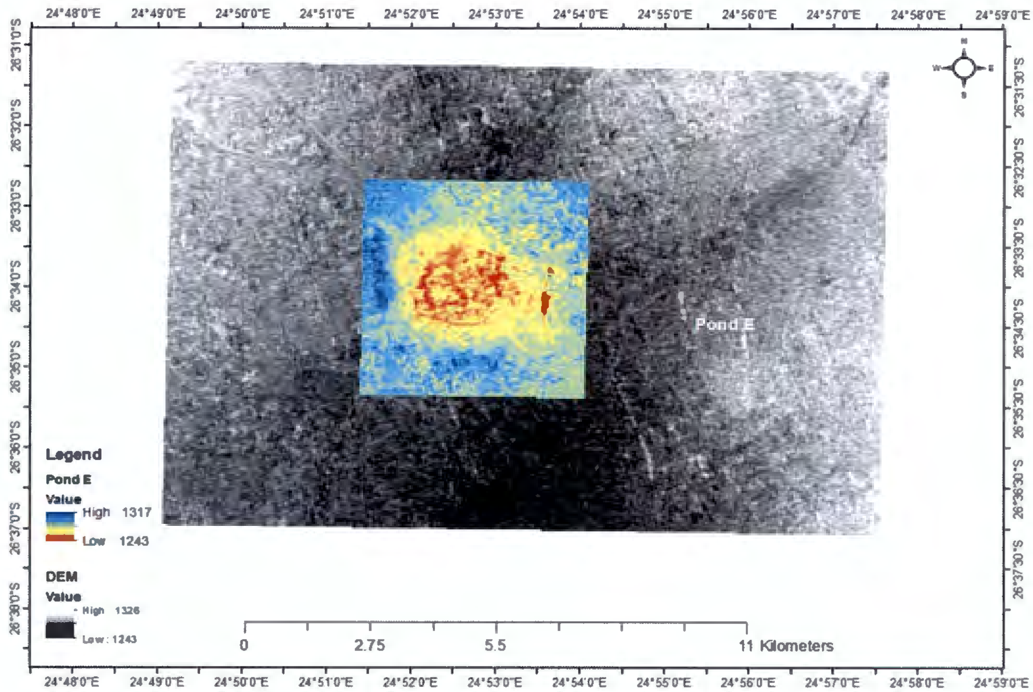

Figure 6: Map of site E showing spatial location

Due to the slope length and poor soil permeability, it is able to store a lot of water during the rainy season. The water can, therefore, be used for irrigation. The altitude and the slope surrounding the ponds assist in determining the amount of water that collects in the ponds and consequently their suitability and longevity for irrigation. All the ponds collect enough water during periods of average and high rainfall and can, therefore, be used for irrigation except pond D that has low water depth.

3.4 Effects of Land use Land Cover Change on Ephemeral Pond Water

Recent studies have shown that land use and land cover change have effects on water quality (Gallo *et al.,* 2012). Land use and water quality have a bi-directional relationship. Land use activities affect water quality, while water quality influences how land is used (NSW Environmental Heritage, 2015). Water of good quality may be used for domestic purposes while poor water quality may be used for mining and construction. This section of the study analyses the effects of land use and land cover change on ephemeral pond water quantity in the study area. There were five main land uses: woody plants, grass, fresh water, build-up area and bare area.

The woody plants in the study area consist predominantly of the Kalahari Thornveld and shrub of the Bushveld type. Grass comprises vegetation mainly for grazing. Water refers to ephemeral pond water, patches of water on the soil after rain and ephemeral streams that contain water during periods of high rainfall. Tracks, paths, areas exposed due to fire, over-grazing and parts of the pond that become dry due to low rainfall, evaporation and infiltration constitute bare-areas. Land use land cover change of site A for 2004 and 2013 is shown in Figure 7.

3.4.1 Land use land cover characteristics for Site A

The area covered by the various land cover classes is shown in Table 1 and the maps in Figure 7. The classes identified were woody plants, grass, bare area and water. This site is located far from settlements; hence there is no land cover for built-up areas.

Table 1: Land cover classes in (ha) for site A

Sites A	2004	2013	Variation (ha)	% change
Woody plants	122.85	201.42	78.57	63.96
Grass	302.76	238.88	63.88	21.09
Fresh water	47.61	92.45	44.84	94.18
Bare areas	178.2	119.82	58.38	32.76

The woody plant cover in 2004 was 122.853ha and that for 2013 was 201.42ha representing 63.96%increase. During the same period, grass cover reduced by 21.09%. The reduction in grass cover could be attributed to over-grazing and bush encroachment. There is a large population of cattle that graze in the area. They use the pond as a source of drinking water. This results in overgrazing around the pond. Moleele and Vanderpost (2002) reported about 37,000 km^2 of near infrared reflective bush encroachment in 1994 in Botswana. This was attributed to changing of water points and kraals. There are no goats in the area; lack of browsers promotes bush encroachment (O'Connor *et al.*, 2014). In addition, there was 32.76% reduction in the area covered by bare area. The area lost was due to the patches of water that collected on the surface due to rain. Also the area covered by water increased by 44.84ha which could be attributed to rainfall variability. Immediately after a rain storm, more water collects on the soil surface. Consequently, the area covered by water increased. This is shown by more patches of water on the map of 2013 (Figure 7).

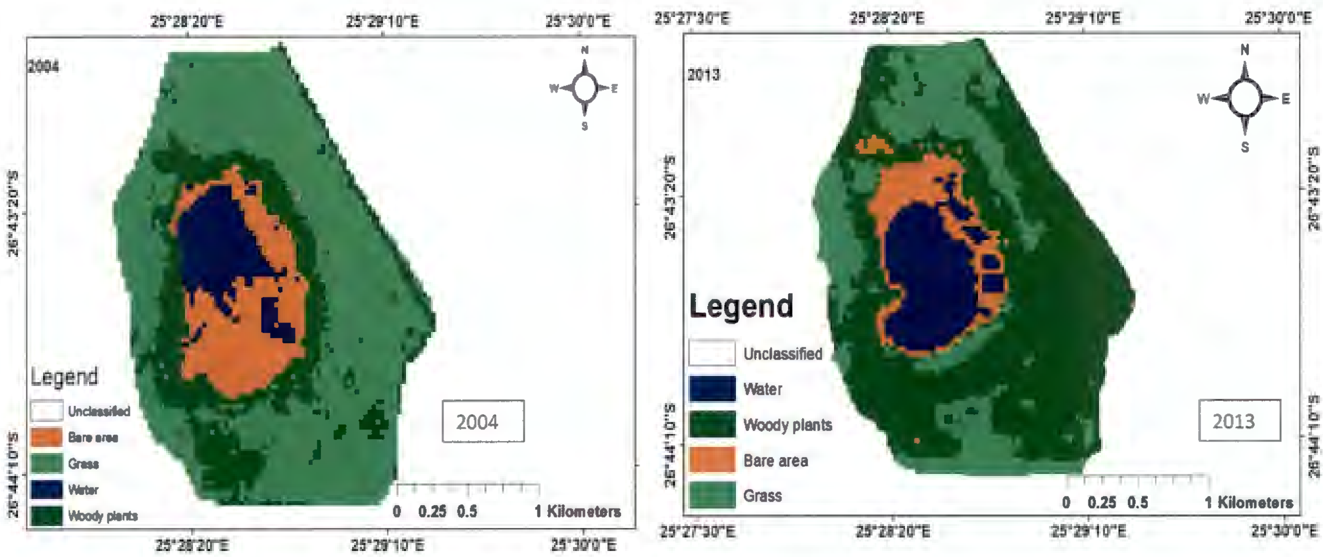

Figure 7: Maps showing Land use land cover for site A

3.4.2 Land use land cover change characteristics for Site B

Human activities affect land cover characteristics and these also influence water quality and quantity. The pond is located next to Delareyville and has all the classes comprising, woody plants, grass, build-up area, bare area and water. Table 2 shows the size of the land cover classes at site B. The maps in Figure 8 shows land use land cover for site B.

Table 2: Land cover classes in (ha) for site B

Site B	2004	2013	Variation (ha)	% change
Woody plants	168.93	206.06	37.13	21.97
Grass	336.96	399.29	62.33	18.50
Freshwater	379.17	186.14	193.03	50.91
Bare areas	107.07	235.67	128.6	120.10
Build up area	360.45	411.14	50.69	14.06

Human activities affect land cover characteristics and these also influence water quality and quantity (Gallo *et al*., 2012). The maps in Figure 8 shows land use land cover for site B. There was an overall increase of 21.97% and 18.50% in the area covered by woody plants and grass during the study period respectively (Table 2). The pond is located in town and there are few browsers and grazing animals. The area covered by water decreased from 379.17ha to 186.14ha amounting to 50.91%. This could be due to climate variability. Built-up area increased by 14.06%. Since 2004, there has been an increase in the number of RDP houses in Delareyville in the North Eastern part of the town. This resulted in the use of greater parts of bare areas. Also the property boom in early 2000 attracted many people from the middle class from the surrounding villages such as Madibogo and Setlagole to the town to enjoy good services. Parts of the land occupied by water might have been used to construct houses. Some people migrated from the villages to Delareyville to look for employment and since they could not afford to pay heavy rentals they resorted to building sharks for accommodation. The point was sustained by Adeoye (2012) and attributed the increase in build-up areas to the construction of residential areas and commercial activities. The bare area however increased by 120.10% from 2004 to 2013. The reduction in the area occupied by water created more bare area.

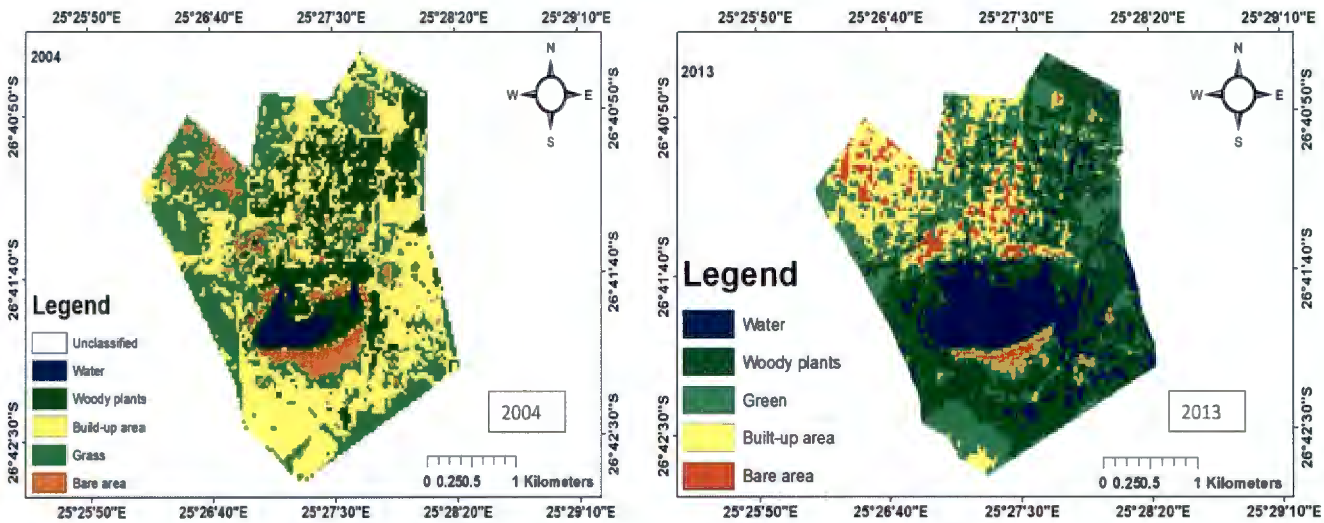

Figure 8: Maps of Land Use land Cover of Site B

3.4.3 Land use land cover change characteristics for Site C

Land use and land cover change for the years of 2004 and 2013 for site C has been represented in Figure 9 and it is discussed by making reference to Table 3, which outlines the spatial extents and the changes in land use between 2004 and 2013.

Table 3: Land cover classes in (ha) for site C

Site C	2004	2013	Variation (ha)	% change
Woody plants	110.34	239.51	129.17	117.06
Grass	246.42	313.58	67.16	27.25
Freshwater	69.39	92.43	23.04	33.20
Bare areas	196.02	17.64	178.38	91.00

The sub-catchment area around pond C consisted of woody plants, grass, bare area and water. No built-up area was identified due to lack of settlements. The pond is located on a farm where the main land use activity is grazing. The pond is used as a watering point for animals.

In 2004, the woody plants covered an area of 110.34 ha and increased to 239.51 ha in 2013 representing 117.06%. Similarly, grass cover also increased by 27.25% with simultaneous decrease in the size of bare area by 91%. During the 9-year period, greater parts of the bare area were occupied by grass and woody plants. With regard to water, there was an increase in the area occupied (23.04 ha). Greater parts of the bare area were occupied by grass and woody species. This could be attributed to the pond being located on a private farm where the correct stocking rate is maintained. Proper pasture management is practised including rotational grazing resulting in fewer bare areas. Camps are allowed to rest, this promotes seeding and the seeds are dispersed to cover bare areas. The increase in the size of the area occupied by woody plants can be attributed to bush encroachment (O'Connor et al., 2014).

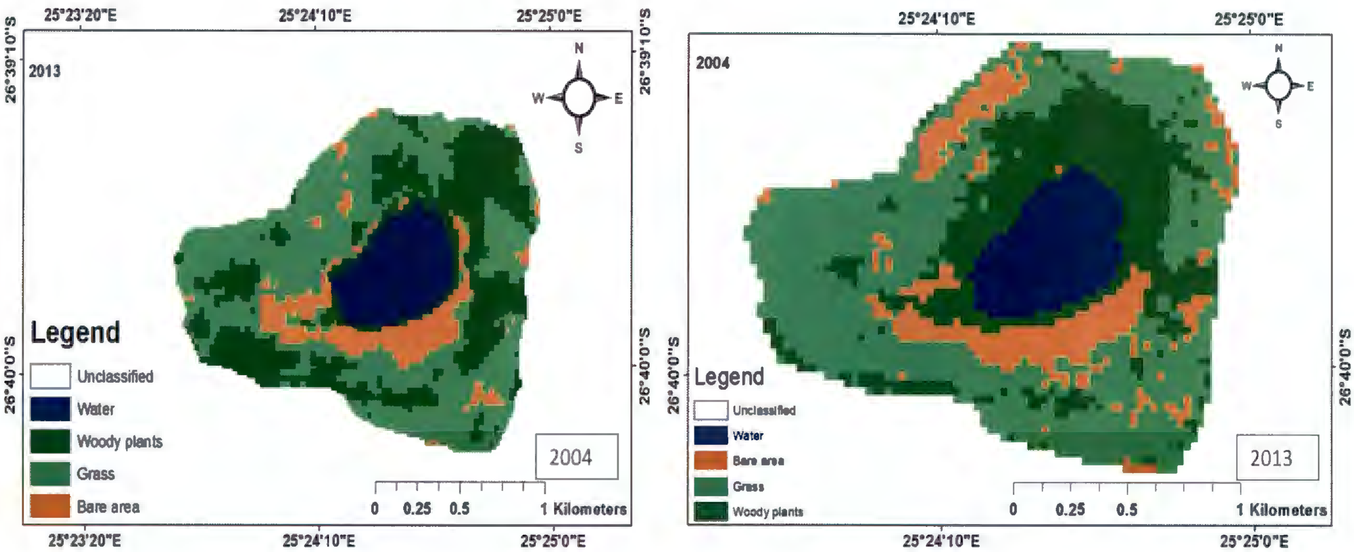

Figure 9: Maps of Land Use Land Cover for Site C

3.4.4 Land use land cover change characteristics for Site D

Land use land cover change for the years of 2004 and 2013 for Site D has been shown in Figure 10 and the land cover classes for Site D is shown in Table 4. This outlines the spatial extents and the changes in land use between 2004 and 2013. Four classes were observed. Comprising bare area, grass woody plants and water

Table 4: Land cover classes in ha for site D

Site D	2004	2013	Variation (ha)	% area change
Bare Area	3153.63	2072.52	1081.11	34.28
Water	278.99	0	278.99	100
Grass	1892.53	1837.13	55.4	2.93
Woody plants	1155.53	2223.36	1063.83	92.06

Table 4 shows land cover change of site D. The sub-catchment area consisted of bare area, water, grass and woody plants. There was no built-up area due to lack of settlement at the site. The bare area reduced by 34.28% from 3153.63 ha in 2004 to 2072.52 ha in 2013. Part of the bare area was occupied by woody plants. During the same period, the pond was dry. This could be due to the lower rainfall (342 mm) in 2004 and (342 mm) in 2013. Owen and Horton (2013) reported that during periods of low rainfall only 20% of ephemeral ponds in the Montana Prairie wetlands had water. The area covered by grass in 2004 and 2013 were 1892.53 ha and 1837.13 ha, respectively, amounting to 2.93% decrease. The reduction in the area covered by grass can be attributed to bush encroachment. The absence of browsers encourages bush encroachment. There are no goats in the area and could have resulted in overgrazing and, consequently, the creation of more bare areas. There was a 92.06% increase in the area covered by woody plants from 2004 to 2013. More woody plants occupied the bare area due to bush encroachment. In 2013 there was no water in the pond. This was due to the low rainfall in 2013.

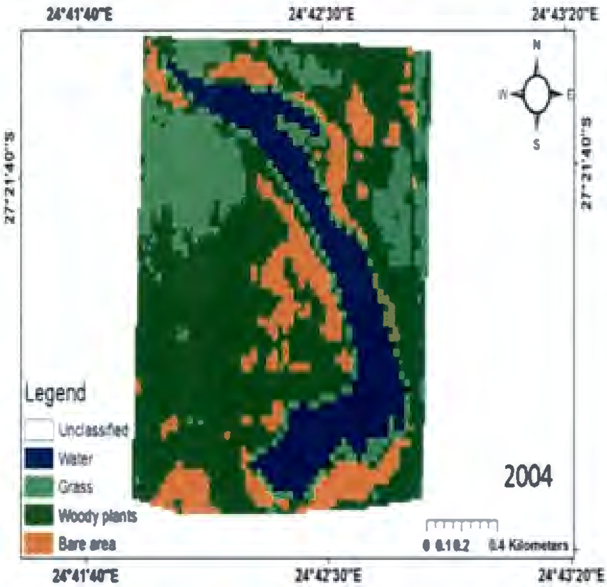

Figure 10: Maps of land use land cover of Site D

3.4.5. Land use land cover change characteristics for Site E

The lack of settlements at site E created only four land cover classes comprising woody plants, grass, bare area and water and these are shown in Table 5. Figure 11 shows land use land cover class of Site E

Table 5: Land cover classes in ha for site E

Site E	2004 Area (ha)	2013 Area (ha)	Variation (ha)	% change
Woody plants	294.03	146.27	147.76	50.25
Grass	238.23	374.87	136.64	57.36
Freshwater	69.39	130.43	61.04	87.96
Bare area	47.34	42.05	05.29	11.17

The area covered by woody plants reduced by 50.25% between 2004 and 2013. During the same period, grass cover increased by 57.36%. The catchment area is an open field and the people from nearby villages cut the woody plant as fuel wood. Hence, the vacant area created was colonized by grass. The area covered by freshwater in 2004 and 2013 were 69.39 ha and 130.43ha respectively. This represents about 88% increase and the reason for the increase was due to daily variability in the rainfall pattern. This is indicated in the map where there are more patches of water in 2013 than in 2004. Images might have been collected a few hours after a rain storm event. According to the South African Weather Service, Kimberley, on April 19, 2013 a daily rainfall of 13mm was recorded in the study area.

