EVALUATING THE EFFECTS OF INVASIVE ALIEN PLANTS ON WATER AVAILABILITY AND USABILITY OF LAKE WATER INGAUTENG PROVINCE

by

LAMECK RWIZI

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Supervisor: **Dr Luxon Nhamo**

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DECLARATION

I, Lameck Rwizi, hereby declare that the research reported herewith on the topic "**Evaluating the Effects of Water Hyacinth on Water Availability and Usability of Lake Water in Gauteng Province**", is my own work and that all the sources used or quoted in this dissertation have been indicated and acknowledged by means of complete referencing.

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Signed (Author)

Date: ………………………………….

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Signed (Supervisor)
Date:

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ACRONYMS

ANOVA	**Analysis of variance**
CARA	**Conservation of Agricultural Resources Act**
CBD	**Convention on Biological Diversity**
DEA	**Department of Environmental Affairs**
DEM	**Digital Elevation Model**
DWAF	**Department of Water Affairs and Forestry**
EMM	**Ekurhuleni Metropolitan Municipality**
ET	**Evapotranspiration**
GIS	**Geographical Information Systems**
GPS	**Geographical Positioning System**
IAS	**Invasive Alien Species**
IPCC	**Intergovernmental Panel on Climate Change**
IPPC	**International Plant Protection Convention**
IUCN	**International Union for the Conservation of Nature.**
NIR	**Near Infrared Radiation**
NISC	**National Invasive Species Council**
SAPIA	**South African Plant Invaders Atlas**
TIR	**Thermal Infrared Radiation**
UNEP	**United Nations Environmental Programme**
WfW	**Working for Water Programme**

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ABSTRACT

The invasion of ecosystems by alien species is a growing threat to the delivery of ecosystem services. This study explored the spatial distribution of water hyacinth in the Benoni Lakes and made analysis of its impact on water availability and usability in order to understand the evolution and its propagation rates. The study used satellite imagery for lake level modelling using Remote Sensing and Geographical Information Systems for calculations of area covered by weeds in each lake from 2002 to 2012.The modelling approach illustrates the potential usefulness in projecting invasive plants under climate change and enabled the quantification of long term changes in aquatic weeds. The results showed that aquatic infestations in lakes may be used as powerful predictors of correlations between plant abundance and climate change. The study therefore informs decision makers to identify areas where invasion is likely to occur and increase surveillance for early invaders.

Key words: water hyacinth, invasive alien plants, abundance, spatial extent, Benoni Lakes.

CHAPTER: 1

1. INTRODUCTION

1.1 INTRODUCTION

Invasive alien species have had extensive effects on the habitats they have invaded, altering forest cycles, nutrient cycling, hydrology and energy budgets in native ecosystems. They also compete with, prey on, and carry and cause diseases to native species. While the absolute number of alien species causing harm to native ecosystems and species may be low, individually and cumulatively they have had extensive negative effects in South Africa (van Wilgen *et al.*, 2012). Global change stressors including climate change and variability and changes in land use, are major drivers to ecosystem alterations. The water hyacinth (*Eichhornia crassipes*) is a noxious weed that has attracted worldwide attention due to its fast spread and congested growth, which lead to serious problems in navigation, irrigation and power generation. It is a free floating aquatic weed that can form dense mats on open water bodies. Its introduction to new sites is usually a result of deliberate release in the new areas. Once introduced, it can spread rapidly under optimal conditions, especially in water bodies polluted by nitrogen and phosphorous fertilisers, as is the case in many dams. Its abundance can fluctuate over time (Keller and Lodge, 2009) , as it is often flushed out of water systems by floods, only to cover again when conditions improve (McNeely, 2005). As a result, research concerning the control (especially biological control) and utilisation (especially wastewater treatment or phytoremediation) of water hyacinth has boomed up in the last decade (Malik, 2007).

The invasion of ecosystems by alien species is a growing threat to the delivery of ecosystem services. Invasive alien species are as a result of the ongoing and increasing human re-distribution of species to support agriculture, forestry, mariculture, horticulture and recreation as well as a by-product of accidental introductions.

The interaction between stressors and invasive species, although not well understood, exacerbate the impacts of climate change on aquatic ecosystems, and likewise climate change may cause further invasion. There are several examples of high- level strategies to deal with the problem of invasive alien species, both at global (McNeely, 2004) and national levels (Richardson and van Wilgen, 2004; Shekede *et al.,* 2008). These strategies all call for reducing the risk for new introductions of invasive species, the control of existing invasions to mitigate impact, and the establishment of management and legislative capacity to guide implementation.

Furthermore, aquatic vegetation forms an essential component of a lake ecosystem, influencing its physical and chemical processes as well as affecting human activities. It is therefore imperative to have reliable methods of investigating the past and present status of aquatic vegetation. Therefore, Remote Sensing, Geographic Information Systems (GIS) and multiple regression techniques provide a means to detect and understand long term changes in aquatic vegetation species composition and abundance. Incidences of growth and widespread infestation in the water bodies of South Africa are increasing and constitute a great threat not only to the environment but also to the socio economic conditions of the country (Richardson and van Wilgen, 2004; van Wilgen *et al.*, 2012).

Information on the spatial distribution of aquatic weeds is needed in order to understand the evolution of weed invasion, determine affected areas and evaluate the efficiency of control measures and management actions (Shekede *et al.*, 2008). It is however at this level that availability of automated, real time data becomes imperative. These needs are best addressed through the use of Remote Sensing .The advantages of Remote Sensing include its ability to capture and record earth surface details instantaneously, provide a synoptic view of a land surface, and the ability to store efficiently and analyse data effectively using GIS (Holcombe *et al.*, 2007).Since quantitative ground investigations on the scale of invasion of whole lakes over time are laborious and time consuming, Remote Sensing techniques are increasingly being used for mapping aquatic plants and estimating their distribution and impacts.

However, in the Middle, Civic and Kleinfontein Lakes of Benoni area in the Gauteng Province of South Africa, there has been a proliferation of the water hyacinth since 2006, with little research dedicated to this invasion. This sentiment is also echoed by Meela (2010) and Sydow (2010). This research therefore endeavours to evaluate the effects of invasive alien plants on water availability and usability in these lakes using Remote Sensing, GIS and multiple regression techniques. The study evaluates the impact of invasive water hyacinth in these lakes for a period of 10 years, from 2002 to 2012 .The use of Remote Sensing and GIS to identify and map the spatial distribution of aquatic weeds provides a practical and more reliable measure of the magnitude of the problem as will be shown in this study. However, studies have shown that even with limited data, and other constraints, it is possible to control invasive species (Meela, 2010). The control operations, if carried out effectively, will be worth the effort. Additionally, formal collaboration between organisations to address capacity building and educational transformation in the field of invasion ecology would represent a significant step forward.

The South African legal framework that governs the control and management of invasive alien plants (IAPs) includes eleven national and provincial laws which contain mechanisms for regulating the different threats posed by AIPs (Paterson, 2006). Certain of these laws are framework in nature while the majority are sectoral (Strydom and King, 2009) and aimed at regulating AIPs for one of the following four main purposes: biodiversity conservation; water conservation; agricultural management; and fire risk management. The responsibility for administering these laws spans four national departments, nine provincial conservation authorities, numerous local and statutory authorities. This fragmented regime, coupled with the adoption of a "command and control approach" to regulation, has proven inept in effectively regulating the spread of AIPs in South Africa.

These laws according to Paterson (2006 include: the National Environmental Management Act of 1998 (NEMA); National Environmental Management: Biodiversity Act 10 of 2004, (Biodiversity Act); National Environmental Management: Protected Areas Act 57 of 2003 (Protected Areas Act); Conservation of Agricultural Resources Act 43 of 1983 (CARA)-including the regulations published in GN R1048 Government Gazette 9238 of 25 May 1984, as amended; Agricultural Water Act 36 of 1998 (NWA); Agricultural Pests Act 35 of 1983, and various provincial nature conservation Ordinances and Acts. From these laws NEMA is South Africa's main framework environmental law that seeks to prescribe an integrated environmental framework for the country (Strydom and King, 2009). Firstly, it purports to give effect to the overarching principles of co-operative governance contained in the Constitution of the Republic of South Africa and co-ordinates the functions of the myriad authorities whose activities may impact on the environment. Secondly, it aims to fulfil the government's constitutional imperative under Section 24(b) of the Constitution to take reasonable legislative and other measures to protect the environment.