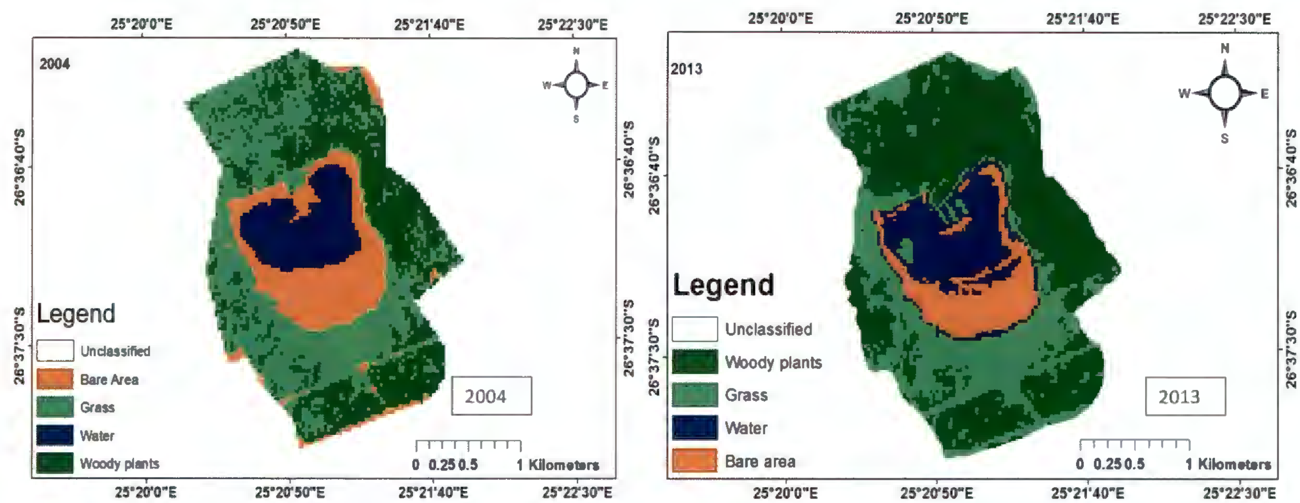

Figure 11: Maps of Land use land cover of site E

3.6 Accuracy Assessments

Accuracy assessments are carried out in remote sensing to determine to which extent the thematic classifications and their variables agree with the actual situation on the ground. This is normally determined by the producer's and user's accuracies and the Kappa coefficient. In addition, the inter-class confusion is discussed. Table 6 shows the error matrix for site A.

Table 6: Error (confusion) matrix for classification in site A

Classification data	Reference data					
	Bare area	Grass	Water	Woody plants	Total	User's accuracy (%)
Bare area	**28**	3	0	0	31	90.32
Grass	5	**31**	1	3	40	77.50
Water	0	1	**10**	0	11	90.91
Woody plants	0	0	2	**16**	18	88.89
Total	33	35	13	19		
Producer's accuracy (%)	85.85	88.57	76.92	84.21		
Overall accuracy = 85.00 %						
Kappa coefficient = 78.85 %						

The overall Kappa coefficient was 78.85%, this showed a moderate agreement between the correctly classified classes and the reference data. The producer's accuracy ranged from 76.92% to 88.57%. The lowest value for the user's accuracy was 77% while the highest was 90.91%. Grass had the lowest user's accuracy of 77.50%. This was due to inter-class confusion between woody plants and grass. Seven and a half percent of the pixels were wrongly classified as woody plants. Grass and woody plants sometimes form a homogeneous mix and makes spectral separation difficult (Palamuleni, 2009). Grass and water also showed inter-class confusion of 2.5% and 11.1%. Sometimes in a pond vegetation and water can occur in the same environment and can create confusion during classification resulting into commission errors. Table 7 shows error (confusion) matrix for classification in site B.

Table 7: Error (confusion) matrix for classification in site B

Classification data	Reference data					
	Bare area	**Grass**	**Water**	**Woody plants**	**Total**	**User's accuracy (%)**
Bare area	**5**	1	0	0	6	83.33
Grass	0	**43**	5	4	51	79.63
Water	0	4	**14**	1	19	73.68
Woody plants	1	3	0	**18**	23	85.71
Total	6	54	19	23	100	
Producer's accuracy (%)	100	84.31	73.68	78.26		
Overall accuracy =80.00 %						
Overall Kappa coefficient = 68.61 %						

The overall accuracy was 80%. It meant that 80 out of 100 of the data were correctly classified. There was a moderate value for the Kappa coefficient (68.61%). It represented a chance agreement of about 31.39%. All the values for the user's accuracy were below 90% and could be attributed to confusion between classes. The confusion value between bare area and grass was 16.6% which could be attributed to spectral similarities between red soil (0.0974) and dry grass (0.7588) and distinguishing between them becomes difficult. However, an error of omission occurred between grass and water where 10% of the pixels for grass were wrongly classified as water. The producer's accuracy ranged from 73.68% to 100%. However, a commission error also occurred between grass and water, grass and woody plants representing 7.4% and 5.6% respectively. Table 8 represents error (confusion) matrix for classification at site C.

Table 8: Error (confusion) matrix for classification in site C

Classification data	Reference data					
	Bare area	**Grass**	**Water**	**Woody plants**	**Total**	**User's accuracy (%)**
Bare area	**17**	0	0	1	18	94.44
Grass	0	**31**	6	0	37	83.78
Water	0	5	**9**	0	14	64.29
Woody plants	0	0	3	**28**	31	90.32
Total	17	36	18	29	100	
Producer's accuracy (%)	100	86.11	50.00	96.55		
Overall accuracy = 83.00 %						
Overall Kappa coefficient = 76.27 %						

All the user's accuracies were high except that for woody plants (94.44, 83.78, 64.29, and 90.32). Similarly, the producer's accuracies were above 80% except that of water (100, 86.11, 50, and 96.55). This was translated into high overall accuracy (83.00%). It indicated that more than 80% of the data were correctly classified. The Kappa coefficient was 76.27%. However inter-class confusion was observed between grass and water. Some grass grows in water and produced an error of 13.8%. Also a confusion error was observed between water and woody plants. The branches and leaves of tall trees masked water and resulted in the error of omission. An error of omission of 5.6% was recorded between woody plants and bare area and this was due to masking of bare area by tall trees.

Table 9: Error (confusion) matrix for classification site E

Classification data	Reference data						
	Bare area	**Built up area**	**Grass**	**Water**	**Woody plants**	**Total**	**User's accuracy (%)**
Bare area	**9**	1	4	0	1	16	56.25
Built up area	1	**22**	2	3	1	29	75.86
Grass	0	3	**24**	0	1	28	85.71
Water	0	3	0	**10**	0	13	72.92
Woody plants	0	1	0	0	**13**	14	92.86
Total	10	30	30	13	15		
Producer's accuracy (%)	90.00	73.33	80.00	71.43	81.25		
Overall accuracy = 78.00							
Overall Kappa coefficient = 71.52							

The user's accuracies of 56.25, 75.86, 85.71, 72.92 and 92.86 were calculated. An omission error of 25% was identified between grass and bare area. Some grass grows on bare area and could not be identified due to the 30m spatial resolution of Landsat data This is not accurate enough to identify small field data. An error of omission of 10.3% was recorded between built-up area and grass. Thatched roof and some buildings have similar spectral values as grass which makes it difficult to distinguish between the two (Palamuleni, 2009). A commission error of 10% was observed between built-up area and water. During heavy rain water collects in built-up areas and is included in built-up area in the classification. The overall accuracy showed that about 78% of the data were correctly classified. The Kappa coefficient indicated that about 29% of the data that was classified was due to chance.

3.7. Summary

In summary, there were changes in land cover classes of woody plants, grass, bare area and water. The reasons for the change were human and natural. Daily and seasonal rainfall variability was responsible for the changes in water cover. The changes in land cover for woody trees were attributed to the cutting of wood for fuel by nearby villagers. Also the reduction of the area covered by grass was linked to over-grazing and the subsequent encroachment by woody species. Moreover, the reductions in vegetation cover in general and bare area was attributed to construction and property development that accompany population increases. The overall accuracies and the Kappa coefficient were high. Nevertheless there was some inter-class confusion. It was observed between woody plants and bare areas, grass and water and that of water and bare areas. Confusion also occurred between built-up area and water. Sometimes vegetation and water; bare area and water occur in the same environment creating a commission error. Dry vegetation and bare area produce similar spectral value making it difficult to differentiate between the two. The same explanation could be given to confusion between built-up area and vegetation.

CHAPTER 4

LAND USE LAND COVER CHANGE AND WATER QUALITY OF EPHEMERAL PONDS

4.1. INTRODUCTION

Land use land cover change has effects on the quality and quantity of ephemeral pond water (Johnbosco & Nnaji, 2011).It is for this reason that LULC has to be identified and monitored regularly to determine its effects on ephemeral pond water. The common land uses in the study area are vegetation, bare soil, built-up areas and water. Excessive use of fertilizers and chemicals pollute the soil. During rain, nutrients and chemicals are washed into the ponds and thus affecting water quality. In addition, grazing animals leave a lot of droppings that can enter the ponds through runoff since the ponds serve as watering points for animals.

Vegetation cover, in general, traps silt, manure, fertilizers and debris, preventing them from flowing into ephemeral pond water. This helps to reduce pollution of the pond water. A bare area is created during land preparation for planting, over-grazing and veldt fires. Construction also contributes to the formation of bare areas. When the soil surface is exposed more sediment and water enter the pond. This has effects on the quantity and quality of water in the pond. Built-up areas have profound effects on the quality of water in the ponds. Effluents from mining, industries, homes and municipal waste mix with runoff and storm water and eventually end up in ephemeral ponds. Built-up areas form hard surfaces and speed up the flow of water into the ponds. Contamination of the pond water by sewerage is of special concern. This is associated with improper treatment of sewerage and irresponsible human defecation around the ponds. It is, therefore, important to assess the effects of LULC on the pond water quality. This chapter, therefore, analyses the effect of land use on water quality of ephemeral ponds in the study area.

4.2 Methodology

The methodology section comprises water sampling, chemical analyses of data and statistical analysis of data.

4.2.1 Water quality data

Water samples were collected for analysis of chemical and microbiological parameters. Water samples were collected in triplicate from the middle of the ponds just below the surface using 500ml plastic bottles sterilized and neutralized with sodium thiosulphate. The water samples were replicated to ensure the accuracy of the data. Each bottle was filled to 90% full and then covered using a clean tissue paper in the hand. The bottles were kept in a cooler box at a temperature between 4-10°C before sending it to the laboratory for analysis. Table 10 shows the water quality parameters that were analysed.

Table 10: Water quality parameters, measurements and units

Parameters	Measuring instrument	Unit of measurement	Reason for measurement
pH	pH meter	1-14	Suitability for irrigation
Electrical conductivity	Conductivity meter	Ms/m	Suitability for irrigation
Cations Na^{+},K^{+},Ca^{++},Mg^{++}	VariantAtomic Absorption Spectrometry	Mg/l	Suitability for irrigation
Heavy metal Cd,	Variant Atomic Absorption Spectrometry	Mg/l	Suitability for irrigation
Anions, PO_4^{-3},Cl^{-}, NO_3^{-1}	Colorimetry	Mg/l	Determination of pollution
Total coliform	Membrane filtration	Colony units/100m·	Suitability for irrigation
E coli	Agar test	Colony unit/100m·	Suitability for irrigation

The microbiological analysis was done within 24 hours. In situ measurements for temperature, pH (hydrogen potential), and electric conductivity (EC) were done using standard procedures (Ballance, 1996) by way of field meters. Samples for chemical analysis were collected and taken to the laboratory for analysis. Chemical analysis included cations such as sodium ($Na^{+)}$, potassium ($K^{+)}$, magnesium ($Mg^{++)}$, calcium (Ca^{++}) and Cadmium (Cd). The anions analysed included phosphate (PO_4^{-3}), nitrate (NO_3^-) and chloride (Cl^-).

The water analysis data were combined with the results of land cover change to run multi-linear regression equations to determine the effects of LULC on the pond water quality. Five sites namely A, B, C, D and E together with the corresponding percentage LULC data (grass, water, bare area) were used as the independent variables. The average water quality parameters, EC, NO_3^- , Na^+ Cd and *E-coli* for each of the selected sites were used as the dependent variables. All the data were run simultaneously by using regression analysis embedded in Excel software. This was followed by selecting water quality parameters as Y-range and the LULC values as the X-range. Finally, standard residual was selected. The results were then verified using SPSS software.

4.2.2 Statistical analysis of results

Statistical software SPSS and the Excel spreadsheet were used in analyzing data. The significant level for analysis of data was set at 0.05. The mean and standard deviation were calculated for all the water parameters namely, pH, EC, cations, anions, *E. coli* and total coliform using SPSS software. The standard deviation showed how the individual values vary from the mean. The mean was compared with the guideline values set by DWAF, FAO and WHO water quality standards. The values indicated if the water was suitable for irrigation with respect to the water constituents

The water quality variables and land cover change within the catchment were combined to run multiple linear regression equations to show the relationships between land use land cover change and water quality parameters.

$$Y = \exp(\beta 1 \text{ x land } 1 + \beta 2 \text{ x land } 2 + \beta 3 \text{ x land } 3 + \ldots\ldots \beta i \text{ x land i}) \qquad \textit{Equation 2}$$

where:

y is the dependent variable referring to the water quality parameter

Beta (β) is a correlation between land use change (%) and water quality variable

The beta value indicates how strongly each of the predictor variables affects the dependent variable; and it is measured in the units of standard deviation. When the independent variable (β) is negative it means it is inversely correlated with the water quality parameter. When it is positive, it implies a positive relationship and therefore has effects on the dependent variable. In addition the coefficient of determinant (R^2) values were calculated. Coefficient of determination can be expressed by percentage ranging from 0-100.

4.3 RESULTS AND DISCUSSION

The section below outlines the results obtained from water analysis data. The results are presented in the form of diagrams, pictures and tables which makes the results easy to interpret. It also includes detailed discussions of the results based on literature and the conclusions drawn from them.

4.3.1 Water analysis

The section about water analysis includes the results of the physic-chemical and micro-biological analysis of the water samples collected from five ephemeral ponds from Vryburg District in April 2014 after the rainy season. It is also followed by a comprehensive discussion of the results vis-à-vis the DWAF, WHO and FAO water quality guidelines.

4.3.1.1 Chemical characteristics of water in ephemeral ponds

There are many chemical constituents that determine suitability of water for irrigation. Some can be measured in situ and others are analysed in the laboratory. However, pH and electrical conductivity are some of parameters that can be measured in-situ. Table11 shows the results of pH and EC.

Table 11: pH and EC values of the sampled water

Sample ID	pH	EC (mS/m)
A	8.66 ±0.18	734 ±13
B	8.57 ±0.1	405 ±1.7
C	8.74±0.01	432 ±7
D	10.63 0	379±44
E	8.69 ±0.12	780±0.01
DWAF	**6.5-8.4**	**0-70**
FAO	**6.5-8.4**	**0-70**

pH

pH measures the concentration of hydrogen ions in solutions. The optimum pH range for growing crops is 5-7 (Cox, 1995). Lower or higher values have effects on crop quality and yield. The effect is more pronounced when it is accompanied by high alkalinity (Cox, 1995). The mean pH value recorded was 9.10 and the values ranged from 8.57 to 10.63. All the data from the sites were higher than the recommended values set by DWAF and FAO. Aguilar (2009) reported of a gradual reduction in plant height, dry matter weight among others in three marigold cultivars when they were irrigated with higher salinity water compared with the non- saline water. Also the effect on the growth parts was more severe when the pH was 8 compared to 6.8. In this study, the high pH values recorded may be attributed to the underlying rock which is dolomite and could also be from anthropogenic activities such as fertilizer application. Water samples from pond D recorded the highest pH value. This pond is next to an agricultural farm where fertilizer and lime application is common; and might have contributed to the high pH value. In addition, the underlying rock in Taung area is dolomite. This rock consists mainly of calcium and magnesium which are base minerals hence their presence in water increases its pH. The relatively low pH values obtained from ponds A, B and C might be due to the underlying rock consisting of andersite, siltstone and tillite. According to DWAF (1996), the effect of pH on crops is not all that severe but significant symptoms are only observed under extreme conditions. Irrigating crops with water with pH over and above the recommended limit may create problems such as yield reduction, poor quality products, foliar and fruit damage (DWAF, 1996). The problem can be reduced by an application of $CaSO_4$ to the soil (FAO, 1994; DWAF, 1996). This will create acidic conditions in the soil thereby reducing the pH. Application of organic matter is also recommended. Organic matter will improve the soil structure, make the soil well aerated, and increase the water holding capacity of the soil. It will also reduce the stickiness and cohesion of clay. In addition organic matter will supply nutrients and increase microbial population in the soil. In order to reduce foliar damage sprinkler irrigation should be avoided (FAO, 1994).

Electrical conductivity

The mean value for electrical conductivity was 546mS/m. The lowest value was 379mS/m for pond D whilst, the highest was 780 mS/m for pond E. This might be due erosion of rocks. This could be a possible reason for the high EC value. In addition, the pond serves as a watering point for game and grazing animals. The relatively low value recorded from pond D is expected. The pond is located far from town and the land use is grazing. The surrounding vegetation consists of a thick grass cover that traps sediments from runoff; hence the low electrical conductivity value. The recommended values for FAO and DWAF are 70 mS/m.

All the readings recorded were far beyond the recommended limits for FAO and DWAF. The high EC values recorded might be due to accumulation of sediments through erosion. Water sampling was done immediately after the rainy season. During the rainy season, a lot of sediments enter the ponds giving rise to high EC values. There is normally a significant difference in EC between the rainy season and the dry season (Shabalala *et al.*, 2013). Adamu (2013) assessed irrigation quality of a dam and irrigation canals of the Watara Irrigation Project based on its electrical conductivity. It was found that the water was suitable for irrigation for it satisfied the recommendation set WHO. Irrigating crops with water of electrical conductivity value between 270 mSm and 540 mS/m may result in about 20% reduction in yield when moderately tolerant crops are grown (FAO, 1994). In Addition, there will be foliar damage. Nevertheless, there are a variety of crops that can tolerate water of higher EC values such as cereals including maize (*Zea mays),* rice *(Oryza sativus),* sorgum *(Sorghum bicolor), (Triticum* *aestivum),* and barley *(Hordeum vulgar)* (DWAF, 1996). Maize is of a particular importance to the study area and is a good source of carbohydrates. It has a short growing season and can be planted on a variety of soil with easy cultural practices. It can be harvested green and serve as an easy source of food to rural communities. The plant material left after harvesting can serve as fodder for grazing animals. Fodder can also be used to prepare hay for animals during the dry season. The growth rate of the animals can improve and provide meat to the farmers. Animals and excess maize can be sold to give cash to the farmers. Money that would have been used to buy fodder will be saved. Moreover, lucerne is a fodder crop that is grown in the study area. Ephemeral pond water can be used to grow Lucerne (*Medica sativa*) to provide food for animal during the dry season. It is also a useful source of proteins for animals.

Some vegetables including tomatoes, vegetables such as broccoli (*Brassica, (oleracea botrytis*), spinach *(oleracea, Spinacia)*, cabbage *Brassica oleracea var capitata*, beans (*Phaseolus, vulgaris*), and lettuce (*Lactuca, sativa*) can also tolerate moderate EC values. These vegetables are useful source of minerals and vitamins. They can improve the quality of the diet of people in the study area. Leogrande *et al.* (2012) irrigated tomatoes (*Solanum lycopersicum)* with water of EC values of 299mS/m and 495mS/m and recorded no difference in yield. The same point was echoed by Singh and Pandor (2012) when a similar experiment was conducted on mustard using the salinity value of 748mS/m. and comparing it with that of good quality water. Despite the high EC values obtained in this study, the water can be used for irrigation and will go a long way to improve food security for the communities. In addition, olive is one of the tree crops that can be planted in the study area that can tolerate high EC values.

In order to mitigate the effects of high EC values, it is recommended that annuals must be planted at high density and a lot of water must be applied to wash away excess salts from root zones. Also EC - tolerant crops must be planted. Ondrasek *et al.* (2011) recommended ways to control salinity by using micro irrigation at low intervals, mulching of the soil and reducing the use of fertilizers. It was also added that genetically modified crops must be planted to adapt to the condition of high electrical conductivity of the pond water.

The EC and the pH values from all the sites were above the recommended limits set by DWAF, (1996) but the selection of appropriate crops and through proper soil and water management, the pond water may be suitable for irrigation.

4.3.1.2 Chemical characteristics of the water in ephemeral ponds

Besides pH and EC, there are other parameters that affect water quality, there are also some chemicals that impact on water quality and consequently could affect human health.

Cation characteristics of water in ephemeral ponds

Table 12 shows the mean values of the cations that were obtained from water analysis from ephemeral ponds.

Table 12: Mean values of five major cations from ephemeral ponds

Sample ID	Na+(mg/l)	K+(mg/l)	Ca++(mg/l)	Mg++(mg/l)	Cd(mg/l)	SAR
A	37.33±2.52	2.50 ±1.58	20.33 ±2.7	40.00 ±1.0	0.02 ±0.02	
B	38.00 ±1.0	3.30 ±0.98	20.33 ±5.3	38.66 ±1.5	0.03 ±0.02	
C	45.66 ±1.0	2.90 ±0.65	27.66 ±1.5	53.00 ±1.4	0.02 ±0.02	
D	40.00 ±1.0	3.80 ±0.30	29.00 ±1.0	53.00 ±1.0	0.03 ±0.02	
E	39.20 ±1.0	3.30 ±0.40	30.33 ±1.0	44.33 ±1.5	0.03 ±0.02	
FAO	**0-70**	**0 - 2**	**0 – 20**	**0 - 5**	**Not available**	**0-3**
DWAF	**0-70**		**Not available**	**Not available**	**0 - 0.01**	**0-2**

Sodium (Na+)

Sodium concentration from the study area recorded a mean value of 40.04 mg/l and a range between 37.33 mg/l and 45.66 mg/l. All the readings were below the limits set by FAO and DWAF. The relatively high value (45.66 mg/l) recorded from pond C might be due to the nature of the underlying rock consists of dolomite and siltstone. In general, the low concentration of sodium in the study area could be attributed to rainfall and the rocks through which runoff flows might contain little amount of sodium mineral. Samples were collected at the end of the rainy season hence the sodium content might have been diluted. According to (Ochieng *et al.*, 2013; & Muyen *et al.*, 2011) sodium chloride concentration in pond water increases when water level is low. This is due to evaporation and infiltration of water. Kahlaoui observed different results in leaf area, petiole size and chlorophyll content in three cultivars of tomato when they were irrigated with water concentrations of 100% 80% and 50%. Also differences in magnesium, calcium and sodium contents were recorded in the crops. The low concentrations of sodium make the water suitable for irrigation. Hence a variety of crops can be grown using the pond water for irrigation without any adverse effects.

Potassium (K^+)

The concentration of potassium was high low with a mean value of 3.16 mg/l and ranged from 2.50mg/l to 3.80mg/l. There are no guideline values recommended by DWAF. But the high concentration measured could be linked to husbandry practices such as veldt burning. Potassium is a macro-nutrient that is required in large quantities by crops. A study was conducted by Smith and Sposito (2015) to compare the harmful effects of sodium, potassium, calcium and magnesium on the physical properties of soils in Australia. It was reported that the damage caused by potassium is one third that caused by sodium. However there have been reported cases of destruction of physical properties of soil when wastewater of high concentration was used in irrigation (Smith & Sposito, 2015). Potassium has been found to be a useful bionutrient (Chaboussou, 1985). It is useful for the health and vitality of crops. A study conducted by Chaboussou (1985) shows that average amount of potassium to higher levels is suitable for the growth of rice under a higher pH concentration. The concentration of potassium in the pond water shows that it is suitable for irrigation.

Calcium and Magnesium (SAR)

There are many constituents that are used to describe the suitability of water for irrigation. One of the commonest measurements is SAR (Fipps, 2013). It describes the relationship between sodium ions and that of magnesium and calcium. The calcium and magnesium ions counteract the harmful effects of sodium ions in water. The mean values for calcium and magnesium were 25.53mg/l and 45.79mg/l respectively. There are no recommended values by DWAF. Nevertheless, the relationship between sodium, calcium and magnesium is expressed as Sodium Adsorption Ratio (SARS). The study calculated a SAR value of 6.33 whilst the recommended value of 2 is stipulated by DWAF (1996). Fipps (2013) however, stated that SAR value between 1 and 10 is suitable for growing most crops except avocado. Also the value ranging from 10 to 18 requires interventions such as the application of gypsum (Bauder & Brock, 2010). Higher SAR measurement is a concern for irrigation. Clay soil develops crust and becomes impermeable (DWAF, 1996). The water may be suitable for growing many crops except sodium sensitive crops.

Cadmium

The mean concentration of cadmium was 0.03mg/l; and the values ranged from 0.02mg/l to 0.03mg/l. The values were higher than that recommended by DWAF but they are below the maximum acceptable values allowed for Cd (0.05mg/l).The water could be suitable for irrigation over a short period for growing field crops and potted plants (DWAF, 1996). The crops cannot accumulate enough cadmium to the toxicity level before they are harvested. The higher concentrations recorded from the ponds might be due to the proximity of the ponds to settlements and major roads. Ponds located close to towns receive municipal waste effluents contaminated with discarded batteries, leakage and spills from petrol stations. In addition, a lot of littering takes place from passengers near roads that end up in ponds.

Cadmium absorption by crops is enhanced by high concentration of chloride ions (DWAF, 1996) but the data obtained for chloride ions were very minimal. Anim *et al.* (2012) and Khan *et al.* (2014) investigated the concentration of heavy metals in water, soil and crops by using wastewater for irrigation. Anim *et al.* 2012 recorded higher concentration of cadmium above the recommended limits in water, soil and crops. Khan *et al.* (2014) on the other hand registered only higher concentration in crops. It, therefore, means that crops have the potential to absorb cadmium from irrigation water. It could also bioaccumulate in humans hence its concentrations have to be monitored regularly. Aweng *et al* (2011) recommended that wastewater could be used to irrigate maize and other field crops but using it to water vegetables must be avoided. In addition, leaf analyses have to be done on leafy vegetables as they tend to absorb cadmium faster. The quality of the pond water is not suitable for irrigating vegetables but can be used to irrigate field crops.

Major anion pollution in ephemeral ponds

Most chemical analyses of water for irrigation tend to focus more on cations than anions. Nevertheless, some anions can have negative impacts on the quality of water for irrigation. The discussion for the study will be limited to chlorides, nitrates and phosphates. Results of the anion concentrations from the sampled ponds with comparison to FAO and DWAF acceptable levels are presented in Table 13.

Table 13: Chemical data (Anions) from water analysis

Sample ID	**Cl^-(mg/l)**	**NO_3^-(mg/l)**	**PO_4^-(mg/l)**
A	17.13 ± 0.28	0.63 ±0.001	17.87 ±1.29
B	19.33 ±2.09	1.52 ±0.14	60.86 ± 4.55
C	5.45 ±4.38	0	19.60 ±6.69
D	12.68 ± 4.30	0	29.73 ±33.34
E	10.17 ±0.78	0.08 ± 0.04	15.88 ± 0.01
FAO	**0-140**	**0-5**	**Not available**
DWAF	**0 – 140**	**0 – 5**	**Not available**

Chloride ion (Cl^-)

The mean value for chloride was 12.95mg/l and values ranged from 10.17mg/l to 19.33mg/l. All the data were below the recommended limits by FAO and DWAF for irrigation. The low concentration could be attributed to a lack of intensive crop farming. The geology of the area is characterised by dolomites, siltstone, andersite and tillite that yield low concentrations of chloride mineral. Additionally, rain might have diluted the chloride concentrations in the environment at the time when water sampling was done. It therefore means that the water might be suitable for irrigation with respect to chloride. The low concentration of chloride would improve the quality of leafy crops by preventing foliar damage.(DWAF, 1996).Similar studies have reported high levels of chloride in untreated sewerage for irrigation above WHO guidelines (Anim *et al*., 2012). It was, therefore, recommended that sewerage discharge and industrial wastewater must be monitored in order to prevent pollution of water. In the study area, there is no direct discharge into the ponds hence the low concentrations of chlorides in the pond water.

Nitrate ($NO3^-$)

The recorded concentrations of nitrates ranged from 0mg/l to 1.5 mg/l with a mean value of 0.45mg/l. This was below the recommended limits set by DWAF (1996). The growth of algae and other nuisance plants might not occur in the ponds. Based on the calculated values, the pond water was suitable for irrigation of all types of crops. The low level of nitrate might be due to low application of inorganic fertilizers and the extensive grazing system which did not contribute to the accumulation of nitrates in the ponds. According to FAO (1994) nitrate concentration below 5mg/l is beneficial to all kinds of crops more especially during the early growing stage until flowering. However any nitrate concentration above 5 mg/l may interfere with plant nutrition and cause toxicity of certain ions in solution. High levels of nitrogen cause excessive leaf growth making plants susceptible to pest attack. In addition it causes lodging of plants in windy areas. Hence the concentration of nitrate in the pond water may improve healthy plant growth, proper leaf development and good yield.

Curt *et al*. (2002) performed fertilizer trial using foliar nitrogen application on winter wheat at five sites in Oklahoma, over a two-year period. The experiment was replicated to evaluate effects on straw yield, straw nitrogen content and its content in grain wheat. UAN was applied at rates of 0, 11, 34 and 45 kg/ha. In addition, sulphate of ammonium was applied at a rate of 22 kg/ha at the entire site. The fertilizer was applied at both pre and post flowering stages. It was found that there was no significant difference in straw yield and straw nitrogen content with all the application rates. However, there was a significant difference in nitrogen content in grain wheat at the application rate of 34 kg/ha. It was therefore concluded that late application of nitrogen improves nitrogen content and consequently protein content in winter wheat.

Phosphate

The mean value for phosphate was 28.78 mg/l; and values ranged from 15.88 mg/l to 60 mg/l. There are no guideline values for phosphate concentrations in irrigation water set by DWAF. Nevertheless, the recorded values were higher than the usual range of phosphate (0-2) mg/l in irrigation water (FAO, 1994). Pond B recorded the highest concentration of phosphate of 60 mg/l. This might be due to extensive grazing in the catchment area. In addition, the pond is next to residential area and there were traces of human faeces around it which could be a contributory factor to the high level of phosphate in the pond. High concentration of phosphate in irrigation water does not adversely affect plant growth and development. However it causes eutrophication in streams, rivers and dams. Consequently it interferes with aquatic life. All the ponds serve as watering points for grazing animals and game and might have been contaminated with the droppings from the animals. Also it might be due to runoff since the water sampling was done immediately after the end of the rainy season.

Anim *et al.* (2012) recorded higher levels of phosphate in untreated sewerage wastewater and shallow wells used for irrigation of vegetables in Tamale, Ghana. Divya and Belagali (2012) also measured higher levels of phosphate from groundwater and lakes that received water from agricultural fields through the use of fertilizers. It implies that ponds that will be used for irrigation should be fenced so as to prevent phosphorus contamination from grazing animals. In addition, application of fertilizers and other pesticides in the catchment areas must be controlled.

4.3.1.3 Micro-biological characteristics of the water in ephemeral ponds

The presence of micro – organisms in irrigation water above the recommended guideline values poses a threat to human health. They can be ingested through eating raw fruits and vegetables. Levels of total coliform and *Escherichia coli* were analysed as indicator organisms for microbial pollution and the mean values are given in Table 14. The results were compared with WHO and DWAF irrigation water quality guidelines. This means that their presence in water above the recommended values warns of the potential of a disease. And the water may not be suitable for irrigation for crops that are eaten raw or uncooked. The WHO guidelines do not recommend such water to be used to irrigate parks that are used for recreation.

Table 14: Microbiological data from water analysis

Sample ID	E coli	Total coliform
A	70 ±68	997 ±490
B	110 ±39	888 ±206
C	08 ±8.9	2275 ±250
D	0 ±0	2277 ±250
E	201 ±46	2420 ±0
WHO	**0-10^3**	**10^3-10^6**
DWAF	**0 – 10^3**	**Not available**

Escherichia coli

The mean value for *Escherichia coli* was 78 count/100ml and they ranged from 0 to 201 count/100 ml. Comparing the mean value to that of WHO limits implies the water was suitable for irrigation. It implied little contamination with faeces. This might be due to grazing animals and human activities. The ponds are sited far from settlements except pond B. The pond is close to town and there were signs of open human defecations close to it hence the high levels of the bacteria compared to the other ponds. Pond E is next to a major road and also serves as a watering area for grazing animals hence the highest number of E coli counted. Based on the values recorded, the water could not be used for irrigation. However, El Zanfaly (2015) recommends that the water could be used to irrigate field crops, pasture but should not be used to irrigate vegetables and crops that are eaten raw.

Ijabadeniye *et al.* (2011) recorded higher levels of *Escherichia coli* in Loskopdam in Mpumalanga, South Africa above the recommended value set by WHO. Also higher levels were observed on vegetables that were irrigated with the dam water. Fonseca *et al.* (2012) also recorded longer survival rate of *Escherichia coli* on vegetables when sprinkler 1method was used for irrigation as compared to furrow and sub –surface drip irrigation. When high levels of *Escherichia coli* is analysed in pond water sprinkler irrigation must be avoided. However, in the study area the common method of irrigation is the sprinkler and can transmit diseases to fruits and leafy vegetables when ephemeral pond water is used for irrigation. Vegetables must be cooked before eaten and fruits should be washed before consumption (DWAF, 1996).

Total coliform

The mean number of total coliform was 1779 count/100 ml. The least number measured was 888 count/100 ml whilst the highest count was2460 count/100 ml. All the ponds registered values below WHO recommended limits for wastewater use. Based on the data recorded the pond water was suitable for irrigation of vegetables and fruit crops. Guideline values for field crops are not available. Akrong *et al.* (2012) also recorded higher numbers of total coliform ended limits in tap water that was stored in ponds, streams and wastewater obtained from drains. In addition, higher counts were noticed during the wet season than for the dry season. In this study, the analysis was done during the end of the rainy season hence the high counts of total coliform which could be attributed to runoff and droppings from farm animals and game; since the ponds are also used as watering points for farm animals.

Although the pond water did not satisfy the criteria set by WHO; through proper selection of crops, soil and water management, the water could still be used for irrigation. El Zanfaly (2015) discussed the use of wastewater for irrigation in Tunisia. Currently, about 20, 000 ha of land in Tunisia is irrigated by wastewater effluent. The use of the water is regulated by a decree signed by the ministers of Agriculture, Environment and Land Use and Public Health. Only specific crops are permitted to be irrigated by the water. They include tree crops, citrus, vines; fodder, cereals, hotel gardens and pastures. Vegetables that are eaten raw are not allowed to be irrigated with wastewater. In addition, monitoring of physic- chemical and micro- biological characteristics of the wastewater and crops is done on regular basis. Lastly precautions are taken to protect the health of workers and the general public. As such, the pond water from the study area could therefore be suitable to irrigate field crops and fodder for they are not eaten raw and cannot pose any health risk. When it is used to irrigate vegetable and fruit crops, furrow and sub – surface irrigation methods should be used to prevent contact with the crops (Jhansi & Mishra, 2013). This must also be coupled with hygiene practices such as proper washing and disinfection of vegetables before eating. In addition, the catchment area around ponds must be controlled to prevent faecal pollution. Humans must be protected from exposure to contaminated ponds. Hence farmers must wear protective clothing such as overalls, water boots, gloves and helmets (DWAF, 1996). The quality of ephemeral ponds must be tested regularly to know the appropriate management options to be implemented.