1.2 RESEARCH BACKGROUND

Plant invasions are a serious threat to natural and semi–natural ecosystems worldwide. In many areas, catchment-scale hydrological modifications and invasive alien plants are among the most influential agents of degradation. Significantly, biological invasions by non–native and animal species are considered one of the greatest threats to natural ecosystem and biodiversity (Enright, 2000; Gorgens and van Wilgen, 2004; Binns *et al.* (2001) contend that the post-apartheid South Africa faces a serious water supply crisis. Unreliable and inadequate rainfall, together with a burgeoning demand from agriculture, industry and domestic uses have led to a water supply problem which cannot be satisfied entirely by the construction of large dams and water transfer schemes. In addition, South Africa has a long history of problems with invasive alien species and of research and management of biological invasions. Estimates that invasive alien plants would use significant amounts of water were a major factor in the establishment of South Africa's Working for Water (WfW) programme, which aims to protect water resources by clearing these plants (Richardson and van Wilgen, 2004; Holmes *et al*., 2008).

In practice the WfW programme has focused on hydrological and social concerns (as embodied in the name of the programme) and its ecological goals are less clearly defined. The aim of improving the ecological integrity of natural ecosystems through the control of invasive alien plants has not always been clear to both programme participants and stakeholders.

This study reviews the understanding of the hydrological effects of water hyacinth on water availability and usability in the Benoni lakes in the Gauteng Province of South Africa. The study considers that the invasion of ecosystems by alien plants could have deleterious effects on water availability and its usability from catchment areas. The study also draws on published sources and highlight some important research challenges in invasion ecology that need to be met in order to address critical gaps in the understanding of invasive alien plants. The quality of available water resources is of major importance to ensure that the multiple uses of water are met in a more sustainable manner. The depletion of water resources and limitation of its usability due to water hyacinth and pollution limit the availability of water for all the downstream uses, intensifying water scarcity (Versfeld *et al*., 1998; Enright, 2000). The different components of water as a resource system are influenced by various land use activities.

1.3 PROBLEM STATEMENT

Invasive alien species introduced in South Africa from different parts of the world (both intentionally and unintentionally) are affecting indigenous plants and animal communities. The intentional spread has been as a result of ongoing and increasing human redistribution of species to support agriculture, forestry, mariculture, horticulture and recreation. This supplies a continuous pool of species from which invasive aliens are recruited (WfW, 2004).The invasive alien species were also introduced as commercial plants or ornamental garden plants for example the Australian acacias in KwaZulu Natal and in the south-western Cape was introduced for timber, bark products and to stabilise sand dunes. Invasions also occurred countrywide as a result of seed introductions, of tree and shrub clearing for pasture and grazing infestations (Richardson and van Wilgen, 2004). The unintentional introductions of IAPs include disease organisms, agricultural weeds and insect pests. However, they were brought here in this country without their natural enemies, which results in plants reproducing copiously.

Furthermore, as the global climate patterns shift, the distribution of invasive species will change, and so will the susceptibility of particular habitats to the impacts of new species introductions. The abundance of the water hyacinth in an environment fluctuates over time, as it is often flushed out of water systems by floods, only to cover them again when conditions improve. Water hyacinth hinders irrigation by impending water flow, by clogging irrigation pumps, and by interfering with weirs. Multi-million dollar flood control and water supply projects, which require decades to construct, can be rendered useless by water hyacinth infestations. Infestations also block access to recreational areas and make them unattractive, decreasing the value of waterfront properties. Invasive alien species often impact the livelihoods of the communities that depend on fishing and water sports for revenue. Challenges posed by IAPs in dams are also seen in the Hartbeespoort Dam which has increasingly become eutrophic due to severe algae growth. Secondly to algae blooms has been the prolonged growth of water hyacinths in the dam due to rapid urbanisation, associated with increased run off, erosion, sedimentation and solid waste entering the dam annually (DWAF, 2007). This pose a high risk to human health and detrimental impacts on recreational in the North West Province and entire aquatic ecosystems. Therefore, invasive species are of concern, not only nationally but globally.

1.4 RATIONALE FOR DOING THE RESEARCH

Previous studies have shown that invasive alien plants use significant amount of water. This was the major factor in the establishment of South Africa's Working for Water (WfW) programme. The projections were made by combining the results of hydrological experiments conducted to assess the effects of afforestation with alien trees on water resources with an ecological understanding of the spread and establishment of invasive trees. The projections were then scaled up to arrive at national estimates of corresponding water consumption (Gorgens and van Wilgen, 2004; Richardson and van Wilgen, 2004; Mgidi *et al.*, 2006; Holmes *et al.*, 2008). While there are some studies that have assessed the effects of invasive plants on native biodiversity and the underlying community dynamics, there is still a gap on measuring the effect of invasive plants (both terrestrial and aquatic) on water usability and availability. This study thrives to fill this gap by assessing the impact of water hyacinth on water availability and usability in South Africa, taking the Benoni lakes as a case study.

The study examines the ecological evidence of the impacts of water hyacinth plants in the Benoni lakes. The ecological rationale for this research is that water hyacinth reduce water yield, threaten biodiversity and reduce land productivity. The research draws on published and unpublished sources, and highlights some important research challenges in invasion ecology filling the critical research gap in the understanding of the impact of invasive alien species on water availability and its usability. Although South Africa has problems with invasive alien organisms from most major taxonomic groups (van Wilgen *et al.,* 1997; Gorgens *et al.,* 2004; Henderson, 2001; Holmes *et al*., 2008), this study focuses only on water hyacinth plants in semi-natural freshwater ecosystems.

Furthermore information on the spatial distribution of these aquatic plants is required for understanding the evolution of the invasion and propagation rates. According to Shekede *et al.* (2008), such information is vital in identifying affected areas and relating weed abundance to probable changes in environmental conditions and human actions including management practices within the study area. Information on aquatic weed distribution also assists in evaluating the effectiveness of control measures and management actions.

1.5 RESEARCH QUESTIONS

The overall aim of this research is reflected in the following research questions:

(i) How does water hyacinth affect the water in the lakes of Benoni area?
(ii) What was the nature of water availability and usage before and after water hyacinth invasions?
(iii) How does climate change aid invasions of lakes by aquatic weeds?
(iv) How water hyacinth affects the economic, recreational and environmental uses of the lakes?

1.6 AIM AND OBJECTIVES

1.6.1. Aim

The study aims to determine how water hyacinth impact on water availability and its usability, taking the Benoni lakes in the Gauteng Province of South Africa as a case study.

1.6.2. Objectives

The specific objectives of the study are to:

(i) Investigate how water hyacinth impact on the usability of the Benoni lakes.
(ii) Assess the water availability and usability of the lakes before and after water hyacinth invasions.
(iii) Demonstrate how climate change and variability aid the invasion of alien species.

(iv) Demonstrate how water consumption by water hyacinth affects the economic, recreational and environmental uses of the lakes.

1.7 DESCRIPTION OF THE STUDY AREA

The area around Benoni has numerous lakes such as the Homestead, Middle, Civic, Kleinfontein and the Rynfield lakes and many pans, and as a result the city of Benoni is affectionately known as the City of Lakes (Naledzi, 2007). These lakes are owned and managed by the Eastern Region of the Ekurhuleni Metropolitan Municipality (EMM), previously by the Benoni Municipality (Aurecon, 2010).