4.3.2 Correlation and regression analyses of water quality

There are many constituents in irrigation water. Sometimes there are relationships between the variables. Correlation analysis is used to measure the relationship between two continuous variables that are dependent or independent. It can also be used to quantify the strength of the association. The objective of the study was to determine the association between the variables. This could be useful in some of the management decision about the use of pond water for irrigation.

Regression analysis is used to measure the relationship between dependent variables and independent variables. That is the risk factor and the confounder. This analysis is used to test a hypothesis about cause and effects. Lastly linear regression is used to determine if one value of a variable corresponds with another value of the other variable. Regression analysis can be used to solve environmental problems by identifying the risk factor. The two statistical tools have been selected to investigate the types of relationships between the variables and their strengths so as to make certain management decisions about the pond water and its suitability for irrigation.

Correlation Analysis

Relationships between water parameters are shown in Table 15.

Table 15: Water analysis parameters for correlation analysis

Sites/ Water Parameters	**A**	**B**	**C**	**D**	**E**
pH	8.66	8.57	8.74	10.63	8.69
EC (ms/m)	734	405	432	379	780
Na^{+}(mg/l)	0.70	1.20	1.00	1.00	1.20
K^{+}(mg/l)	2.50	3.30	2.90	3.80	3.30
Ca^{++}(mg/l)	0.22	0.23	0.81	0.29	0.30
Mg^{++}(mg/l)	0.11	0.08	0.38	1.10	0.38
Cd(mg/l)	0.02	0.03	0.02	0.03	0.03
Cl^{-}(mg/l)	17.13	19.33	5.45	12.68	10.17
NO_3^{-}(mg/l)	0.63	1.52	0	0	0.08
PO_4^{--}(mg/l)	17.87	60.89	19.60	29.73	15.88
E coli	70	110	08	0	201
Total coliform	997	888	2275	2277	2420

R^2 values for correlation analysis show the strength between variables. The R^2 values have been shown in Table 16.

Table 16: R^2 Values of Correlation analysis

		pH	EC	Na+	K+	Ca++	Mg++	Cd++	Cl-	NO3-	PO4---	*E-coli*	total coliform
Pearson Correlation	pH	1.000	-.465	-.072	.716	-.128	.956	.371	-.092	-.448	-.033	-.544	.413
	EC	-.465	1.000	-.253	-.507	-.323	-.407	-.185	.040	-.127	-.599	.675	-.014
	Na+	-.072	-.253	1.000	.635	.015	.053	.757	-.118	.130	.464	.494	.306
	K+	.716	-.507	.635	1.000	-.198	.744	.861	-.044	-.175	.353	-.029	.450
	Ca++	-.128	-.323	.015	-.198	1.000	.061	-.533	-.838	-.489	-.326	-.445	.488
	Mg++	.956	-.407	.053	.744	.061	1.000	.366	-.356	-.653	-.195	-.469	.661
	Cd++	.371	-.185	.757	.861	-.533	.366	1.000	.274	.161	.491	.430	.170
	Cl-	-.092	.040	-.118	-.044	-.838	-.356	.274	1.000	.844	.637	.206	-.865
	NO3-	-.448	-.127	.130	-.175	-.489	-.653	.161	.844	1.000	.817	.246	-.904
	PO4---	-.033	-.599	.464	.353	-.326	-.195	.491	.637	.817	1.000	.016	-.573
	E-coli	-.544	.675	.494	-.029	-.445	-.469	.430	.206	.246	.016	1.000	-.047
	Total coliform	.413	-.014	.306	.450	.488	.661	.170	-.865	-.904	-.573	-.047	1.000

There was a strong positive correlation between pH and magnesium ($p<0.05$); sodium and cadmium also showed a strong positive relationship ($p<0.05$). There was a high positive correlation between nitrate and phosphate ($p<0.05$) and also between potassium and cadmium ($p<0.05$). In addition, phosphate and chloride displayed a high positive relationship ($P<0.05$) whilst a strong negative relationship was observed between total coliform and nitrate ($P<0.05$).

Water pH was dependent on magnesium concentration. Dolomite is a dominant rock in the study area and upon weathering magnesium is produced. Magnesium enters the pond through runoff. The presence of magnesium in water makes it alkaline hence the high pH values recorded in the analyses.

4.3.3 The effect of land use on ephemeral water quality

The assessment of the effect of land use on water quality is of ultimate importance to all water users. It serves as evidence to decision makers and water planners to take action to control and plan land use in a catchment area. This section, therefore, discusses multiple linear regression equations that relate to land use and water quality parameters and how they affect ephemeral pond water quality in the study area. Besides, it assesses the R^2 values about the distribution of the data in relation to the models.

Grass and bare area have no impact on nitrate level in ephemeral pond water ($p< 0.422$). The $R^2$of 0.886 indicates that the model fits well with the data. Grassland in the study area is mainly used for grazing. Roche *et al.* (2012) studied the effect of livestock grazing on meadows in the U.S.A and found no significant effect on nutrient level (nitrate) through grazing in the water. Bare area has a negative impact on EC on ephemeral pond water and grass has no effect on EC ($p<0.576$). The R^2 of 0.78 indicates that about 80% of the data can be accounted for by the equation.

Sodium concentration in ephemeral pond water is of special concern for irrigation. It accumulates around the root zone of plants to the extent that it affects osmosis of water in plants. This leads to poor crop development. In addition, high levels of sodium destroy soil structure making less water available to crops. According to the model, sodium concentration in ephemeral pond water does not depend on grass ($p<0.36$; R^2=0.92). However, the presence of sodium is mainly through erosion of rocks. Hence, the presence or absence of grass does not contribute to the amount of sodium in ephemeral pond water. Also sodium concentration in the pond water does not depend on bare area. Bare areas are created by drought, burning, over-grazing and land preparation. These practices do not affect erosion of rocks that could increase the concentration of sodium in the water. A high percentage of the model can be explained by the data Table 17 shows a model regression equation and the adjusted R^2.

Table 17: Model equations and the respective adjusted R^2 values for each of the selected water quality parameters related to each land use

Water Quality Parameter	Model Equation	R^2 Value	P-value
Nitrate(NO_3^-)	NO3 =-5.317 + 0.026 GRASS + 0.041 FRESH WATER + 0.036 BARE	0.886	0.422
Electrical Conductivity (EC)	EC = 182.264+6.949GRASS+ 2.857FRESHWATER - 0.378BARE	0.779	0.576
Sodium (Na^+)	Na = 71.408- 0.137 GRASS - 0.264FRESHWATER – 0.146 BARE	0.918	0.360
Cadmium (Cd)	Cd = -0.015+ 0.00 GRASS + 0.00 FRESH WATER + 0.00 BARE	0.449	0.849
Ecoli	Ecoli = -544.259+ 5.986 GRASS + 4.224 FRESHWATER + 2.735 BARE	1.00	0.006
GRASS=vegetation use, FRESHWATER=Fresh water use, BARE= Bare areas			

According to the regression analysis model, grass cover does not have effects on cadmium concentration in the pond water ($p<0.849$; R^2=0.45). Also the presence of cadmium in pond water does not depend on bare area. According to the coefficient of determinant value, the model is poorly suited for the data (R^2=0.45*)*.

Grass is a predictor for *E. coli* abundance in water in the catchment area. Grass has a significant (P= 0.006) positive effect on *E coli* in ephemeral pond water. The grass in the study area is used for grazing. Hence, when there is abundant grass a lot of grazing takes place around the catchment and the ponds. This results in the water being polluted by micro-organisms from the excreta of grazing animals. The model is well suited for the data (R^2=1). When the soil surface becomes bare, less grazing takes place and the water is protected from microbial contamination. Bacterial contamination affects fruits, leafy vegetables and crops that are eaten raw (WHO, 2006). Water containing high levels of *E-coli* above the recommended limits may not be fit for irrigating crops. Hence, the catchment around ponds has to be controlled from grazing and human excreta to improve the water quality. At the same p-value and R^2, bare areas have a positive effect on *E-coli* in ephemeral pond water. When soil is bare, excreta from humans and manure are washed into the pond water which increases the quantity of *E coli* in the water.

All the values recorded for the physical characteristics were higher than the limits recommended by DWAF and FAO. However, the chemical parameters were within the limits except for cadmium. The value calculated for SARS (6.33) was higher than what was recommended by DWAF (1996) water quality guidelines for irrigation. *E-coli* measurements satisfied the requirements set by WHO whilst total coliform values were higher. The water could therefore be suitable for irrigation but should be accompanied by crop, soil and water management.

In general ephemeral pond water quality is affected by land use. Also the various models have proved successful in determining the effects of land use land cover change on water quality parameters of ephemeral pond water in the study area.

CHAPTER 5

WATER BALANCE MODELLING FOR EPHEMERAL PONDS BASED ON CLIMATIC DATA

5.1 INTRODUCTION

Ephemeral pond water is an available resource that can be of enormous benefit to humans. It can serve as a habitat for a variety of organisms (Hoverman & Johnson, 2012), can be used to water farm animals, for recreation, domestic use and for small scale irrigation. In order to effectively perform those functions, the longevity of the water is critical. It is, therefore, important to model mathematical equations to determine the water balance of the pond. According to Maidment (1993) a model is a conceptualization of a real system that retains the essence of that system for a purpose. A good model can determine the water balance and its usefulness for small-scale irrigation.

Kannan *et al.* (2014) developed a mathematical model of water balance of a detention pond in the city of Austin in Texas, USA as shown in Equation 3:

$$V = V_{backup} + V_{flowin} - V_{flowout} + V_{pep} - V_{evap} - V_{seep} \qquad \textbf{\textit{Equation (3)}}$$

where:

V = volume of water in the retention pond at the time step (m^3 of water).

V_{backup} = volume of water stored in the pond at the beginning of the time stem (m^3 of water).

$V_{flowing}$ = volume of water entering the pond during the time stem (m^3 of the water).

$V_{flowout}$ = volume of water flowing out of the pond during the time step (m^3 of water)

V_{pep} = volume of precipitation falling on the detention pond during the time step (m^3 of water.

V_{evap} = volume of water removed from the pond by evaporation during the time stem (m^3 of water), and

V_{seep} = volume of water lost from the pond by seepage.

The model was based on SWAT (soil and water assessment tool) developed in the United States. The model was suitable for small-scale wetlands located in mixed, urban environment (Khan, 2014). It can be used as a tool to evaluate the water balance of other detention ponds. However, the model had some limitations. The total annual rainfall was assumed instead of measuring it. The model did not take into consideration the variability in soil characteristics and classification.

5.2. Water Balance in Semi-arid Areas

In arid regions such as the study area, the main factors affecting water balance of ephemeral ponds are precipitation, infiltration and evaporation. This section therefore discusses the climatic factors that affect water balance and the subsequent modeling of equations to determine it. In the study area, ephemeral ponds are formed during the wet season. At the end of the rainy season there is no more precipitation (in flow of water) and no supply from groundwater. The only forces that affect the water balance are infiltration and evaporation. Infiltration rate of water depends on soil characteristics such as texture, structure and the nature of the sub-soil.

5.2.1. Effects of evaporation on ephemeral pond water

Jensen (2010) studied the water balance of a pond and observed that about 80% of water loss was due to evaporation. Solar radiation is the main climatic element that causes evaporation of water from pond surfaces. The difference between the incoming radiation from the sun and the reflected radiation from the pond surface is called the net radiation. It is this energy that is responsible for evaporation of water. A small amount of this energy flows to the bottom of the pond and it is stored there. In the case of shallow ponds, the effect of this energy on evaporation is not much. However, with deeper ponds, during periods of less solar radiation, the energy may be available at the pond surface and contribute to evaporation of water during cooler seasons (Jensen, 2010).

The conventional method of measuring evaporation rate is the use of the pan. Daily readings are multiplied by a coefficient so as to estimate the rate of evaporation from other water bodies. Over the last few years, various models have been developed to measure evaporation using climatic data. Popular among them is the Priestley and Taylor (1972) model.

LE = 1.26 [$\Delta/\Delta+\gamma\gamma$] (Rn-G) ***Equation (4)***

LE is the rate of evaporation, Δ is the slope of saturated vapour pressure in relation to temperature; γ is the psychrometric constant, Rn is the net radiation.

The use of pan evaporation can also be used to estimate evaporation rate from water bodies such as ponds and lakes by referring to Pen (1948) equation.

$$E = \frac{K(e_s - e)E_P}{(e_p - e)}$$ ***Equation (5)***

Where E is the main evaporation rate from the water body, E_p is the mean evaporation rate of the pan, K is an empirical constant, e_s the mean saturated vapour pressure of the air at the water surface temperature, e_p mean saturated vapour pressure at pan surface. E being the mean vapour pressure of the air at reference point.

The effectiveness of pan evaporation rate is improved when there is a dry surrounding and heat transfer is minimised.

5.2.2. The effects of wind on evaporation of ephemeral pond water

Temperature is the main cause of evaporation from ephemeral pond water however; the effect of wind cannot be discounted. As water molecules leave the pond, they accumulate on the surface in the form of vapour. The water vapour exerts pressure on the water called vapour pressure or relative humidity. This continues until equilibrium state is reached when the vapour pressure is equal to the water pressure. Hence the net water loss from the pond is equal to zero. Nonetheless wind may blow away the vapour from the water surface to disturb the equilibrium state (Hipsey & Sivapalan, 2003). Consequently the relative humidity reduces and evaporation resumes. Meyer (1942) came up with an equation to estimate evaporation rate from lakes and reservoirs by following equation (6):

$E = (a+b_u)(p_w-p_r)$ ***Equation (6).***

where:

E_0= evaporation rate

a and b are constant

a = 0.000116 velocity of water evaporated per second kg/s

b = 0.000126

Pr - Pw = air density difference space air temperature in I – P units relative humidity

5.2.3 Effects of rainfall on ephemeral pond water

In arid and semi-arid regions such as the study area, rainfall is the main source of water for ephemeral ponds. The longevity of the water is influenced by the length of the rainy season and the intensity of the rainfall event. Direct rain adds water to ponds but the main source of water is from runoff. When it rains, excess water runs down the slope of ephemeral ponds to fill them. The amount of runoff depends on slope length, steepness, nature of soil and land cover (USGS, 2016). When the slope around a pond is long and steep, more runoff enters the pond. Hard surfaces also increase the speed of runoff into a pond. Land cover such as forest and grass allow more seepage into the soil; this limits the quantity of runoff that flows into ephemeral ponds.

5.2.3. Effects of soil on ephemeral ponds

Land cover, especially forest and grass cover limits the amount of water that enters ephemeral ponds. The soil and its characteristics also influence the water balance in a pond. The amount of water that is stored in ephemeral ponds depends on the permeability of the soil below the water. Sandy soil has macro-pores and more total pore space. When a pond is formed on a sandy soil, the water percolates under the force of gravity into the sub-soil (Gardner, 1985). This causes the pond water to drain out fast. On the contrary, clay soil has micro-pores and consequently smaller total pore space. Micro-pores are first filled with water during rainfall event and when the soil becomes saturated it impedes the downward movement of water (Gardner, 1985) allowing more water to remain in the pond. This increases the hydro-periods of ponds. However, cracks on clayey soil allow more water to seep downwards. In some cases, sediment and vegetation from pond water settle on the bottom of the pond and form a layer that reduces the downward movement of water from the ponds. Organic matter in the pond promotes the formation of soil aggregates which allows more seepage of water from the ponds. When a pond is formed over a rock the longevity of the pond water is prolonged.

5.2.4. Effects of infiltration capacity/rate on ephemeral ponds

Infiltration rate is the speed at which water moves down the soil. It is measured in millimetres per hour. The rate is affected by the type of soil below the pond, the layers below the sub-soil and the recharge of the water below the pond. According to Sharma *et al.* (2013), there are three stages of infiltration of water in the soil. The first stage is characterised by low speed as the water needs time to get attached to the surface of the soil particles and also to fill up the micro-pores. During the second stage, the water moves very fast in the soil as a result of gravity and unsaturated flow. During the last stage, infiltration rate slows down because the soil becomes saturated with water hence excess water remains on the soil surface. This occurs on ephemeral ponds during heavy rain and long rainfall season. Water remains in the pond for a long time. Also when a pond is recharged from groundwater, infiltration rate reduces. When the subsoil is unsaturated infiltration rate increases; but the presence of impermeable layers and rock below the sub-soil impedes the rate of infiltration of ephemeral pond water.

5.3 Methodology

The methodology section provides a description of data sources and how they were analysed. It also explains how the mathematical model was developed.

5.3.1 Climatic data

The main climatic elements used for this study were rainfall, temperature, evapo-transpiration and wind speed. The data were obtained from South African Weather Service in Kimberley and were complemented with data from Agricultural Research Council (ARC) station from Potchefstroom. The data consisted of maximum and minimum daily temperatures, mean monthly evapo-transpiration rates and mean annual rainfall as well as mean monthly wind speed. For all data sets, rainfall values were from October to March which is the rainfall season in the study area. With regard to temperature, evapo-transpiration rate and wind speed the data were from

January to December. Average data covering the period from March to June were calculated because this period coincides with the availability of water in ephemeral ponds in the study area. The climatic variables influence the longevity of the ponds and the values were used to calculate the water balance in the ponds.

5.3.1.1 Rainfall data

To determine the normality of the rainfall distribution in the study area, the rainfall anomaly index was computed. The daily rainfall data were summed-up using Microsoft Excel to calculate the total summer season rainfall. The summer season is the total of October to March rainfall. Standardised Precipitation index (SPI) was used to predict wet and drought years. SPI has been commonly used to monitor precipitation in drought-prone regions such as the West African Sahel and Southern African semi-arid climatic regions (Katz, 1978; Hulme, 1992). SPI involves standardizing the annual or seasonal total rainfall for an individual station by subtracting the station's mean and dividing by its standard deviation, with the mean and standard deviation being computed from the station's historical record. Thus, SPI is the transformation of the precipitation time series into a standardised normal distribution (Z-distribution). This method was used to define normal, below normal or above normal rainfall intensities and also define the extreme wet events for any of the time scales. Extreme wet episodes occur any time when the SPI is continuously positive and reaches a threshold of 706 mm. For this study, values of SPI above 415 mm denoted extreme wet rainfall events while values below 234 mm represented extreme dry rainfall events. SPI values range from -1 to +1. The average rainfall corresponded with zero value on the SPI scale while +1 represented the highest rainfall recorded and -1 represented the lowest rainfall recorded in the study area during that period. The above +1 and below -1 denotes extreme and drought rainfall event. To construct SPI, annual (seasonal) rainfall total is normalized as in Equation 7:

$$R_{ji} = \frac{x_{ij} - \mu_i}{\delta_i} \qquad \textit{Equation (7)}$$

where:

R is the normalized annual (seasonal) rainfall total for station *i* in year *j*; assume, *xij represents* total rainfall for station *i* in year *j*.

μi and δi the mean and standard deviation of the rainfall total during a specified reference period respectively.

The rainfall variability at the rainfall station was determined using the departure from the mean (Equation 7). Frequency tables were drawn and simple descriptive statistical measures were derived to describe rainfall variations. The values were used to show yearly variations of rainfall, indicating drought and wet years.

5.3.1.2 Temperature data

Direct recording of daily temperatures introduces anomalies. Therefore the data that were obtained from weather stations had to be standardized. Microsoft excel was used to calculate mean monthly and annual minimum and maximum temperatures from the daily mean readings from 1983 - 2013. The period between March and June (season) was critical to the study for it affected the longevity of the ponds. The Z-distribution test was used to determine the mean monthly, seasonal and annual temperatures from 1983-2013 to determine temperature anomalies. It was also useful to determine average surface temperatures which were further used during the water balance modeling.

5.3.1.3 Wind speed data

The wind speed data obtained from weather stations were standardized. Daily average wind speed was obtained from South African Weather Service, Kimberly for 1983 to 2013. Microsoft excel was used to calculate the mean monthly wind speed. These values were then added up and the mean was obtained for 30 years. The various 30-year monthly mean wind speeds were standardized to a height of 10 m using the power law equation. The data were then used to discuss the effect of mean monthly speed on ephemeral pond water balance.

The various 30-year mean wind speed were standardised to a height of 10 m using the power law equation.

$$\frac{V}{Vo} = \left(\frac{H}{Ho}\right)^{\alpha}$$ ***Equation (8)***

where:

V_0 = known wind speed

V= wind speed in metres per second

H= height when wind speed was recorded

H_0= reference height

α= power law index

The power law index is an empirically derived coefficient that varies depending on the stability of the atmosphere. The value depends on topography, roughness of the surface, environmental conditions, meteorological lapse rate and weather stability (Zekai *et al.,* 2012; Rahn & Blvd, 2016)

5.3.2. Evaporation data

Evaporation is a major cause of water loss from ephemeral ponds. Evapo-transpiration data obtained from ARC station at Potchefstroom from 2004 to 2013 were taken to represent evaporation rate for the study area. The values represented the evaporation rate for each month. All the daily average evaporation rates were summed up to obtain the total for each month using Microsoft excel and the total for each year for the ten years. Similarly seasonal evaporation rate from March to May was calculated. The value was used to calculate the water balances of the ponds.

Furthermore, bar graphs were drawn to show the monthly variations in evaporation rate while line graphs depicted variability in annual mean evaporation rates in the study area.

5.3.3. Infiltration rate data

At the end of the rainy season, the infiltration rates for the various ponds were determined. An auger was used to dig in the dry pond a hole about 30 cm deep and was filled with water until it drained out. The hole was filled again with water and the decrease in the water column was measured with a ruler after 15minutes. It was then computed for was repeated for all the ponds to determine the infiltration rates. The results were compared with the FAO measured infiltration rates (Table 18).

Table 18: Infiltration rate data (cm/hour) for various soil types (FAO, 2010)

Soil Type	Basic infiltration rate
Sand	less than 3.0
Sandy loam	2.0 – 3.0
Loam	1.0 – 2.0
Clay loam	0.5 – 1.0
Clay	0.1 -0. 5

5.4 Results and Discussion

Climate is an important factor that affects water balance in ephemeral ponds. This section, therefore, provides an overview of rainfall, temperature, wind speed and evaporation; and how they affect the water balance of ephemeral ponds.

5.4.1. Effect of Climatic variables on Ephemeral Water Balance

5.4.1.1 Rainfall

Precipitation is the main element that supplies water to ephemeral ponds (Owen & Horton, 2013). In arid and semi-arid regions such as the study area, there is great variability in the amount and the distribution of rainfall. The study area experiences its rainfall from October to March. This is mainly caused by the Mozambican currents; but the amount of rainfall gradually decreases from the east to the west of the country. The study area is located in the North West Province next to the Kalahari Desert hence low annual rainfall is recorded yearly.

The graph in Figure 11 describes the rainfall distribution of the study area. The 30-year mean rainfall from 1983 to 2013 was 415mm and the standard deviation was 132. This indicates a high variability in rainfall. The highest rainfall that was recorded was 706 mm and was recorded in the year 88/89 and 2005/2006, whereas 1991/1992 was the driest year over the 30-year period and recorded a mean annual rainfall of 234 mm

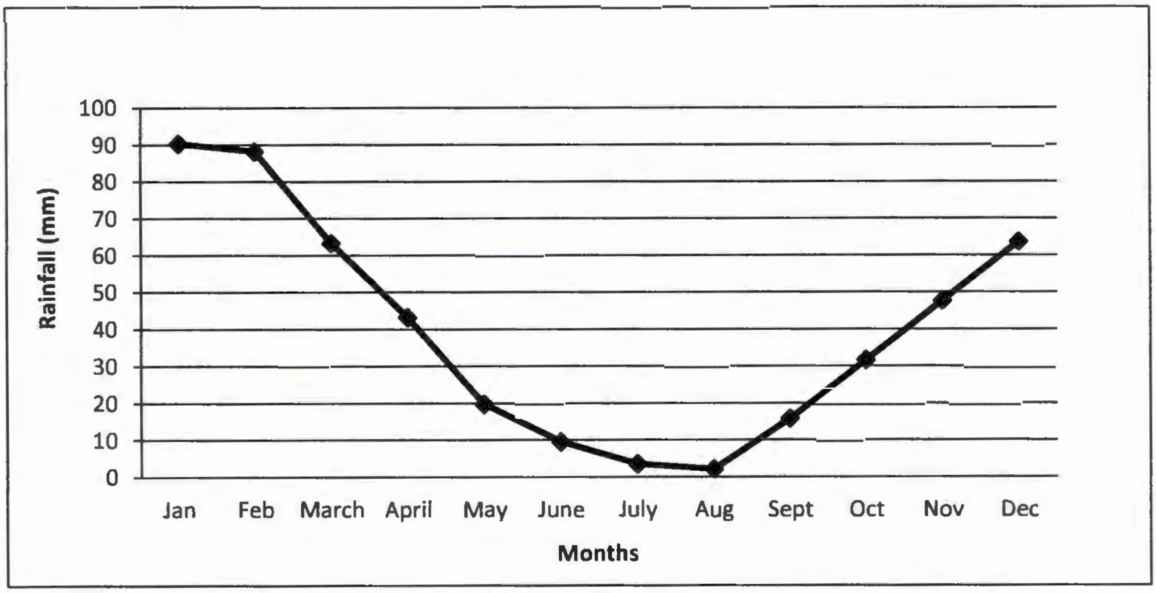

Figure 12: A 30-year monthly rainfall distribution

The highest mean monthly rainfall was recorded in January; and the period from June to August experiences very low or virtually no rainfall (Figure 12). During periods of average and high rainfall, the ponds begin to fill in January until end of March or mid-April. Some ponds continue to contain water until July. Ephemeral ponds may be useful for irrigation when planting of crops starts in January in order to have enough water to grow to maturity. During the months of June and August the pond do not receive water hence they will not be useful for irrigation.

Years of 1992, and 2012 were extremely dry whilst 1989 and 2006 were the extreme wet years (Figure 13). The period from 1983 to 1986 indicated below average rainfall; and then the rainfall figures started to rise from 1987 until it reached its peak in 1989. Thereafter the rainfall pattern was on the decline until it reached the lowest level in 1992. In 1996, the rainfall figures had been oscillating around the mean until 2004 when it started to rise again to reach a maximum amount in 2006. Since then rainfall figures have been low reaching the minimum level in 2012.

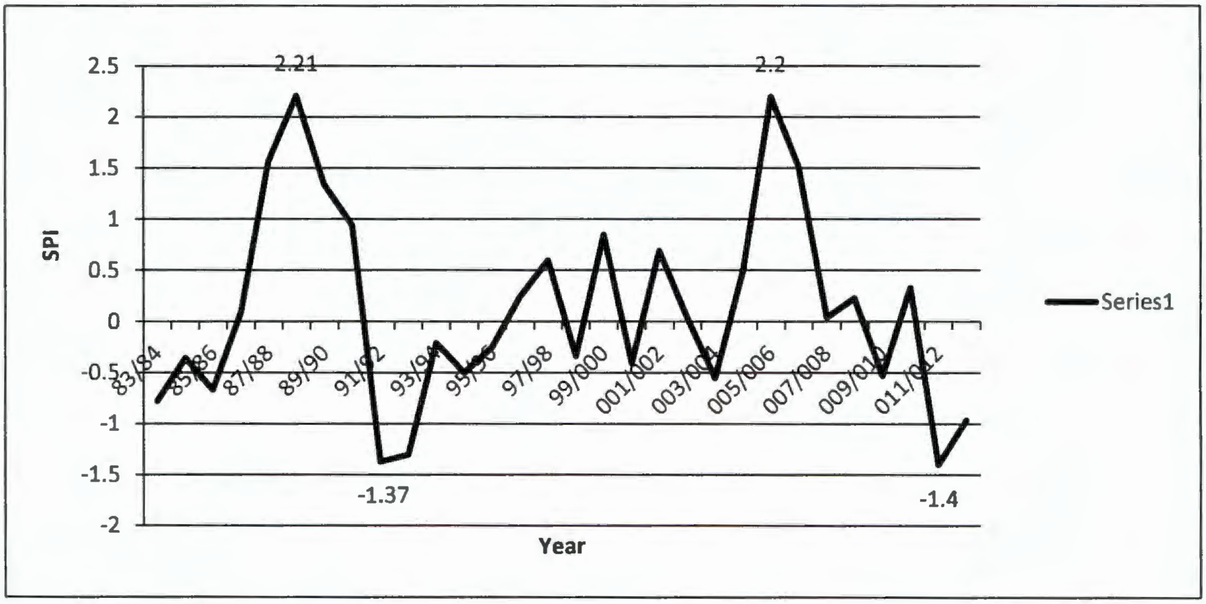

Figure 13: Standardized Precipitation Index from 1983 to 2013.

During periods of high rainfall most of the ponds are filled with water and the water lasts longer. They will be suitable to irrigate long-seasoned and short- seasoned crops. But when the rainfall is low most of the ponds dry up quickly hence will not be suitable for growing crops. Owen and Horton (2013) in their study of about 200 basins in the Canadian Prairie observed that during average rainfall season, 50% of the basins had water. In contrast, during drought years only 20% of the basins had water. When the rainfall amount in a season is very low most of the ponds will not contain water and they will not be suitable for irrigation. During periods of average rainfall the longevity of the ponds is short. However, in order to improve the longevity of the pond water for irrigation, dykes and check banks should be constructed to allow more run off into the ponds (Al Zayed *et al.*, 2013). Also, short-seasoned crops should be planted to make use of the available water to grow the crops to maturity.

5.4.1.2. Temperature

The temperature of a place is influenced by solar radiation and its location on the earth surface. Albedo also affects the reflection and the retention of heat on the earth's surface. The graph in

Figure 13 shows the mean monthly variations of temperature for the year 2014. Temperatures are very high in summer from November to February. This coincides with the peak of the rainy season. High temperatures accelerate the rate of evaporation from water surfaces. During summer more water is lost from ephemeral ponds and can be replaced by the rainfall during that period.

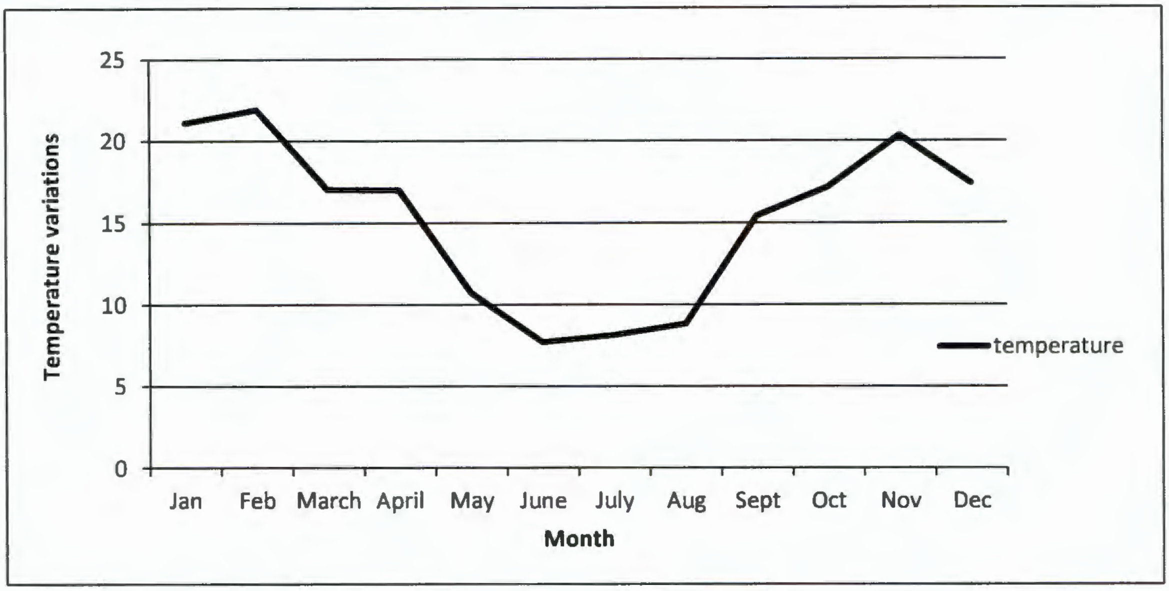

Figure 14: Mean monthly temperature variations for the year 2014

In winter, due to low temperatures evaporation from the water surface is minimised (Pomeroy, 2010). In addition, the effect of low evapo-transpiration is insignificant to water balance in the ponds in winter for most of the pond might have dried up already hence no water available for irrigation. High temperatures are likely to affect the longevity of the pond water and may render some ponds unsuitable for irrigation. Hence certain interventions have to be implemented such as the construction of wind breaks and covering of the ponds surfaces with material.

Figure 15 shows a 30-year variation of temperature from 1983 to 2013. The highest annual average temperature was recorded in 1992whilst the lowest was in 2009 (17.27°C).

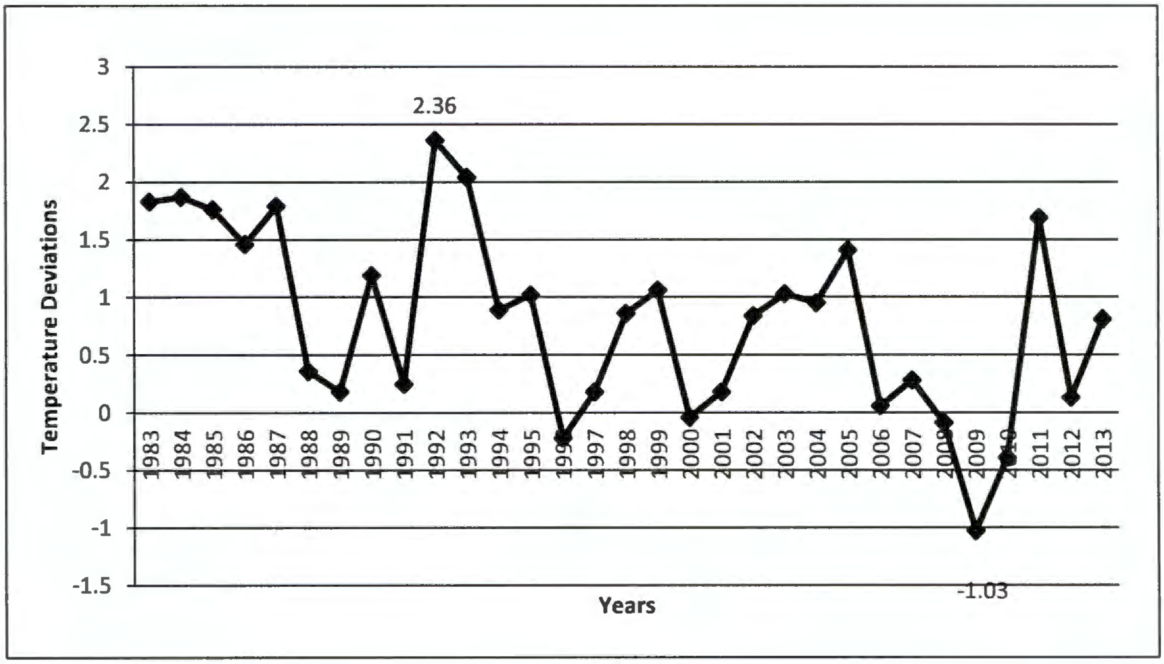

Figure 15: Standardised temperature anomalies

The years of 2000 and 2006 registered average temperatures for the 30-year period. In 2009, the extreme lowest annual average temperature (17.27°C was recorded while in 1992, the study area recorded the extreme highest temperature (19.85°C). In general the high temperatures experienced in the study area can be attributed to climate variability. Climate variability can have a significant effect on pond filling and the longevity of the pond water. During drought period as a result of global warming most ponds are not filled and water is not available for irrigation. Also high temperatures raise the temperatures of shallow ponds and results in high evaporation rate from ponds surfaces (Finch & Calver, 2008). According to Morrison *et al.* (2001) climate change affects both the quantity and quality of water from ponds. Rong *et al.* (2013) studied the effects of climate variability such as temperature; humidity and wind speed on evaporation in Lake Dongpin in China from 2003-2010. It was realized that there was a general increase in temperature, solar radiation and wind speed. These contributed to an annual change in evaporation from the lake surface. However, the most contributory factor was attributed to temperature. The study area experiences high temperatures during the rainy season. This can accelerate evaporation of water from the ponds. Hence, the construction of wind breaks and the provision of cover on the pond surfaces can create a cool environment. Wind breaks can also reduce the wind speed which has effects on evaporation of water from pond surfaces.

5.4.1.3. Evaporation

Evaporation is the major cause of water loss from water bodies. It is accelerated by temperature, wind speed and the relative humidity of the area. This section assesses yearly variation in evaporation rate and its effects on ephemeral ponds. In the study area, there is a great variability in evaporation rates as shown in Figure 16.