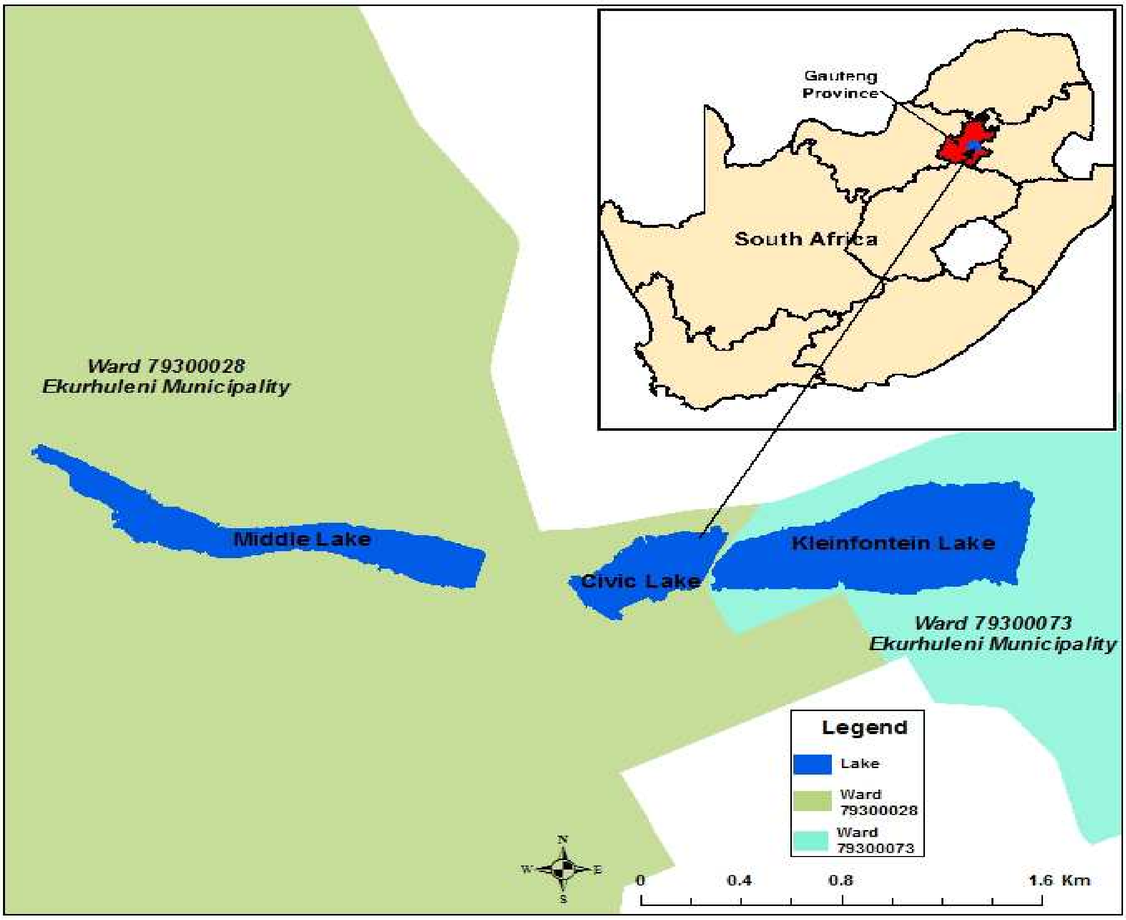

Figure 1.1: Location of the lakes in Ekurhuleni Municipality and in South Africa

The EMM is located in the Eastern region of Gauteng Province. It borders the Johannesburg Metropolitan Municipality to the West, the Tshwane Metropolitan Municipality to the North-West, the Kungwini Municipality to the North and Delmas Municipality to the East and the Midvaal and Lesedi Municipalities (both part of the Sedibeng District Municipality). The EMM extends for about 45km from East to West and for about 55km from North to South covering an area of approximately 1 932km^2. The EMM has a number of gold mines, some still operational but others have closed.

This study was conducted in three of the Benoni lakes, which are the Middle, and Civic and Kleinfontein Lakes found along the Bleshokspruit River in the Ekurhuleni Metropolitan Municipality as shown in Figure 1.1. Figure 1.1 also shows the location of the lakes in the Gauteng Province and South Africa. These Lakes are homogeneous earth-fill embankments, which have been classified as category 2 embankments located on Kleinfontein Farm, 67 ER.

A railway line and the N12 highway border the lakes on the northern side. The Kleinfontein Lake which is the biggest of the three has the actual dam wall of 6m high (Aurecon, 2010). However, a significant volume of mine waste has been dumped over the dam crest which extends downstream for approximately 400m which most (if not all) of the embankment being buried. Only a partial evaluation of the embankment was possible based on visual observations. Figure 1.2 is a satellite view of the lakes and the surrounding built up area, also showing the railway line the N12 highway.

Figure 1.2: The map of Benoni showing the study lakes
Source: Google Earth (2012)

The spillway of the Kleinfontein Lake is located on the right bank and consists of a 11m wide trapezoidal concrete channel, tapering to 7,5m, with near vertical side slopes and offering a maximum flow depth of 1,5m. The maximum discharge of the concrete lined channel is 22m^3 However, the last Dam Safety Inspection report Recommended Design Flood (RDF) was calculated to be 187m^3/s thus indicating, that the current capacity of the spillway is inadequate

(Aurecon, 2010). Furthermore, frequent flooding of the adjacent road and business centre due to the inadequate capacity of the spillway has occurred in the last wet seasons and poses an immediate danger to property surrounding the lake, and possibly lives.

These lakes are mainly used for recreational activities such as boating, fishing and yachting. The lakes benefit local communities by providing recreational activities, and for sightseeing and the wildlife that comes with a healthy ecosystem. The lakes are home to a host of fish species, like barbell, bass and carp. The lakes are in a hypertrophic state as a result of their high nutrient levels comprising phosphates and nitrates. The hypertrophic state of the lakes is due to pollution from sewer spillages, washing powders and fertilizers. The result has been the invasion of algae and the water hyacinth which in turn cause the degradation of the lakes (Naledzi, 2007).Besides the water hyacinth which has occupied the lakes there are other invasive alien species which have invaded Benoni area as shown by Table 1.1.

Table 1.1: Invasive alien plants found in Benoni area

Invading Species	*Habitat Invaded*	*Impact on ecosystem*
Ageratum Conyzoides	In wastelands close to the lakes	Fast growth and easily dispersal seeds help in fast spreading and it has allelopathic inhibition against native species.
Eichhorniacrassipes (Water hyacinth)	Cover the Lakes	Chokes water bodies and reduces biodiversity by causing anoxia and degrades water quality.
Ipomoea carnea	Wetlands between the lakes lowing large amount of sand and clay.	Due to fast growth rate it is replacing indigenous species and also has negative effect on wetlands in the semi-aquatic nature.
Lantana Camara	Wastelands and river banks and lakes	High nutrient extraction efficiency favours its faster growth and supplant native vegetation.
Salviniamolesta	Best in stagnant or slow-flowing water.	Suppress growth of native species in water bodies, forms floating mats on the lakes.

Source: Meela, 12 February 2010, Benoni City Times)

The Blesbokspruit River runs from Benoni in the East Rand part of the Ekurhuleni Metropolitan Municipality (EMM) to Heidelberg in Lesedi Municipality, Gauteng Province. It falls into the Crocodile River catchment to the West. This study focused on the upper part of the Blesbokspruit that is in Benoni. This land use of the Blesbokspruit catchment is heavily altered due to urban, industrial and mining development (DWAF, 2008). These developments have significantly affected the water quantity, quality, flow and water regime, as well as altering stream morphology affecting the multiple water uses.

The low hills and ridges of the Witwatersrand form a major watershed that divides the Vaal River basin to the South from the Limpopo River basin to the North (McCarthy and Venter, 2006). The EMM area straddles this watershed with the mining belt located in the Vaal River basin. The Klip River and Blesbokspruit catchments lie within the Vaal Barrage catchment with the Klip River draining the Southern slopes of the Witwatersrand Ridge between Roodepoort and Germiston while the Blesbokspruit drains the southern slopes of the ridge between Benoni and Daveyton. They both discharge their waters into the Vaal Barrage. Within EMM there are two underground water basins (Central and Eastern), separated by a block of un-mined ground. These two basins are dewatered to allow mining. Surface and underground water are interconnected through surface water ingress and underground water pumping.

The gold bearing reefs of the Witwatersrand Super group and Transvaal sequence sub - outcrop and outcrop along an arc in the East Rand Basin group stretches from Benoni eastwards towards springs and then southward to Nigel. Outcrops of the Witwatersrand Reef occur in some areas within the Eastern Basin, at Springs against the Transvaal Sediments. The Black Reef Quartzile Formation and the Malmani dolomites form part of the Transvaal sequence (Digby Wells and Associates, 1996).

1.7.1 Precipitation and Temperature

The annual average surface temperatures of (EMM) varies between a minimum of <0^{o}c recorded during June and July and a maximum of 25 to 27,5^{o}c recorded during January. The annual average rainfall varies between and 500-750mm with high annual variability (25–30%) (Appendix 1). Rainfall occurs mostly from November to March in form of thunderstorms.

A pan equivalent evaporation (the reference potential evaporation for Southern Africa) is 2000-2250mm i.e. 2,7 - 4,5 times higher than rainfall), resulting in annual water deficits and a semi-arid climate.

1.7.2 The Southern Dolomite Outcrop

The study area lies within the Southern Dolomite Outcrop, an important aquifer, which is an underlying granite along the EMM. The topography varies from rolling countryside to hills. Borehole yields vary between 2 and 10 *l/s* and the water table varies from 10 metres in vlei areas to 50 metres below ground level (DWAF, 2008). Therefore, the management of this dolomite aquifer is necessary to ensure long term sustainability of both quantity and quality of both underground and surface waters.

Furthermore, the area underlying EMM has rocks that vary from the Swazian to the Mesozoic Eras. The geology of the area is fairly simple and stable with underlying sedimentary rocks of Karoo and Transvaal age overlying formation of gold bearing Witwatersrand (Dini, 1999).

1.7.3 Land use and vegetation

Land Use in the area varies from natural, agricultural, industrial, mining, urban and rural settlements as well as recreational and nature reserves as follows:

(i) **Natural**: Marivale Bird Sanctuary

(ii) **Agricultural**: Irrigated crops such as maize, vegetables, lucerne, and lawn grass exist within the catchment and water from the Blesbokspruit is being utilized for irrigation. Animal watering exists in the catchment and also water from the Blesbokspruit is being utilized.

(iii) **Industrial and mining**: The Witwatersrand Basin, made up of East, Central and West Rand Basins in South Africa is famous for its prolific gold, coal and uranium deposits and mining has been going on in the basin since the late 1800 (Handley, 2004). Records of water ingress into underground mines in the East Rand date back to 1909 (Scott, 1995). Many mines in the vicinity discharge their polluted water into the Blesbokspruit, and currently the largest and operational mine in Springs discharges between 80 and 100Ml/d underground water into the Blesbokspruit (Schoeman and Steyn, 2000). There are also industries in the catchment that dispose their waste into the slimes dams which in turn pollute the Blesbokspruit.

(iv) **Urban and rural settlements**: The towns of Boksburg, Benoni and Brakpan lie in the Northwest, Nigel located on the South, Springs in the East and Heidelberg on the south west of the Catchment. There is a full sewage reticulation system in these towns and all of them discharge their effluent in the Blesbokspruit. The townships in the area are semi urban and are connected to the sewer system.

(v) **Recreation and nature reserves**: The Marivale Bird Sanctuary, in the southern part of the catchment covers approximately 100 hectares and is about 7.4km long. It attracts mainly birdwatchers and hikers. The Suikerbosrand Nature Reserve forms an enclave into the western edge of the Lesedi Municipal Area. This nature reserve is situated in the Suikerbosrand Hills which contribute substantially to the natural beauty of the area. The nature reserve is well managed and the ecosystem is fully protected in this area (LLM, 2006).

(vi) **Vegetation:** The Ekurhuleni Metropolitan Municipality (EMM) falls within Sac's Grassland Biome (Low and Rebelo, 1996). This grassland biome is one of the most threatened in SA, with 60-80% irreversibly transformed, while only 2% is formally conserved. The biodiversity status of the area includes two grassland vegetation types, according to Low & Rebelo (1996), namely Moist Cool, Highveld Grassland and Rocky Highveld Grassland (Bredenkamp and van Rooyen, 1996), the former vegetation type covers approximately 55% of the area, while the latter covers 45%. The vegetation has an abundance of grass species and dicotyledonous forbs, while a woody vegetation component occurs as sheltered islands of temperate mountain bushveld within the grassland.

CHAPTER: 2

2. RESEARCH PROBLEM THEORY

2.1 INVASIVE SPECIES: THE CONCEPT AND INVASION PROCESS

Invasion is considered as the second most important threat to biodiversity after habitat destruction (Holmes *et al.,* 2008). Alien species, which become dominant in the local environment and invade natural communities, are referred to as invasive species. The term invasive alien species (IAS) is defined by the National Invasive Species Council (NISC, 2006) as a species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health. Versfeld *et al.* (1998) also defines IAS as species that becomes established in natural or semi-natural ecosystem or habitat, is an agent of change and threatens biological diversity. Invasive species are such a threat to the environment so much that the Biodiversity Convention advocates for measures to prevent the introduction, control or even eradication of these alien species (Versfeld *et al.,* 1998). These invaders could be a plant, animal or microbial species. Invasive species are either accidentally introduced or they are introduced by man to fill his needs. After their introduction they can propagate their population and create non-specific thickets.

After consultation with stakeholders the Benoni Municipality opted to use the Watermaster Classic III to remove the invasive alien species from the water-bodies within its vicinity. The Watermaster Classic III shown in Figure 2.1 was recommended for the removal of alien species as it does not pollute the water itself. However, by 2011 the water hyacinth team had completely removed the plant from Kleinfontein and Civic lakes (Meela, 2011). But the invasive plants somehow and notoriously reappear after a short while.

The municipality and other stakeholders persistently urge local communities to refrain from dumping waste in the wetlands and water-bodies as these create conducive environments for invasive alien species. The local environmental groups like the Hyacinth Aquatic Committee have repeatedly warned residents against dumping waste anywhere as these are responsible for the growth of the water hyacinth (Meela, 2010).

Historically the lakes in Benoni have always been playing an important role of filtering water, facilitation of groundwater recharge, maintenance of biodiversity, retention of agricultural pollutants, income generation by harvesting of reeds, fishing and eco-tourism, recreational activities and aesthetics. However, these lakes have been affected by a number of stresses caused by sewage spills, mining and industrial activities, improper waste disposal and erosion gullies (Naledzi, 2007). Urban development particularly the construction of the Lakeside Mall in Benoni and the road construction (the Gauteng N12 Freeway Development Project) are equally contributing to the current deterioration of the lakes. In many instances the outlets of the lakes are poorly maintained creating opportunities for erosion gullies and bursting. Gauteng is one area that is heavily infested with alien invasive plant species and Ekurhuleni Metropolitan Municipality is no exception (Palmer, 2002). The invasive plant species are associated with excessive water consumption, allelopathetic inhibition, and they also out-compete the native species for other resources. As a result they impact upon indigenous plant species which are essential for maintaining ecosystem processes.

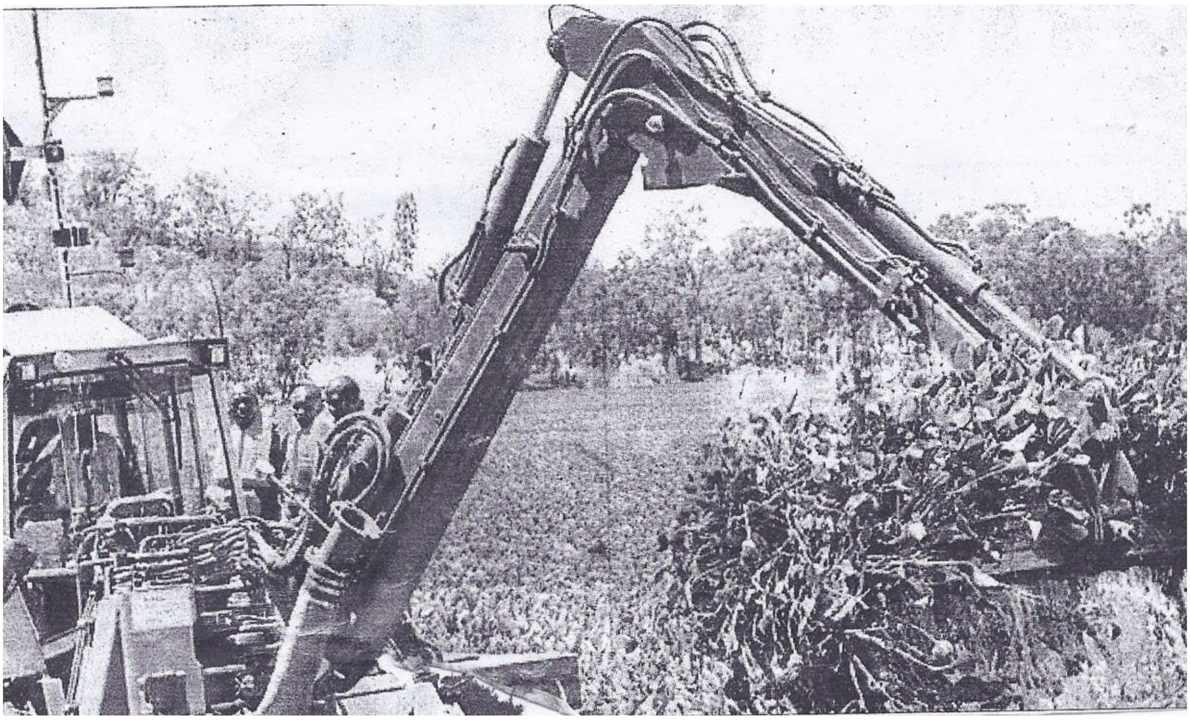

Figure 2.1: The Water-master machine clearing invasive plants in the Kleinfontein Lake. (*Source: Meela, 2010*)

The water hyacinths can double its biomass in less than 2 weeks during the peak of its growing season. This means that it can reproduce quicker than it can be removed mechanically. The absence of natural enemies and highly enriched/polluted water allows for prolific growth. Kleinfontein Lake and neighbouring lakes require an integrated strategy, combining biological control with herbicides and/or mechanical control and water purification (Henderson, 2010).

2.2 FACTORS CONFERRING INVASIVENESS

Factors which play key roles in the propagation and survival of alien species are unrestrained vegetative spread, escape from biotic constraints, prolific seed production, highly successful seed dispersal, germination and colonisation, adaptive morphological and ecological characters, superior propagule characteristics favouring greater mobility and ability to supplant native flora either competing for resources or exerting allelopathic effects (Versfeld *et al.,* 1998; Holmes *et al.,* 2008).