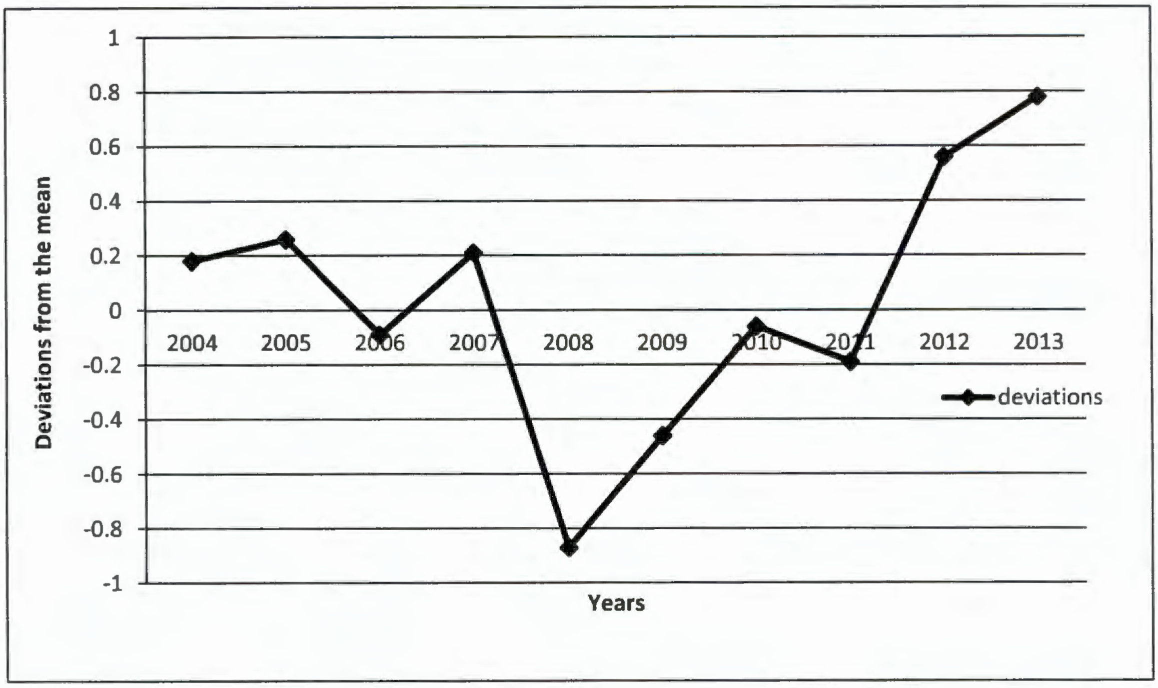

Figure 16: Standardised evaporation rate

The highest evaporation rate was recorded in 2013 with a value of 2023.2 mm/year. The lowest mean evaporation rate was registered in 2008 with a value of 1156.2 mm/year. With the exception of the year 2007, all the years from 2006 to 2011 recorded evaporation rate below average. This might be due to the low temperatures recorded during the period (Figure14). The high evaporation rate recorded for 2007 correlate with the high temperature recorded in the same year 2007; low evaporation in 2008, 2009 also correlate well with the low temperatures recorded for the same period. Hence, temperature has an effect on the rate of evaporation. However, there was a high evaporation rate in 2012 but the same year recorded the lowest temperature which could be attributed to the low rainfall recorded for that year. During years of high evaporation rate, which are usually accompanied by drought episodes and high temperatures, the water balance in the pond is affected. The few ponds that form lose water fast and may not be suitable for irrigation. Crops that are planted using the pond water wilt and die before maturity due to lack of pond water for irrigation. During the periods of low rainfall most of the ponds dry up (Thomas *et al.*, 2010), hence evaporation rate reduces.

There is a high evaporation rate in summer from November to February with January recording the highest rate of 5.71 mm/day. This is the major cause of water loss in ephemeral ponds. Hauwert and Sharp (2014) linked about 70% loss of precipitation from a Karst aquifer to evaporation which was exacerbated by the absence of trees. In order to reduce the high rate of evaporation from the pond surface, cover must be provided. Cover intercepts the radiant energy from the sun and reduces the net energy that is transmitted to the water; this in turn reduces evaporation rate from the water. Sahoo *et al.* (2012) observed that the use of a biological cover on a farm pond reduced evapo-transpiration by 1.18mm/day compared to the control pond. Alternatively, chemicals can be applied to increase the cohesion force between the water molecules on pond surfaces to reduce the rate of pond water evaporation. An experiment was performed by Elvira *et al.* (2013) to determine the efficiency of three different chemicals: steary alcohol, ethylene glycol and mono octadecyl in reducing evapo-transpiration rate. It was found that all the chemicals could reduce the rate of evapo-transpiration between 13 % and 17%. Nevertheless at higher temperatures and wind speed above 3m/s the efficiency of the chemicals reduces (Elvira *et al.,* 2013). The average wind speed at the study area is 4.35m/s which is above the recommended limits. Hence the chemical method for reducing evaporation from the pond may not be suitable.

In addition, to the use of cover and chemicals to reduce evapo-transpiration rate, surface mulch can be applied to the soil surface. Mulch reduces evaporation, controls the temperature of the soil, reduces weed growth and adds organic matter to the soil. Also narrow-leafed crops and short season crops should be planted to reduce the rate of evapo-transpiration (Morison *et al.,* 2008). Evaporation can affect the water balance in ephemeral pond especially during periods of average rainfall and renders the pond water unsuitable for irrigation. In order to avert the negative effects of evaporation on the pond, chemicals should be applied to the pond surfaces or cover should be provided.

In the study area, it was also observed that there is a monthly variation in evaporation rate, which could affect the water levels in the ponds. Figure 17 displays the relationship between evaporation and the months of the year. The mean monthly evaporation rate was 134.37mm and the standard deviation was 19. The mean daily evapo-transpiration rate was 4.48mm. This value represents a low evaporation rate and is mainly due to the dryness of the study area for the greater parts of the year. The period from January to June is critical because it is the period when the ponds are filled with water. During this period, the mean monthly evaporation rate was 112.89 and a mean daily evaporation rate was 3.76mm.

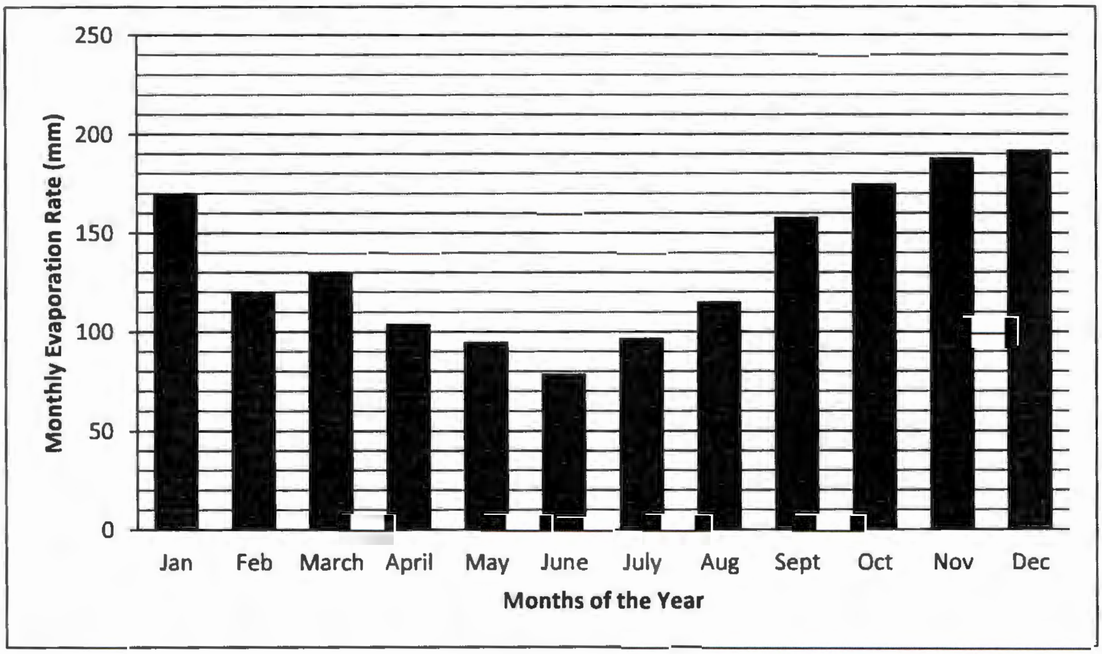

Figure 17: Average monthly evaporation rate from 2004-2013

December records the highest evaporation rate. During this month the sun is vertically overhead in the southern hemisphere. The solar radiation is high and increases the net energy in water in the ponds. Coupled with the highest wind speed during December, there is high evaporation rate from the water surface. Nevertheless, the high temperatures and the high wind speed may not have significant effects on the water balance due to relatively high rainfall during that month.

Rong *et al.* (2013) and Finch and Calver (2008) stated that there is a seasonal variability in evaporation rate and it is due to solar radiation and the net radiation in water. Low evaporation rates were recorded for the months of May, June and August when net radiation is low. The lowest evaporation rate was registered in June. In winter, less solar radiation reaches the surfaces of the ponds resulting in cold conditions in the water. This can reduce evaporation from the ponds and make the water last longer. Under this condition the water can be used to irrigate winter crops such as peas and onions.

5.4.1.4. Wind Speed.

The wind speed was taken at a height of 1245m and was standardised at a height of 10 m using equation 8. The standardised wind speed values are higher than the measured ones. Obstruction of winds such as buildings, tall trees and rough surfaces are discounted. The average wind speed was 4,35m/s and the highest was recorded in November. May was the month with the lowest wind speed. In general, the area experiences low wind speed and may not contribute much to evaporation of water from the pond. The high wind speed recorded in October can be attributed to rainfall. The rainfall season normally begins in October and is always accompanied by thunderstorms due to the development of low pressure systems in the interior of the country resulting in high wind speed. Rainfall ends in March hence, the absence of rainfall could also result in the low wind speed.

Figure 18 shows the relationship between actual wind speed (series 1) and the standardised wind speed (series 2) in the study area. During the rainy season especially from October to January, the wind speed is relatively high, but the period coincides with the rainy season when the ponds are being filled with water through precipitation. Winds reduce saturated water vapour pressure of water by blowing away the water molecules from the surface of ponds.

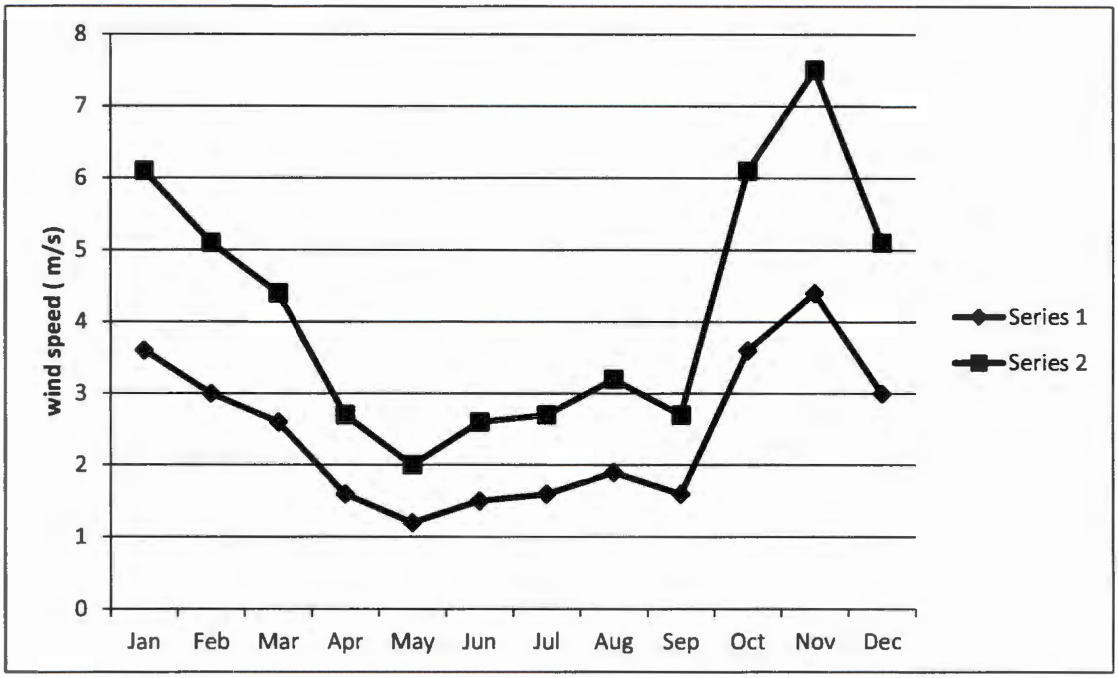

Figure 18: Standardised wind speed

This accelerates evaporation from ponds surfaces. However, wind speed from March to June is very low and this is the period when the ponds are useful for irrigation. The wind therefore does not contribute much to water loss from the ponds. Nevertheless, windbreaks can be built around the ponds to reduce any possible effect of wind on evaporation from the ponds surfaces and also increase the albedo thereby reducing the net heat in the ponds. Spraying of surfaces of ponds with chemicals such steary alcohol, mono octadecyl ether reduces evaporation of water from the water surface (Elvira *et a*l., 2013) because these chemicals bind water molecules together.

5.4.2. Assessment of Water Balance in Ephemeral Ponds

In the study area, evaporation and rainfall are the main climatic variables that influence water balance in a pond. However, infiltration rate and soil characteristics equally control the quantity of pond water. This section shows the results of water balance in the various ponds at different stages using Equation 9 to determine their suitability for irrigation.

Water balance equation:

$$\frac{dv}{dt} = Qv - Qint - Qevt - C \qquad \textbf{\textit{Equation (9)}}$$

But V$\propto$ h (height of water column

Hence the equation becomes:

$$\frac{dh}{dt} = h - (Qint + Qevt + C) \qquad \textbf{\textit{Equation (10)}}$$

Q_{int} can be substituted with Darcy's (1856) equation for infiltration rate

Q_{evt}can be substituted with Penman (1948) method for potential evaporation rate

$$\boldsymbol{H_w = h_o - \left(24K\left[\frac{L+S_f+h_o}{L}\right] + 0.35(1+0.24U_2)(e_s - e_a)\right)} \qquad \textbf{\textit{Equation (11)}}$$

The water balance was calculated using equation 10

Where:

H_w =water balance

Qv =initial volume of water in the pond at the end of the rainy season

Qint= infiltration rate

Qevt= evaporation rate

C = correction factor

Qint can be substituted with Darcy's equation for infiltration rate

Qevt can be substituted with Pens method for potential evaporation

L= total depth of subsurface ground in question (mm)

S_f=wetting front soil sunken head (-ψ)

K= hydraulic conductivity (mm $hour^{-1}$)

h_o= the depth of ponded water above the ground surface

e_s= vapour pressure of water surface

e_a= vapour pressure of water

u= wind speed at 2m

The Darcy equation for infiltration rate is substituted with the literature value from the FAO value based on the soil texture. Pen's method of evapo-transpiration rate is substituted with the computed average evaporation rate per day from January to June. The combined water loss from infiltration and evaporation rate per day: =2.4cm+0.376cm=2.776cm.

Water balances from pond A after a day:

Hw = 162.0cm - (2.4+0.376) cm

Hw = 159.224cm

Table 19 compares the measured infiltration rates of the various soil types with that of FAO.

Table 19: Ponds, soil types and infiltration rates

Sample I.D	Soil Types	Infiltration Rate cm/hr (FAO)	Measured Infiltration Rates (cm/hr)
A	Clayey Loam	0.5-1.0	0.6
B	Clayey Loam	0.5-1.0	0.5
C	Clayey Loam	0.5-1.0	0.5
D	Clay	0.1-0.5	0.2
E	Clay	0.1-0.5	0.2

The water from ponds A, B and C recorded the highest infiltration rates. This was attributed to the soil texture on which the ponds were formed. Clay loam has more macro pores than clay (Gardner, 2005) this accounts for the higher infiltration rates from those ponds. The slight difference in the infiltration rate between ponds A and that of B and C could be due to variations in the nature of the sub-soil and the underlying rock. The presence of hard layers below the topsoil can reduce soil permeability. Pond D and E were formed over clay soil. This resulted in low infiltration rate. The pore space consisted mainly of micro-pores. This does not allow easy flow of water into the deeper layers. The infiltration rates and evaporation rates from the ponds are shown in Table 20

Table 20: Infiltration, evaporation rate and total water loss/day

Ponds	Soil Types	Initial water column (cm)	Infiltration rate/hours (cm)	Infiltration rate/day (cm)	Evaporation rate/day (cm)	Total water loss/day (cm)
A	Clay loam	162.0	0.6	14.4	0.367	14.767
B	Clay loam	254.0	0.5	12.0	0.367	12.367
C	Clay loam	226.0	0.5	12.0	0.367	12.367
D	Clay	45.0	0.2	4.8	0.367	5.167
E	Clay	215.0	0.2	4.8	0.367	5.167

Infiltration and evaporation affect water balance in a pond. Pond D had the lowest water depth. It has a flat shape and has a small outlet that drains the water. Pond B, C and E were deep and could be attributed to the topography of the area. Pond A was surrounded by a medium slope hence the medium water column.

Pond B was the deepest while pond D was the shallowest. The other ponds were of medium depths. Pond B was formed at built-up areas; the formation of hard surfaces increases runoff into the pond hence the highest water balance (254.0 cm). Moreover the pond is fenced thus animals cannot use it for watering resulting in more water being conserved. It is also surrounded by trees whose shade reduces evaporation from the pond surface. Ponds A and C are located in open fields, therefore, more evaporation takes place on the surfaces. Secondly, the ponds are used to water animals. This accounts for the low water column. Pond D had a low water column due to the effects of grazing and the presence of a small exit point. Pond E had a high water column but is more saline and this result in a decrease in evaporation rate (Oroud, 1995).The water balance for the various ponds has been represented in Table 21. The values in column A, B, C, D and E show the water balance after every 10 days.

Table 21: Pond water balance

Water balance	Ponds A	B	C	D	E
0	162.0	254.0	226.0	45.0	215.0
10	158.33	246.66	222.33	41.33	211.33
20	154.66	242.99	218.66	37.66	207.66
30	150.99	239.32	214.99	33.99	201.99
40	3.22	130.33	6.66		149.33
50		6.66			97.66
60					45.99
70					
80					
90					

Water balance is mainly affected by evaporation and infiltration. At the end of the rainy season, the soil at the bottom of ephemeral ponds is completely saturated with water; the water table is close to the soil surface hence infiltration rate is zero (Thomas *et al.,* 2010). At this stage water loss is mainly due to evaporation. According to Collins (2005) infiltration rate is affected by the vadose zone below the ponds. In the calculation of the water balance, an average time lag of 30 days is given before infiltration takes place. It therefore means that for the first 30 days it is only evaporation that affects the water balance of the ponds.