Factors contributing to rapid and wide dispersal include;

a. Prolific seed production,
b. Efficient wind dispersal of the seeds, combined with enormous reproduction potential, allowing the weed to encroach on large areas,
c. Long distance seed dispersal by flower pickers roadside grass cutters and vehicles,
d. The weed is ornamental and is planted and spread by gardeners who are ignorant of the dangers of doing so,
e. Vigorous growth from seed to flowering in one growth season,
f. Ability to produce new stems from a rootstock e.g. pompom weed, and
g. Ability to germinate under a range of environment conditions e.g. drought tolerant (Montana, 1990).

2.3 INVASION PROCESS

There are three major phases of plant invasions: Introduction, colonisation and naturalisation. When an ecosystem is disturbed either by natural process or due to some anthropogenic factors it provides a kind of invasion window to the alien propagule. Gradually it overcomes the environmental, reproductive and dispersal barriers and expands its population (Vosse *et al.,* 2008). Environmental factors, like resources availability, favouring the establishment of alien propagule are in phases because introduced propagule has to compete with the established flora that is already well adapted to the site.

2.4 GEOGRAPHICAL RANGE AND IMPACT OF THE PROBLEM IN SOUTH AFRICA

Several estimates of the spatial extent of alien species invasion in South Africa have been made. According to Richardson and van Wilgen (2004) a rapid reconnaissance in 1996/97 suggested that about 10 million hectares of South Africa has been invaded by approximately 180 species that were mapped. This survey identified mainly woody invaders that impact on water resources. However, the comprehensive set of records for the whole country is the South African Plant Invaders Atlas (SAPIA) (Henderson, 2001). The SAPIA data demonstrates the overall magnitude of the problem and shows that the greatest number of species occurs in the Western Cape, along the eastern seaboard and interior as shown in Figure 2.2.

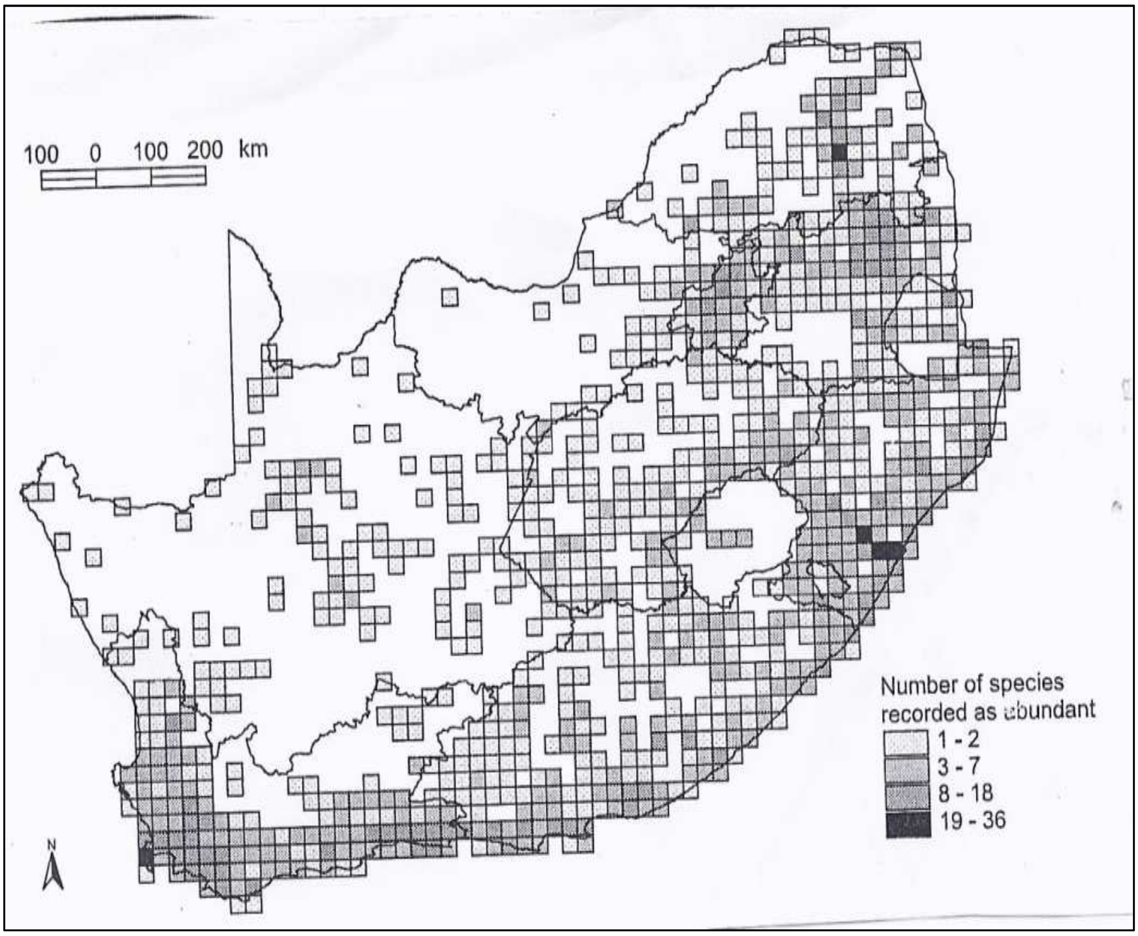

Figure 2.2: The distribution of invasive alien plants in South Africa.
(*Source: Richardson and van Wilgen, 2004: 46*)

Invasive alien plants waste about 7% of South Africa's vital water resource (Richardson and Van Wilgen, 2004). According to van Wilgen and Gelderblom (1999), if nothing is done to clear invading alien plants in the next 10 to 20 years there will be a loss of 30% of our runoff water to rivers and 20 to 40 years, 74% will be lost. Preenthlall *et al.* (2007) argued that the cost of controlling invasive plants in South Africa is estimated at R600 million/year. The capacity of these plants to speed and grow is enormous as is the cost to clear them (DEA, 2009).

McNeely (2004) and Preenthlall *et al.* (2007) further argued that the impacts are significantly higher on a percentage basis during drought periods as the riparian invaders still have access to water. The invasion of alien plants in river catchments is influencing the water resources system and affecting all sectors. A study by the NISC (2006) on the invasion of exotic knotweeds *(Fallopia spp)* in European riparian habitats found out that large scale invasion by exotic *Fallopia* species is likely to seriously affect biodiversity and reduce the quality of riparian ecosystems for amphibians, reptiles, birds and mammals whose diets are largely composed of arthropods. In addition, this will eventually lead to further reduction in stream flow during the low flow seasons which will cause severe detrimental effects on riverine ecology and available water for basic needs.

The nature and extent of invasive alien plants, the effects thereof on available water resources, the threat to ecological environment and the impacts on society need to be understood to ensure the success of the integrated approach to control the spread of invasive alien plants in South Africa. Although the ecological needs of rivers have received much recognition (WfW, 2004; Gorgens and van Wilgen 2004; Richardson and Wilgen, 2004) particular attention should be given to the minimum flow requirements of vulnerable ecosystem of rivers, lakes and wetlands. These requirements must be met before other needs can be supplied.

In addition, plant invasions are a large and growing threat to ecosystem integrity in many parts of the world, as they change the structure and functioning of ecosystems, with negative consequences for the conservation of biodiversity and the delivery of ecosystem services (Mooney, 2005; Shekede *et al.* (2008) support this assertion by saying that, incidences of growth of aquatic weeds and widespread infestation in the water bodies of the Southern African Development Community (SADC) region are increasing and constitute a great threat not only to the environment but also the socio-economic conditions of the region. There are however several examples of high-level strategies to deal with the problem of invasive alien species, both nationally and globally (McNeely *et al.,* 2001) and national level. These strategies call for the reduction of the risk of new introductions of invasive species, the control of existing invasions to mitigate impact, and the establishment of management and legislative capacity to guide implementation.

Van Wilgen *et al.* (2012) argue that in South Africa, the strategy over the past 15 years has been to implement a large, national-scale, government-sponsored alien plant control programme known as Working for Water (WfW). The programme combines mechanical and chemical control of all invasive alien plant species in targeted areas with the provision of employment to people from impoverished rural communities as its main thrust. This has been supplemented by;

(i) the development of biological control options that target selected priority alien plant species (Zimmermann *et al.,* 2004; Moran and Hoffmann, 2011),
(ii) the promulgation of legislation that requires landowners to deal with the problem (van Wilgen *et al.,* 2011), and
(iii) the encouragement of systems of payment for ecosystem services that will generate funding to support control programmes (Turpie *et al.,* 2008).

While the WfW programme has kept records of expenditure per species and geographical area since 2002, the ability to address questions regarding the effectiveness of their operations is limited because the programme has not implemented an effective system of monitoring and evaluation, (Levendal *et al.*, 2008).

2.5 IMPACTS OF INVASIVE ALIEN PLANTS

Various species of alien plants have been brought into South Africa, either deliberately as commercial plants or accidentally through seed pollution (Holmes *et al.*, 2008; Vosse *et al.*, 2008; DEA, 2009; Strydom and King, 2009). The DEA (2009) further states that without adequate control and through seed distribution by wind and birds, plant growth had spread to areas where they are causing serious and negative effects. With no natural enemies present in their new environment many become invading and spread aggressively. Seventy percent of invading alien plants in South Africa came from Australia and South America (Poona, 2008). The black wattle *(Acacia mearnsii),* Silver water *(A. dialbata),* blackwood *(A melanoxylon),* bluegum *(Eucalyptus sp),* the notorious water hyacinth *(Eihhornia crassipes),* the water milfoil or parrot's feather *(Myriophyllum aquaticum)* and pines (mostly *Pinus Pinaster*) had, according to van Wilgen *et al*. (1997) the largest negative impact on water usability and availability.

Global research on the effects of plant invasions by Richardson and van Wilgen (2004) suggest that most damaging species transform ecosystems by using excessive amounts of resources (notably nitrogen, light, oxygen and water) by adding resources (notably nitrogen), by stabilising sand movement and/or promoting erosion, by accumulating or redistributing salt. Invasive plants have also invaded river banks, affecting the indigenous riparian trees, and thereby reducing the flow of water. The leaves of riparian trees, which are the natural food for the aquatic organisms, are also replaced by the less suitable leaves of the alien trees. The accumulation of leaves of invasive alien plants on river beds reduces water levels causing fish deaths and give rise to algal blooms and other poor water quality impacts. These also have impact on the recreational value of the rivers and lakes (van Wilgen *et al*., 1997).

Further to that, it is now well recognised that invasive alien species particularly tree species often have much increased water usage compared with native vegetation. Perhaps less well understood are the reasons for this increased water use and whether it should be expected from all species of invading alien plants under all conditions. Answers to these questions are important so that financial resources directed towards the eradication of alien invaders can be used to maximum (Preenthlall *et al*., 2007).

Many of these aquatic alien plants such as, the water hyacinth, the water milfoil and the Kariba weed blanket many of African dams, lakes and rivers as shown in Figure 2.3.

Figure 2.3: The water hyacinth creating watery graves across Middle Lake in Benoni
(Source: Photograph taken in January 2014)

An example of the most dangerous, notorious and troublesome of an invasive plant is the water hyacinth (*Eichhornia crassipes*) of South American origin (Groote *et al.,* 2003; UNEP, 2012). It gained attention as an ornamental plant because of its attractive purple flower, and was first distributed by gardens and horticulturists more than a century ago. Malik (2007) argues that the water hyacinth is a tropical species belonging to the pickerelweed family (*Pontederiaceae*). A native of Brazil and possibly other central South American countries, now it occurs in lakes, slowly moving rivers and swamps in most countries of the world lying between 40^0 N and 40^0S, including India, South Africa and the USA. As such water hyacinth is found across the tropical and subtropical regions. Originally from the Amazon Basin, its entry into Africa, Asia, Australia and North America was facilitated by human activities (Dagno *et al.*, 2012).

The water hyacinth is a free floating aquatic plant well known for its production abilities and the removal of pollutants from water. Keller and Lodge (2009) add that it multiplies faster than any other known freshwater plant. However, the water hyacinth has also been labelled as the world's worst water weed and has garnered increasing international attention as an invasive species (Zhang *et al*., 2010). Efficient in utilising aquatic nutrients and solar energy for profuse biomass production, the water hyacinth can cause extensive environmental, social and economic problems. It is found in lakes, estuaries, wetlands, marshes, ponds, dambos, slow flowing rivers, streams and waterways where growth is stimulated by the inflow of nutrient rich water from urban and agricultural runoff, deforestation, products and industrial waste and insufficient wastewater treatment. According to recent climate change models, its distribution may expand into higher latitudes as temperatures rise, posing problems to formerly hyacinth free areas (Rachel and Olden, 2008; Zhang, 2012).

However, the water hyacinth can tolerate considerable variation in nutrients, temperature and pH levels. The Optimum pH for growth is 6–8. It can grow in a wide range of temperature from 1 to 40 ^{0}C (optimum growth at 25-27, 5 ^{0}C) but it is thought to be cold-sensitive (Wilson *et al.,* 2007). It can quickly grow to very high density (over 60kg m^{-2}), thereby completely clogging water bodies, which in turn may have negative effects on the environment, human health and economic development. Salinity is a major constraint on water hyacinth growth in coastal regions as salinity levels at 6.0% and 8.0% are lethal (Malik, 2007).

Although the water hyacinth removes both nutrients and pollutants from aquatic environments very effectively, it is a pollutant itself for several reasons: Firstly, a dense canopy of hyacinth plants will prevent oxygen transfer to the water from the atmosphere. It will also block out sunlight and prevent production of dissolved oxygen by algal photosynthesis. Secondly when the plants die, they quickly sink to the floor where they decompose. Conditions in the deep water near the lake floor become anaerobic very quickly because of the rotting plant on dissolved oxygen can no longer inhabit these areas of the lake. Thirdly an adequate level of oxygen is also an important factor in the treatment of lake/dam water. Very low dissolved oxygen concentrations require greatly increased doses of alum (aluminium sulphate) to clarify the water by flocculation and sedimentation of suspended solids (Groote *et al.,* 2003; Stanley *et al.,* 2007; Forpah, 2009; Keller and Lodge, 2009).

2.6 THE LEGAL FRAMEWORK REGARDING INVASIVE ALIEN PLANTS IN SOUTH AFRICA

There are legal guidelines that affect the management of alien invasive weeds. In particular, studies have documented the significance of the economic and ecological trends posed by IAPs globally (Pimentel *et al.,* 2000; Bradshaw and Jones, 2005). Similarly, the South African Government has identified the removal of IAPs as a priority and has enacted eleven national and various provincial laws which contain mechanisms for regulating the different threats posed by IAPs (Paterson, 2006). Principal among all these laws are the following:

2.6.1 Constitution of the Republic of South Africa, 1996 (Act 108 of 1996)

Various sections of the Bill of Rights have major relevance to environmental policy. Section 24 of the Constitution attempts to fight the wrongs of past practices which settled poor and disadvantaged communities near dirty and polluting industries and on poor and degraded land. This section of the South African Constitution provides for the right of every South African citizen to a healthy environment, and protects the environment for the benefit of present and future generations through reasonable legislation and other measures that prevent pollution and ecological degradation, promote conservation and secure ecologically sustainable and social development (South Africa, 1996; Bernier *et al*., 2005). Section 24 obliges government to pass reasonable legislation to protect the environment, to prevent pollution and ecological degradation and to secure sustainable development.

2.6.2 Conservation of Agricultural Resources Act (Act 43 of 1983) (CARA)

The Conservation of Agricultural Resource Act (CARA) (Act 43 of 1983) is administered by the Department of Agriculture through its Directorate; Land Use and Soil Management (DLUSM). The CARA was originally enacted to regulate IAPs that may have an impact on agricultural resources, but in the absent of alternate relevant legislation, CARA regulations have been applied to regulate IAPs that impacted on biodiversity, water resource management and fire management (Paterson, 2006). In particular CARA makes provision for the conservation of the natural resources of South Africa through:

a. Maintaining the productive potential of land
b. Preventing the weakening or destructive of water resources.
c. Protecting vegetation
d. Combating weeds and invasive species (ARC, 2008b, Moremi, 2010].

Regulations in terms of CARA were passed in 1984 and 50 plant species were declared as “weeds “or “invader plants” (DWAF, 2001). In 2001 the CARA regulations increase the list to 198 (Wildy, 2005) dividing IAPs into the categories:

Category 1: Plant species that may not be grown anywhere in South Africa and must be eradicated.

Category 2: Plant species with commercial or utility value, which may only be grown with a permit under controlled circumstances and

Category 3: Plant species which have animate value and which need to be eradicated, but which may be planted, propagated, imported or traded (DWAF, 2001; Wildy , 2005; Paterson, 2006; ARC, 2008b).

CARA was promulgated over twenty years ago, but despite these Regulations: IAPs continue to invade valuable South African land and water at an alarming rate and to date there has been one successful conviction under this legislation (Paterson, 2006; ARC, 2008a; ARC, 2008b).

Paterson's (2006:15) critique includes the following:

"The lack of public awareness regarding the nature and extend of the IAPs problem, despite the various nationwide information campaigns implemented by organisations, such as Ukuvuka, Working for Water and South African National Biodiversity Institute SANBLI.
"CARA is administered by the Department of Agriculture whose core functions are to protect agricultural production and not issues of biodiversity conservation and water resource management.
"CARA also fails to provide any clarity on the roles to be played by the various spheres of government in invasive alien plant control.
"CARA Regulations do not provide adequate guidance regarding what control measures would be appropriate within a given context. This causes problems with regard to the implementation and enforcement of the CARA Regulations, given the scale of the problem, the range of the species involved and the need to tailor area specific control measures."