Based on the calculated water balance, the water in Pond A could last for only 40 days, pond B for 50days, pond C last for 41days.The water in pond D lasted for 35 days while pond E could last for 69 days after the rainy season. The water in ponds A, C and D Could not be used to grow crops due to the short longevity of the pond water. The water in pond B could be used to grow short-seasoned crops such as lettuce and beetroot. However, the water in pond E could be used to irrigate other vegetables such as green maize, cucumber and carrots. The water in all the ponds can be suitable for irrigation when it is utilised from the middle of the rainy season. It can also be used to supplement irrigation during dry spells in the cropping season.

5.5 Summary

Climatic factors influence the water balance in ephemeral ponds. During periods of high rainfall pond water is suitable for irrigation. When the rainfall is average, the ponds may be suitable for irrigation through intervention measures. When the rainfall is low most of the ponds do not contain water and are not suitable for irrigation. High temperatures promote evaporation of water from ephemeral ponds and also affect the water balance. Also the suitability of the water for irrigation depends mainly on the water depth and this determines the types of crops that can be grown.

CHAPTER 6

DEVELOPMENT OF SUITABILITY INDICES FOR EPHEMERAL PONDS

6.1. INTRODUCTION

Due to water scarcity in many parts of the world, farmers are under pressure to utilize different kinds of water for irrigation. These include water from wells, industrial wastewater, treated or untreated sewerage water (Amoah *et al.,* 2016). The use of such water often creates problems for humans. Firstly poor water quality contaminates soil, crops and diseases are passed on to humans. Heavy metals absorbed by crops can cause cancer, interference with the endocrine system as well as creating reproductive abnormalities. The presence of pathogenic organisms on vegetables and fruits causes abdominal problems, diarrhea and dysentery. In arid regions, some farmers depend on groundwater including shallow wells for irrigation. This water source sometimes becomes polluted from anthropogenic activities and may affect human health. Also excessive abstraction of water from wells affects the water table. This reduces water availability for irrigation and results in crop failure. The study area experiences low rainfall with annual average of 410mm. The situation is accentuated by the fact that the rainfall is irregular and is accompanied by torrential thunderstorms. Consequently less water remains in the soil. The bulk of the water is lost through runoff. Sometimes some water collects in ephemeral ponds that can serve as watering points for animals or it is lost through evaporation and seepage. The suitability of the pond water for irrigation depends on rainfall amount, the depth of the pond water and lastly its quality. Hence these parameters have been combined to develop indices for irrigation. The suitability of ephemeral pond water for irrigation depends on the amount of rainfall in the area, the depth of the water column and the quality of the water. Hence these criteria were used to develop indices for the pond water suitability for irrigation.

6.2 Methodology

The results of chemical and biological analysis from ephemeral pond water were used to assess water quality as good, moderate and poor. This was achieved by making reference to the South African Water Quality Guidelines for Irrigation (DWAF, 1996). In the suitability index (Table 21), the quality was described as good, moderate or bad. The water that was described as good refers to the Target Water Quality Range. This is also called the No Effect Range. This is the value of the constituent that has no adverse effect on the suitability of the water for irrigation (DWAF, 1996). The moderate water quality describes the acceptable situation that may not have effects on humans when the water is used for irrigation. It also describes the water that can be used to irrigate moderately tolerant crops or less sensitive crops. The water that was referred to as bad is not suitable for irrigation due to the toxicity level of the constituent in water. In addition, the depth of the water column at the end of the rainy season in 2014 was measured with the use of a metal pole and a measuring tape. This was repeated during the dry season to confirm the original measurements and the necessary adjustments were made. The water column with the depth below 100 cm was described as low, the depth between 100cm and 200 cm was considered as moderate while the water whose depth was above 200cm was referred to as high.

Rainfall data were obtained from the South African Weather Bureau, Kimberley and were standardized using the Standardized Precipitation Index (SPI). This resulted into three periods of rainfall: above normal rainfall (706 mm), normal (415 mm) and below normal (243 mm). This was then translated into high rainfall, average and below average. The data were combined to develop suitability indices for ephemeral pond water. Table 22 presents the suitability indices for the use of ephemeral pond water for irrigation.

Table 22: Suitability index for pond water for irrigation

		TOTAL ANNUAL RAINFALL				
		High	*Moderate*	*Low*		
Water Quality	*Poor*	***A***	***B***		*Low*	*Water Depth*
	Moderate	***C***			*Moderate*	
	Ideal	***D***	***E***		*High*	

The index was developed by taking into account water quality, rainfall and water depth.

Suitability index A

A pond that has the characteristics of high rainfall, poor water quality and shallow depth will not be suitable for irrigation due to pollution of water and high soil permeability

Suitability index B

The suitability of a pond for irrigation is impaired owing to low rainfall, shallow water depth and poor water quality due to accumulation of salts.

Suitability Index C

Ponds having the characteristics of high rainfall, moderate water quality and depth can be used to grow short, seasoned crops through soil, water and crop management (Bauder & Brock, 2010)

Suitability Index D

Ponds that form under the conditions of high rainfall, good water quality and high depth have the ideal situations to grow a variety of crops.

Suitability Index E

The pond that is formed having the characteristics of moderate rainfall, good water quality and high depth is suitable for growing crops due to low soil permeability and low evapotranspiration rate.

Other Indices

There are other indices that have not been indicated. However any combination that consists of low depth or poor water quality is not suitable for irrigation. When the depth is low, the longevity of water will be short and the water cannot sustain the growth of crops. Also water of poor quality affects the health of humans when crops are consumed raw or uncooked (WHO, 2006). Water containing heavy metals such as lead, cadmium, mercury and arsenic can pass through the food chain and cause health problems to people (Anim *et al.,* 2012).

Land use and water quality determine how water can be used. Water of good quality may be used for domestic purposes. On the other hand poor quality water may be useful for mining and construction. Water depth is mainly influenced by rainfall and runoff. Other factors such as the slope around ponds, shape and soil characteristics can affect the water column in a pond (USGS, 2016). But after the rainy seasons the main forces that affect the depth of water in a pond are evaporation and infiltration. These factors determine the longevity of the pond water for irrigation.

6.3. Results and Discussion

This section discusses the suitability indices for the five ponds and the reasons for their selection. This was made possible by considering water quality analysis results, water depth and climatic data. It includes a broad discussion of the results that lead to the development of suitability indices for irrigation. The indices are a very important aspect of this thesis for it provides a useful contribution to new knowledge.

Ponds B and C fit into suitability matrix of D or E depending on the rainfall amount of the particular season. The water columns for the two ponds were high (254 cm and 266 cm) and would increase the longevity of the water in them. The biological constituents were within the limits set by DWAF and WHO. The measurements for the anions were within the recommended range of FAO and DWAF. The values recorded for cations were acceptable except for calcium and magnesium. The pH values were close to the highest limits set by FAO and DWAF.

Ponds A and E fit into suitability matrix index C. The water depth was moderate. All the micro-biological constituents were within the recommended limits specified by WHO and DWAF. All the measurements of anions satisfied the recommendations of FAO and DWAF. The measured values for pH and EC are higher than the recommended limits specified by FAO and DWAF. Nevertheless, the ponds can be useful for irrigation through soil, water and crop management (Leogrande, 2012; Bauder & Brock, 2010; Fipps, 2013). These may include the application of gypsum (Bauder & Brock, 2010), avoiding spray irrigation and the planting of salinity tolerant crops such as tomato and mustard. In order to reduce evaporation, the pond can be covered (Sahoo *et al.*, 2012).

Pond D was not suitable for irrigation. The water depth was low and the water could be lost fast through evaporation and infiltration.

6.4. Summary

Rainfall, water quality and water depths were used to develop suitability indices for irrigation. Five sections were identified for the indices. Cells A and B were not suitable for irrigation due to low quality and shallow depths. Cell C could be suitable for irrigation through intervention of crop, water and soil management. Cells D and E could be used for irrigation due to their depths, and water quality. Cell D experienced high rainfall whilst section E recorded low rainfall but the longevity of the water was good due to low infiltration and low evaporation rates. All the ponds were suitable for irrigation except pond D.

6.5. Research Gaps Filled by the Study

Most of the existing models (SWAT, USDA) on water balance focus on a holistic approach involving all water inflows and outflows. However, in semi-arid areas, ephemeral ponds form during the rainy seasons. A few days after the rainy seasons, all the inflows and outflows cease and the only forces that affect the water balance are infiltration and evaporation. The new model is based on these forces. The Darcy's equation for infiltration rate and Pen Montieth equations for evaporation rate were used to substitute for infiltration and evaporation in the old model. The depth of the water column is differentiated to obtain the new model. The model is similar to the Soil and Water Model, which applies to soil water. The model developed by the study can be applied to surface water such as dams, ponds and other wetland.

The recommendations for the suitability of a particular water body for irrigation are based on water quality (WHO 2006, FAO, 1994, DWAF 1996). It involves criteria for a water constituent and information about its effects on crops, soil and humans. None of the guidelines so far mentions the longevity of the water for irrigation. The study has developed suitability indices for ephemeral pond for irrigation. It combines rainfall amount in the area, water quality and pond depth to develop suitability indices for the ponds. The findings can be useful to the national Department of Agriculture Forestry and Fisheries, water users and managers.

CHAPTER 7

CONCLUSION AND RECOMMENDATION

This chapter comprises a summary of all the findings and the recommendations to make ephemeral ponds suitable for small scale irrigation. It also provides suggestions about areas for further studies regarding the use of the pond water.

7.1. Conclusion

Vryburg District is located in the North West Province in South Africa. The area is dry and registers a mean annual rainfall of about 410mm. This has resulted in water scarcity and has created socio-economic problems such as lack of employment opportunities, poverty, food security and migration to urban centres.

The main aim of the study was to investigate the dynamics of ephemeral pond water in the study area and to determine their suitability for irrigation. To this end, the phase file in North West Province was used to display all the ponds in the study area and to locate their spatial distribution. Five ponds with sizes greater than 2ha were selected for the study. Moreover the satellite imagery was processed to observe land use land cover change for the periods 2004 and 2013. The land use categories that were observed were woody plants bare area, water and built-up area. It was found that the built-up area increased in size and was attributed to construction of houses and development in general. The reduction in the area covered by woody plants and grass was due to felling of trees for fuel wood and over-grazing, respectively. The change in the area occupied by pond water was due to daily and seasonal rainfall variability. The mean annual rainfall for 2004 and 2013 was 342.8 mm and 288.2 mm, respectively.

Error confusion matrix was developed to ascertain how the classified images agreed with the field data. The overall accuracy and the Kappa Coefficient were above 75%. This implied that most of the data were correctly classified and only a few were due to chance. Nevertheless, there was some confusion between classes. Some trees were wrongly classified. Some bare area classified as grass and grass classified as woody trees. Grass and woody plants form a homogeneous mix, making it difficult to distinguish between them. In addition, the medium resolution of the images (30 m) made it difficult to differentiate between some of the classes. There was confusion between grass and water and was due to the fact that sometimes grass and water occur in the same environment.

Water quality determines the suitability of ephemeral pond water for irrigation. Water samples were collected from the 5 ponds and were analysed in the laboratory for chemical and microbiological parameters. The computer software SPSS was used to determine the relationships between the various water constituents. Moreover, the relationship between land use and land cover change and water quality was analysed. Firstly, land use and land cover change for each of the sites were determined. These were used together with some water quality parameters to run multi-linear regression equations with the use of Excel and verified with SPSS. At $R^2=0.89$ it was found that grass and bare area had no effect on nitrate concentration in water ($p<0.42$). Grass had no effect on electrical conductivity and also EC concentration did not depend on bare area ($p<0.58$). Vegetation and bare area had no impact on cadmium concentration in the pond water ($p<0.85$). Grass had an effect on *E. coli* concentration in water as well as bare area ($p<0.006$) and $R^2=1$.

The physical, chemical and microbiological constituents were analysed and compared with DWAF, WHO and FAO water quality guidelines. The physical parameter did not meet the limits set by DWAF and FAO but the water could be used for irrigation with few restrictions. All the chemical characteristics were within the limits set by the guidelines suggesting that the water was suitable for irrigation. Using ephemeral pond water for irrigation can create employment, provide income to farmers and improve food security in the study area. The water can be used to grow all types of crops including vegetables, field crops and fodder. As regards the microbiological data, the values did not satisfy the recommendation for DWAF but were within the safe limits for WHO with respect to *E. coli*. Hence the water for the ponds was suitable for growing all types of crops including those eaten raw. However when total coliform was used as the parameter to test for water quality the pond water did not satisfy the recommended limits for crops that are eaten raw or uncooked. However, the pond water could be used to grow field crops, pasture and forage crops and irrigate open fields. Using the pond water to grow forage crops can provide fodder for animals during winter when the pasture condition is poor.

Furthermore a mathematical equation was modeled to determine the water balance in the ponds. This was achieved by combining Darcy equation for infiltration rate with Pen formula for evaporation rate.

Furthermore a mathematical equation was modeled to determine the water balance in the ponds. This was achieved by combining Darcy equation for infiltration r ate with Pen Montieth formula for evaporation rate. The equation was then differentiated to obtain an equation for the water balance. A field testing was done to calculate the water balance of the selected ponds in the study area. This was achieved by collecting climatic data such as rainfall, temperature, win speed and evapo-transpiration from the weather stations. In addition infiltration rates of the soil from the various ponds were determined. The infiltration rates measured were compared with the literature values. The various data obtained from infiltration and evapo-transpiration was used to determine the water balance as well as the longevity of the pond water. The water from ponds A, C, and D could dry up before 42 days and could not be used for irrigation. However the water from ponds B and E was suitable for irrigation.

Based on rainfall amount, water quality status, and the depth of the various ponds, suitability indices were developed to determine the fitness for use of the pond water for irrigation. Sections A and B were found to be unsuitable for irrigation due to their poor quality, shallow depths and rainfall. Section C was found to be suitable for growing only short season crops owing to the average depths and medium quality. Finally section D and E were found to be suitable for growing all types of crops.

7.2. Key findings

The study identified certain important findings. The relationship between land use and water quality was established. A mathematical equation was modeled to determine the water balance of ephemeral ponds. A suitability index was developed for the pond water for irrigation by using rainfall, water quality and water depth as the parameters.

7.3. Summary

The research has found that some ephemeral ponds are of good quality and can last long enough to irrigate short, seasoned crops. This can help to improve food security in rural, semi-arid regions. It established that livestock grazing has effect on ephemeral pond water quality. Some ephemeral pond water can last long enough to be used for small-scale irrigation or supplement dry spells during the cropping season. Finally, suitability indices were developed for ephemeral ponds for irrigation.

7.4. Recommendations

Irrigation

In order to make ephemeral ponds suitable for irrigation there are certain recommendations to be implemented. The pond water should be used for irrigation during the middle of the rainy season; the longevity of the water will be good and can be used to grow a variety of crops drip or spray irrigation.

Crops

Also certain crops such as tomato, mustard and other cultivars that are tolerant to high salinity and alkalinity should be planted when ephemeral pond water is used for irrigation. Moreover certain GMO crops are resistant to high salinity and alkalinity and they must be selected for cultivation when using ephemeral pond for irrigation.

Soil

Soil salinity can be managed by applying micro-irrigation at regular intervals to give the crops enough time to absorb the salts that will otherwise accumulate in the soil.

When leafy crops are planted sub-surface irrigation should be applied to prevent foliar damage due to high alkalinity. Gypsum should be applied to neutralize high alkalinity in ephemeral pond water. This must be accompanied by organic matter application to improve the soil structure and nutrients in the soil.

Land use

Land use affects ephemeral pond water quality. Anthropogenic factors such as agriculture, settlements and municipal activities impair water quality. Land use such as application of fertilizers, chemical and discharge of wastewater around the catchment area of ponds must be controlled so as to prevent pollution of the pond water. High concentration of micro-organisms can affect the quality of crops and can transmit diseases to humans. When the concentration of *E. coli* and total coliform is higher than WHO recommended limits, sprinkler irrigation must be avoided to prevent poor quality crops. In addition, the water should not be used to irrigate leafy and fruit crops and lawns that are used for recreation.

Most of ephemeral ponds receive their water through precipitation and runoff. The water volume can be increased by the building of check-banks and stone dykes to direct more runoff into the ponds. Infiltration rate can be reduced by cementing the sides and the bases of the pond with concrete or with clay; and the volume can be increased through excavation of the ponds. Evaporation is a major cause of water loss from the pond surfaces. This can be reduced by providing a cover to minimize evaporation. The surface can be covered with material to reduce the temperature of the surface. Sometimes the water can be sprayed with chemicals such ethylene glycol and steary alcohol. The chemicals bind the water molecules together making it difficult to break the force of cohesion between the molecules. Hence the rate of evaporation is reduced. Also in arid and semi-arid regions, the rainfall season is short hence, growing of crops should be done in the middle of the rainy season and short seasoned crops should be planted.

With respect to areas of further studies, there should be practical investigations into the use of ephemeral pond water to irrigate different crops to find out its effects on yield and crop quality. The mathematical equation derived must be tested to determine water balance and longevity of water bodies such as lakes and dams.

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APPENDICES

APPENDIX 1: Correlation and Regression Analysis

Correlation analysis between pH and Cations

Correlations							
		pH	Na+	K+	Ca++	Mg++	Cd++
Pearson C Pearson Correlation	pH	1.000	-.072	.716	-.128	.956	.371
	Na+	-.072	1.000	.635	.015	.053	.757
	K+	.716	.635	1.000	-.198	.744	.861
	Ca++	-.128	.015	-.198	1.000	.061	-.533
	Mg++	.956	.053	.744	.061	1.000	.366
	Cd++	.371	.757	.861	-.533	.366	1.000
Sig. (1-tailed)	pH	.	.454	.087	.419	.006	.269
	Na+	.454	.	.125	.491	.466	.069
	K+	.087	.125	.	.375	.075	.031
	Ca++	.419	.491	.375	.	.461	.178
	Mg++	.006	.466	.075	.461	.	.272
	Cd++	.269	.069	.031	.178	.272	.

Correlation Analysis between pH and Anions

Correlations					
		pH	**Cl-**	**NO3-**	**PO4---**
Pearson Correlation	pH	1.000	-.092	-.448	-.033
	Cl-	-.092	1.000	.844	.637
	NO3-	-.448	.844	1.000	.817
	PO4---	-.033	.637	.817	1.000
Sig. (1-tailed)	pH	.	.441	.224	.479
	Cl-	.441	.	.036	.124
	NO3-	.224	.036	.	.046
	PO4---	.479	.124	.046	.