2.6.3 National Environmental Management Act (Act 107 of 1998) (NEMA)

The purpose of this act is to provide for cooperative environmental governance by establishing principles for decision making on matters affecting the environment, institutions that will promote cooperative governance and procedures for coordinating environmental functions exercised by organs of the state and matters connected therewith.

Principles of National Environmental Management Act relevant to the control of Aquatic weeds are:

1. The principles set out by the National Environmental Management Act apply throughout the Republic of South Africa and to the actions of all organs of state that may significantly affect the environment (Paterson, 2006). These principles shall apply alongside all other appropriate and relevant considerations including the state's responsibility to respect, protect, promote and fulfil the social and economic rights as stated in Chapter 2 of the Constitution of South Africa. These principles serve as the general framework within which environmental management and implementation plans must be formulated. The principles of the National Environmental Management Act serve as a guideline in accordance with which any organ of the state must exercise any functions when taking any decision in terms of this act or any statutory provisions

concerning protection of the environment. The National Environmental Management Act serves as a principle by reference to which a conciliator appointed under the act must make decisions. These principles guide the interpretation, administration and implementation of this act and any other law concerned with the protection or management of the environment (Strydom and King, 2009).

2. Environmental management must place people and their needs at the forefront of its concern and serve their physical, psychological, developmental, cultural and social interests equitably.
3. Development must be socially, environmentally and economically sustainable.
4.
    a. Sustainable development requires the consideration of all relevant factors including the following: The disturbance of the ecosystem and loss of biodiversity, for instance from severe infestation by pompom weed, must be avoided, and where complete avoidance is not possible, this should be minimised and remedied. Pollution and land degradation such as that caused by uncontrolled infestation by pompom weed must be avoided and, where this is not possible, this should be minimised and remedied. Non-renewable natural resources must be utilised in a responsible manner and the user must take into account the consequences of their depletion. Development, use and exploitation of renewable resources and the ecosystem of which they form part should not exceed a level beyond which their integrity is jeopardised. A risk-averse and cautious approach should be applied, which takes into account the limits of current knowledge of the consequences of decisions and actions. Negative impact on the environment and on people's environmental rights should be anticipated and prevented and avoided at all costs; where complete avoidance is impossible, this should be minimised and remedied.
    b. Environmental management should be integrated, acknowledging that all elements of the environment are linked and interrelated; it should be kept in mind that decisions have effects for all aspects of the environment and all people in the environmental option.
    c. Environmental justice must be pursued so that adverse environmental impacts are not widespread.
    d. Participation of all interested and affected parties in environmental management should be promoted, e.g. state organs, NGOs and farming communities.
    e. Decision makers must take into account the interests, needs and values of all interested and affected parties and this should include recognising all forms of knowledge, including traditional and ordinary knowledge.

f. Community empowerment and well-being must be promoted through environmental education and awareness and the sharing of appropriate knowledge and experience.
g. The social, economic and environmental impact of activities, including disadvantages and benefits, must be considered, assessed and evaluated and decisions should be appropriate in the light of these considerations and assessments.
h. Occupational Health and Safety standards, norms and procedures must be adhered to during environmental management operations, e.g. workers must wear protective clothing during the control of pompom weeds.
i. Global and international responsibilities relating to environmental management must be discharged in the national interest.
j. Actual and/or potential conflicts of interest between organs of state, relating to environmental management, must be resolved through conflict resolution procedures.
k. The costs incurred in remedying pompom weed infestation must be the responsibility of landowners or users.
l. Organisations such as Working for Water must consider involving previously disadvantaged groups in the community, such as women, the youth and the disabled, in activities such as the eradication of aquatic weeds.

Chapter 5 of the National Environmental Management Act deals with integrated environmental management. Its purpose is to promote the application of appropriate environmental management tools to ensure this integration. General objectives of integrated environmental management as stated in the National Environmental Management Act are stated below.

The objectives of integrated environmental management as stated in this act are:

- To promote the integration of the principles of environmental management set out in Section 2 of the National Environmental Management Act in all decisions which may have a significant effect on the environment.
- To identify, predict and evaluate the actual and potential impact of aquatic weed infestation on the environment, on socio-economic and cultural heritage, its risks and the consequences and alternative options for mitigation, with a view to bringing aquatic weed infestation to an end; to maximise the biodiversity population and productive potential of the land.

- To promote compliance with the principles of environmental management as stated in Section 2 of the National Environmental Management Act.
- To advise environmental managers and land users in order to ensure that infestation of pompom weed on their land is dealt with before action is taken against them, as set out in Section 23 (2) (c) of the National Environmental Management Act.
- To ensure that there is adequate and appropriate opportunity for public participation in decisions that may affect the environment.
- To ensure the consideration of environmental attributes in management and decision-making which may have a significant effect on the environment.
- To identify and employ the models of environmental management best suited in order to ensure that a particular activity is pursued in accordance with the principles of the National Environmental Management Act as set out in Section 2.

In order to give effect to the general objectives of integrated environmental management as laid down in Chapter 5 of the National Environmental Management Act. Issues such as potential human impact on the environment, socio-economic conditions and cultural heritage activities requiring authorization, or permission by law are addressed. Issues that may significantly affect the environment, must be considered, investigated and assessed prior to their implementation and reported to the relevant organs of the state.

The Minister for Environmental Affairs and Tourism may, with the concurrence of the Member of the Executive Committee, or vice versa, in a prescribed manner: Identify activities which may not be initiated without prior authorisation from the Minister or member of the Executive Committee. Identify geographical areas in which specified activities may not be initiated without prior authorisation from the Minister or member of the Executive Committee, and specify such activities. Make regulations in accordance with subsection 24 (3) and (4) of the National Environmental Management Act in respect of these authorisations. Identify existing authorised and permitted activities, which must be considered, assessed, evaluated and reported on. Prepare a compilation of information and mapping of geographical areas infested with alien invasive plants such as pompom weeds. In cases where infestation overlaps with another Minister's area of jurisdiction, a decision in terms of bullet number 1 and 2 above must be taken in consultation with the Minister in question. The investigation, assessment, and communication of the potential impact of alien invasive plants such as the water hyacinth contemplated in Section 24 (1) must take place in accordance with procedures and must comply with Section (24) (7) (a-i) of the National Environmental Management Act.

Any Minister or Member of the Executive Committee of the department entrusted with the responsibility by law to authorise, permit or otherwise allow an activity to manage alien and invasive species such as pompom weeds contemplated in Section 24 (1), may prescribe regulations laying down procedures to be followed and for the report to be prepared for the purpose of complying with bullet number 1 above. Any regulation made in terms of this subsection or any other law that contemplates the assessment of the potential impact of aquatic weeds on the environment must, notwithstanding any other law, comply with Section 24 (7) (a-i) of the National Environmental Management Act.

Section 24 (7) (a-i) of the National Environmental Management Act states that procedures for the investigation, assessment and communication of the potential impact of infestation of land by alien and invasive plants, such as the aquatic weed, must ensure the following:

- Investigation of the land likely to be infested by aquatic weed.
- Investigation of the potential impact that aquatic weeds could have on the land, the chemicals and biological means to control them and the potential harmfulness to the biodiversity of these and their socio-economic effects on the environment.
- Investigation of potential mitigation of measures and the ultimate choice of the most environmentally friendly option. Public information and participation, independent review, perception and views on management of aquatic weeds.
- Investigation and formulation of arrangements for the monitoring and management of aquatic weeds and the assessment of the effectiveness of such arrangements after implementation.

Cooperation and coordination of state organs in the consideration of management of pompom weeds as the responsibility for control of the weeds falls under more than one state organ. Findings and recommendations flowing from the investigations, general objectives of integrated environmental management involving effective eradication of alien invasive plants laid down in the National Environmental Management Act, and the principles laid down in Section 2 of the Act are taken into account in any decision made by organs of state in relation to proposed policy, programme, plan or project. Aquatic infestation is identified in the compilation of information, and the mapping of infested areas as contemplated in Section 24 2(e) of National Environmental Management Act must be considered.

The National Environmental Management Act states that, as organs of the state, the activities of the Department of Environmental Affairs and Tourism, Department of Land Affairs, Department of Agriculture, Department of Trade and Industries, Department of Water Affairs and Forestry, Department of Transport and Department of Defence have an impact on the environment. The National Environmental Management Act also states that the Departments of Environmental Affairs and Tourism, of Water Affairs and Forestry, of Minerals and energy, of Land Affairs, of Housing and of Labour are state organs that exercise functions that involve management of the environment.

2.6.4 National Environmental Management: Biodiversity Act (NEMBA) (Act 10 of 2004)

The purpose of this act is to provide for the management and conservation of South Africa's biodiversity within the framework of the National Environmental Management Act, 1998. This includes the protection of species and ecosystems that warrant national protection; the sustainable use of indigenous biological resources; the fair and equitable sharing of benefits arising from the biosphere involving indigenous biological resources; and the establishment and functions of the South African National Biodiversity Institute and for matters connected therewith.