Correlation Analysis between pH and Micro – organisms

Correlations				
		pH	Ecoli	total coliform
Pearson Correlation	pH	1.000	-.544	.413
	Ecoli	-.544	1.000	-.047
	total coliform	.413	-.047	1.000

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.668[a]	.446	-.108	.92723
a. Predictors: (Constant), total coliform, Ecoli				

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.385	2	.692	.805	.554[b]
	Residual	1.719	2	.860		
	Total	3.104	4			

a. Dependent Variable: pH
b. Predictors: (Constant), total coliform, Ecoli

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	8.703	1.250		6.962	.020
	Ecoli	-.006	.006	-.526	-.998	.423
	total coliform	.000	.001	.388	.737	.538

a. Dependent Variable: pH

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Correlation Analysis between Electrical Conductivity and Cations

Correlations							
		Ec	Na+	K+	Ca++	Mg++	Cd++
Pearson Correlation	Ec	1.000	-.253	-.507	-.323	-.407	-.185
	Na+	-.253	1.000	.635	.015	.053	.757
	K+	-.507	.635	1.000	-.198	.744	.861
	Ca++	-.323	.015	-.198	1.000	.061	-.533
	Mg++	-.407	.053	.744	.061	1.000	.366
	Cd++	-.185	.757	.861	-.533	.366	1.000
Sig. (1-tailed)	Ec	.	.341	.192	.298	.248	.383
	Na+	.341	.	.125	.491	.466	.069
	K+	.192	.125	.	.375	.075	.031
	Ca++	.298	.491	.375	.	.461	.178
	Mg++	.248	.466	.075	.461	.	.272
	Cd++	.383	.069	.031	.178	.272	.

Correlation Analysis between Electrical Conductivity and Anions

Correlations					
		Ec	Cl-	NO3-	PO4---
Pearson Correlation	Ec	1.000	.040	-.127	-.599
	Cl-	.040	1.000	.844	.637
	NO3-	-.127	.844	1.000	.817
	PO4---	-.599	.637	.817	1.000
Sig. (1-tailed)	Ec	.	.475	.419	.143
	Cl-	.475	.	.036	.124
	NO3-	.419	.036	.	.046
	PO4---	.143	.124	.046	.

Correlation Analysis between Electrical Conductivity and Micro – organisms

Descriptive Statistics

	Mean	Std. Deviation	N
Ec	547.8000	196.41461	5
Ecoli	77.8000	82.46333	5
total coliform	1779.0000	768.30951	5

Correlations

		Ec	Ecoli	total coliform
Pearson Correlation	Ec	1.000	.675	-.014
	Ecoli	.675	1.000	-.047
	total coliform	-.014	-.047	1.000
Sig. (1-tailed)	Ec	.	.106	.491
	Ecoli	.106	.	.470
	total coliform	.491	.470	.

ANOVA[a]

Model	Sum of Squares	df	Mean Square	F	Sig.

	Regression	70261.284	2	35130.642	.836	.545[b]
1	Residual	84053.516	2	42026.758		
	Total	154314.800	4			

a. Dependent Variable: Ec

b. Predictors: (Constant), total coliform, Ecoli

Model		Unstandardised Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	414.588	276.394		1.500	.272
	Ecoli	1.609	1.244	.675	1.293	.325
	total coliform	.005	.134	.018	.034	.976

Correlation Analysis between Phosphate and Micro – organisms

Descriptive Statistics

	Mean	Std. Deviation	N
PO4---	28.7880	18.70654	5
Ecoli	77.8000	82.46333	5
total coliform	1779.0000	768.30951	5

Correlations

		PO4---	Ecoli	total coliform
Pearson Correlation	PO4---	1.000	.016	-.573
	Ecoli	.016	1.000	-.047
	total coliform	-.573	-.047	1.000
Sig. (1-tailed)	PO4---	.	.490	.157
	Ecoli	.490	.	.470
	total coliform	.157	.470	.

ANOVA[a]

Model	Sum of Squares	df	Mean Square	F	Sig.

	Regression	459.117	2	229.559	.488	.672[b]
1	Residual	940.622	2	470.311		
	Total	1399.739	4			
a. Dependent Variable: PO4---						
b. Predictors: (Constant), total coliform, Ecoli						

Model		Unstandardised Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	53.815	29.239		1.841	.207
1	Ecoli	-.003	.132	-.011	-.020	.986
	total coliform	-.014	.014	-.573	-.988	.427

Correlation Analysis between Nitrate and Micro – organisms

Descriptive Statistics

	Mean	Std. Deviation	N
NO3-	.4560	.65945	5
Ecoli	77.8000	82.46333	5
total coliform	1779.0000	768.30951	5

Correlations

		NO3-	Ecoli	total coliform
Pearson Correlation	NO3-	1.000	.246	-.904
	Ecoli	.246	1.000	-.047
	total coliform	-.904	-.047	1.000
Sig. (1-tailed)	NO3-	.	.345	.018
	Ecoli	.345	.	.470
	total coliform	.018	.470	.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.493	2	.746	6.056	.142[b]
	Residual	.247	2	.123		
	Total	1.740	4			

a. Dependent Variable: NO3-

b. Predictors: (Constant), total coliform, Ecoli

Model		Unstandardised Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.694	.473		3.580	.070
	Ecoli	.002	.002	.204	.765	.524
	total coliform	-.001	.000	-.894	-3.355	.079

Correlations

		pH	Ec	Na+	K+	Ca++	Mg++	Cd++	Cl-	NO3-	PO4---	Ecoli	total coliform
Pearson Correlation	pH	1.000	-.465	-.072	.716	-.128	.956	.371	-.092	-.448	-.033	-.544	.413
	Ec	-.465	1.000	-.253	-.507	-.323	-.407	-.185	.040	-.127	-.599	.675	-.014
	Na+	-.072	-.253	1.000	.635	.015	.053	.757	-.118	.130	.464	.494	.306
	K+	.716	-.507	.635	1.000	-.198	.744	.861	-.044	-.175	.353	-.029	.450
	Ca++	-.128	-.323	.015	-.198	1.000	.061	-.533	-.838	-.489	-.326	-.445	.488
	Mg++	.956	-.407	.053	.744	.061	1.000	.366	-.356	-.653	-.195	-.469	.661
	Cd++	.371	-.185	.757	.861	-.533	.366	1.000	.274	.161	.491	.430	.170
	Cl-	-.092	.040	-.118	-.044	-.838	-.356	.274	1.000	.844	.637	.206	-.865
	NO3-	-.448	-.127	.130	-.175	-.489	-.653	.161	.844	1.000	.817	.246	-.904
	PO4---	-.033	-.599	.464	.353	-.326	-.195	.491	.637	.817	1.000	.016	-.573
	Ecoli	-.544	.675	.494	-.029	-.445	-.469	.430	.206	.246	.016	1.000	-.047
	total coliform	.413	-.014	.306	.450	.488	.661	.170	-.865	-.904	-.573	-.047	1.000
	pH	.	.215	.454	.087	.419	.006	.269	.441	.224	.479	.172	.245

	Ec	.215	.	.341	.192	.298	.248	.383	.475	.419	.143	.106	.491
	Na+	.454	.341	.	.125	.491	.466	.069	.425	.417	.216	.199	.308
	K+	.087	.192	.125	.	.375	.075	.031	.472	.389	.280	.481	.223
	Ca++	.419	.298	.491	.375	.	.461	.178	.038	.202	.296	.227	.202
	Mg++	.006	.248	.466	.075	.461	.	.272	.278	.116	.377	.213	.112
	Cd++	.269	.383	.069	.031	.178	.272	.	.327	.398	.201	.235	.392
Sig. (1-tailed)	Cl-	.441	.475	.425	.472	.038	.278	.327	.	.036	.124	.370	.029
	NO3-	.224	.419	.417	.389	.202	.116	.398	.036	.	.046	.345	.018
	PO4---	.479	.143	.216	.280	.296	.377	.201	.124	.046	.	.490	.157
	Ecoli	.172	.106	.199	.481	.227	.213	.235	.370	.345	.490	.	.470
	total coliform	.245	.491	.308	.223	.202	.112	.392	.029	.018	.157	.470	.

Appendix 3: Water Analysis Data

Physical analysis data

Variable	Unit	Sample Identity		
		A1	A2	A3
pH readings at 22°C		8.56	8.74	8.69
		B1	B2	B3
pH readings at 22°C		8.57	8.60	8.58
		C1	C2	C3
pH readings at 22°C		8.69	8.72	8.80
		D1	D2	D3
pH readings at 22°C		10.64	10.78	10.63
		E1	E2`	E3
pH readings at 22°C		8.57	8.72	8.80

Variable	Unit		Sample Identity	
		A1	A2	A3
Conductivity) 23°C	(µS.min	743	746	717
Conductivity 23°C		B1	B2	B3
Conductivity 23°C	(µ.ms)	4.06	4.06	4.03

Conductivity 23°C		C1	C2	C3
Conductivity 23°C	(μS.min)	555	542	544
		D1	D2	D3
Conductivity 23°C	(μS.min)	437	476	382
		E1	E2	E3
Conductivity 23°C	(μS.min)	785	775	780

Analyte concentration determined by ion chromatography

Variable	Unit	Sample Identity											
		A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3
Cl-	ppm	16.905	17.236	17.263	18.4278	18.184	21.392	10.528	2.9066	2.958	17.602	10.185	10.264
NO2	ppm	1.248	1.107	1.246	1.173	1.8280	1.1688	0.693	0.886	0.74	0.71	1.384	0.948
NO3	ppm	0.631	0.64	0.649	1.506	1.686	1.3968	10.5					

PO4	ppm	18.0791	16.889	18.649	56.981	65.887	59.748	12.738	22.9416	23.100	67.992	10.135	11.082

Variable		Sample Identity														
	Unit	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3
K^+	ppm	2.8	2.2	2.5	2.5	3.5	3.8	2.5	2.8	3.4	3.6	3.9	4	3.6	3.5	2.8
Mg^{+2}	ppm	39	41	40	39	37	40	52	55	52	54	53	52	43	44	46
Ca^{+2}	ppm	18	22	21	17	21	23	26	28	29	26	31	30	32	29	30
Na^+	ppm	40	35	37	39	37	38	45	45	47	41	39	40	39.1	40.0	39.5
Cd+2	ppm	0.02	0.01	0.02	0.01	0.03	0.04	0.03	0.02	0.02	0.01	0.05	0.04	0.02	0.03	0.03

Table 3.3: Microbial data from Sedibeng water

Variable	Unit	Sample Identity											
		A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3
Total Coliforms	Count/100ml	457	1414	1120	816	727	1120	>2420	1986	2420	1986	2420	2420
E.coli	Count/100ml	3	60	147	120	142	67	14	3	6	0	0	0

Appendix 4: Regression

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	bare, grass, freshwater	.	Enter

a. All requested variables entered.

b. Dependent Variable: EC

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.882[a]	.779	.115	182.70199

a. Predictors: (Constant), bare, grass, freshwater

b. Dependent Variable: EC

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	117485.983	3	39161.994	1.173	.576[a]
	Residual	33380.017	1	33380.017		
	Total	150866.000	4			

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	bare, grass, freshwater	.	Enter

a. Predictors: (Constant), bare, grass, freshwater

b. Dependent Variable: EC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	182.264	1047.710		.174	.890
	freshwater	2.857	8.070	.433	.354	.783
	grass	6.949	7.003	.715	.992	.503
	bare	-.378	5.641	-.088	-.067	.957

a. Dependent Variable: EC

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	410.8200	827.8793	546.0000	171.38114	5
Residual	-94.80860	148.54308	.00000	91.35099	5
Std. Predicted Value	-.789	1.645	.000	1.000	5
Std. Residual	-.519	.813	.000	.500	5

a. Dependent Variable: EC

```
REGRESSION

/MISSING LISTWISE

/STATISTICS COEFF OUTS R ANOVA

/CRITERIA=PIN(.05) POUT(.10)

/NOORIGIN

/DEPENDENT NA

/METHOD=ENTER freshwater grass bare

/SAVE ZPRED.
```

Regression

Notes

Output Created		09-Dec-2016 05:05:05
Comments		
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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT NA /METHOD=ENTER freshwater grass bare /SAVE ZPRED.

Resources	Processor Time	00 00:00:00.031
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	Memory Required	4192 bytes
	Additional Memory Required for Residual Plots	0 bytes
Variables Created or Modified	ZPR_13	Standardized Predicted Value

[DataSet1] C:\Users\Annemari\Desktop\walden\ASARE DATA NEW.sav

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	bare, grass, freshwater	.	Enter

a. All requested variables entered.

b. Dependent Variable: NA

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.958[a]	.918	.671	1.89853

a. Predictors: (Constant), bare, grass, freshwater

b. Dependent Variable: NA

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	40.193	3	13.398	3.717	.360[a]
	Residual	3.604	1	3.604		
	Total	43.797	4			

a. Predictors: (Constant), bare, grass, freshwater

b. Dependent Variable: NA

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	40.193	3	13.398	3.717	.360[a]
	Residual	3.604	1	3.604		
	Total	43.797	4			
1	(Constant)	71.408	10.887		6.559	.096
	freshwater	-.264	.084	-2.352	-3.150	.196
	grass	-.137	.073	-.825	-1.878	.311
	bare	-.146	.059	-1.988	-2.484	.244

a. Dependent Variable: NA

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	37.9395	45.6596	40.0380	3.16989	5
Residual	-1.54357	.98519	.00000	.94927	5
Std. Predicted Value	-.662	1.773	.000	1.000	5
Std. Residual	-.813	.519	.000	.500	5

a. Dependent Variable: NA

```
REGRESSION
/MISSING LISTWISE
/STATISTICS COEFF OUTS R ANOVA
/CRITERIA=PIN(.05) POUT(.10)
/NOORIGIN
/DEPENDENT CD
/METHOD=ENTER freshwater grass bare
/SAVE ZPRED.
```

Regression

Notes

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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT CD /METHOD=ENTER freshwater grass bare /SAVE ZPRED.

Resources	Processor Time	00 00:00:00.032
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Variables Created or Modified	ZPR_14	Standardized Predicted Value

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[DataSet1] C:\Users\Annemari\Desktop\walden\ASARE DATA NEW.sav
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Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	bare, grass, freshwater	.	Enter

a. All requested variables entered.

b. Dependent Variable: CD

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.670[a]	.449	-1.202	.00813

a. Predictors: (Constant), bare, grass, freshwater

b. Dependent Variable: CD

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.000	3	.000	.272	.849[a]
	Residual	.000	1	.000		
	Total	.000	4			

a. Predictors: (Constant), bare, grass, freshwater

b. Dependent Variable: CD

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.015	.047		-.317	.804
	freshwater	.000	.000	1.734	.898	.534
	grass	.000	.000	.767	.675	.622
	bare	.000	.000	1.664	.804	.569

a. Dependent Variable: CD

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.0200	.0297	.0260	.00367	5
Residual	-.00661	.00422	.00000	.00406	5
Std. Predicted Value	-1.634	1.019	.000	1.000	5
Std. Residual	-.813	.519	.000	.500	5

a. Dependent Variable: CD

```
REGRESSION
/MISSING LISTWISE
/STATISTICS COEFF OUTS R ANOVA
/CRITERIA=PIN(.05) POUT(.10)
/NOORIGIN
/DEPENDENT ECOLI
/METHOD=ENTER freshwater grass bare
/SAVE ZPRED.
```

Regression

Notes

Output Created		09-Dec-2016 05:06:22
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	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT ECOLI /METHOD=ENTER freshwater grass bare /SAVE ZPRED.

Resources	Processor Time	00 00:00:00.016
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	Memory Required	4272 bytes
	Additional Memory Required for Residual Plots	0 bytes
Variables Created or Modified	ZPR_15	Standardized Predicted Value

[DataSet1] C:\Users\Annemari\Desktop\walden\ASARE DATA NEW.sav

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	bare, grass, freshwater	.	Enter

a. All requested variables entered.

b. Dependent Variable: ECOLI

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.73230

a. Predictors: (Constant), bare, grass, freshwater

b. Dependent Variable: ECOLI

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	27200.264	3	9066.755	16907.189	.006[a]
	Residual	.536	1	.536		
	Total	27200.800	4			

a. Predictors: (Constant), bare, grass, freshwater

b. Dependent Variable: ECOLI

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-544.259	4.199		-129.604	.005
	freshwater	4.224	.032	1.509	130.584	.005
	grass	5.986	.028	1.450	213.246	.003
	bare	2.735	.023	1.498	120.975	.005

a. Dependent Variable: ECOLI

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.3800	201.1919	77.8000	82.46251	5
Residual	-.38001	.59539	.00000	.36615	5
Std. Predicted Value	-.939	1.496	.000	1.000	5
Std. Residual	-.519	.813	.000	.500	5

a. Dependent Variable: ECOLI

```
REGRESSION

/MISSING LISTWISE

/STATISTICS COEFF OUTS R ANOVA

/CRITERIA=PIN(.05) POUT(.10)

/NOORIGIN

/DEPENDENT NO3

/METHOD=ENTER freshwater grass bare

/SAVE ZPRED.
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Regression

Regression analysis

Notes

Output Created		09-Dec-2016 05:07:12
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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT NO3 /METHOD=ENTER freshwater grass bare /SAVE ZPRED.

Resources	Processor Time	00 00:00:00.031
	Elapsed Time	00 00:00:00.031
	Memory Required	4320 bytes
	Additional Memory Required for Residual Plots	0 bytes
Variables Created or Modified	ZPR_16	Standardized Predicted Value

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Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	bare, grass, freshwater	.	Enter

a. All requested variables entered.

b. Dependent Variable: NO3

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.941[a]	.886	.544	.44283

a. Predictors: (Constant), bare, grass, freshwater

b. Dependent Variable: NO3

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.523	3	.508	2.589	.422[a]
	Residual	.196	1	.196		
	Total	1.719	4			

a. Predictors: (Constant), bare, grass, freshwater

b. Dependent Variable: NO3

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-5.317	2.539		-2.094	.284
	freshwater	.041	.020	1.846	2.100	.283
	grass	.026	.017	.798	1.543	.366
	bare	.036	.014	2.453	2.604	.233

a. Dependent Variable: NO3

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.0001	1.5341	.4460	.61705	5
Residual	-.22979	.36003	.00000	.22141	5
Std. Predicted Value	-.723	1.763	.000	1.000	5
Std. Residual	-.519	.813	.000	.500	5

a. Dependent Variable: NO3