Chapter 3 of this act concerns biodiversity planning and monitoring and its purpose is to: Provide for integration and co-ordination of biodiversity planning. Monitor and conserve the status of various components of South Africa's biodiversity. Promote research on biodiversity.

Part 1 of chapter 3 of the act deals with biodiversity planning, which involves the national biodiversity framework through which the Minister for Environmental Affairs and Tourism must: Prepare and adopt a national biodiversity framework within three years of the date on which this act took effect. Monitor the manner of implementing a biodiversity framework. Review the framework at least every five years and make amendments where necessary. The Minister for Environmental Affairs and Tourism must, by notice in the Government Gazette, publish the national framework and each amendment to this framework.

2.6.5 National Environmental Management: Protected Areas Act (NEMPAA) (Act 57 of 2003)

This act provides for the protection and conservation of ecologically viable areas representative of South Africa's biodiversity and its natural landscape and seascape. This is to be done through the establishment of a national register of all national, provincial and local protected areas to allow for the management of those areas in accordance with national norms and standards for intergovernmental co-operation and public consultation in matters concerning protected areas and for matters connected there with Section 17 (a-l) of this act concerns the purpose of protected areas, which is as follows:

- To protect ecologically viable areas representative of South Africa's biodiversity and its natural landscape in a system of protected areas.

- To protect the ecological integrity of those areas by, for instance, controlling pompom weeds.
- To conserve biodiversity in these areas.
- To protect areas representative of all ecosystems, habitats and indigenous species.
- To protect South Africa's threatened and endangered species.
- To protect an area that is vulnerable or ecologically sensitive.
- To assist in ensuring the sustainable supply of environmental goods and resources.
- To provide for the sustainable use of natural and biological resources.
- To create or augment the destination for nature-based tourism.
- To manage the interrelationship between natural environmental diversity, human settlement and economic development.
- To contribute generally to human, social, cultural, spiritual and economic development.
- To rehabilitate and restore degraded ecosystems and promote endangered and vulnerable species.

Section 23 (1) (a. i-ii b) and (2) of the National Environmental Management: Protected Areas Act concerns the declaration of nature reserves. Subsection (1) (1a .i-ii and b) states that the Minister or member of the Executive Committee may, by notice in the Gazette, specify an area as a nature reserve or as part of an existing nature reserve and assign a name to the reserve

2.7 INTERNATIONAL CONVENTIONS

2.7.1 The Convention on Biological Diversity

The Convention on Biological Diversity (CBD) entered into force in 1993, and has now been ratified by nearly 190 countries (McNeely, 2005). The CBD commits governments to take appropriate measures to conserve biological resources, and promote the fair and equitable sharing of benefits arising from the utilisation of genetic resources. Under the CBD, government agree to prepare national biodiversity strategies and action plans, identify genomes, species, and ecosystems crucial for conservation and sustainable use; monitor biodiversity and factors that are effecting biological systems, establish effectively managed systems of protected areas; rehabilitate degraded ecosystems; exchange information; conduct public information programmes; and carry out various other activities for implementing the CBD's objectives (McNeely , 2005). The CBD has also established an interim financial mechanism, the Global Environment Facility, which provides approximately US$100 million per year to projects for implementing the Convention in developing countries; some of these projects address IAPs (for example, in Galapagos Islands and Lake Victoria).

2.7.2 The International Plant Protection Convention

The International Plant Protection Convention (IPPC), with 111 governments as Contracting Parties, aims "to secure common and effective action to prevent the spread and introduction of pets of plants and plant products, and to promote appropriate measures for their control." Defining pest as "any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products," the Convention has been applied mainly to crops, but it also extends to the protection of natural flora (McNeely, 2005). Thus the scope of the IPPC covers any invasive alien species that may be considered to be a plant pest. The IPPC facilitates the development of internationally agreed standards for the application of phytosanitary measures in international trades to prevent and control the spread of plant pests (many of which are invasive alien species).The expanding impacts of IAS on both global economies and the environment suggests that these international instruments have been insufficient to prevent and combat IAS effectively. Furthermore, expanding international trade is moving ever more organisms more rapidly around the world, thereby increasing the threat of these species to nature ecosystems and potentially overwhelming government efforts to prevent unwanted invasions.

2.8 EVALUATION OF THE SOUTH AFRICAN LEGISLATIVE AND INSTITUTIONAL CONTEXT REGARDING IAS

The results from the studies (Richardson and van Wilgen, 2004; Shekede *et al.*, 2008) have shown that the introduction of species to new environments outside their natural environment carries significant risks. As such, their continuing spread is undermining the ecological, social and economic well-being of entire regions. IAS and their management in Africa is the story of an important UNES/GEP initiative aimed at helping the nations of sub-Saharan Africa to honour their contractual obligations, as parties to the Convention on Biological Diversity, to address the increasingly dire impacts-ecological, social and economic of alien plant invasions (Gordon and Arne, 2013). This research study has potentially far reaching implications for the planning and implementation of other forth coming initiative in this field, both in South Africa and across the developing world. While the issue of invasive alien plants is clearly global in scope (US EPA, 2008; van Wilgen *et al*., 2012; UNEP, 2012), it is imperative that concrete measures be taken nationally. Effective national policies and managing invasive alien species provide a critical basis for enabling stakeholders to join forces in preventing the introduction of invasive alien species and in managing and controlling the many threats posed by such species.

However, it is not all "doom and gloom" there are solutions that can develop/strengthen IAS policies in South Africa, build capacity and create awareness to enable us to implement long-term and sustainable IAS management strategies. Given the severe loss of habitats, loss of productivity and the resulting costs to local and regional economies (Preenthlall *et al.,* 2007; Dagno *et al*., 2012); it is imperative that national government invest significant resources in IAS management. In addition, national government should also foster cooperation between all national stakeholders, because this after all, is a cross-cutting issue; and work forwards regional collaboration in fighting IAS because IAS doesn't respect national borders.

However, it is imperative to note that, at national level, South Africa has a sustained and well-funded programme (WfW) in place for dealing with invasive alien species (DEA, 2009; Gordon and Arne, 2013). The programme now falls under the Department of Water Affairs. It has been instrumental to date in clearing alien plants infestations from more than one million hectares of invaded land (Gordon and Arne, 2013). The programme has succeeded on many levels. Its message, first of all, in being directed at conserving water is readily understood in a country where fresh water is naturally scarce, and where citizens are only too aware of the constraints imposed by water shortages. In South Africa, alien plant invaders are also visibly numerous and rife, particularly in water catchments (Richardson and van Wilgen, 2004).

There had been well-publicised studies showing how water intensive woody alien plant species were consuming huge amounts of run-off from stream flows. So removing such plants seemed perfectly logical to policy makers and members of the public alike. In being able to build upon such an obvious and well-understood link between cause and effect, the WFW programme did not have to sell complex cost-benefit argument (still a major stumbling block for many developing countries) in order to justify invasive alien plant control.

South Africa is also wracked by stubbornly high levels of unemployment. So the programmes' social component that of helping to alleviate poverty by creating jobs for people, in marginalised communities has elicited further popular (and political) support for WfW, projects (Gordon and Arne, 2013; van Wilgen *et al.,* 2012). The publicity has in turn helped to drum up awareness among the wider South Africa public. Such awareness (sorely lacking in most other parts of Africa) is critical in scaling up the battle against alien plant invaders.

An integrated cross-sector approach, meanwhile involving different government departments (including those of Environment, Agriculture, Trade and Industry, Social Services and

Tourism), at both national and provincial levels, together with independent conservation bodies, environmental NGOs, social welfare organisation and private companies, has further contributed to effectiveness of South Africa's response. A clear legislative framework, coupled with the political will to go on providing budgetary support for vertical integrated action programmes extending to, involving and benefiting communities at the local level, has been central to sustaining the South African war on weeds.

Findings from this research point to the need to rationalise legislation on invasive alien species. In particular, several pieces of policy and legislation deal with invasive alien species, such as legislation administered by the Department of Environmental Affairs and Forestry. This legislation must be rationalised and in some instances strengthened. All organs of state in all spheres of government as well as the private sector and general public, need clear guidance and uniform approach to deal with the serious threat of invasive alien species.

In addition, there is need to provide technical support to municipalities to integrate biodiversity into planning and environmental management (US EPA, 2008; Gordon and Arne, 2013). In order to 'mainstream' aquatic ecosystems must be integrated into land-use planning and environmental management. Local government is a key role player in the management of aquatic ecosystems and mitigation of threatening processes. However, many local authorities are unable to cope with their main function of service delivery and local economic development, and note that management of aquatic ecosystems (dams and wetlands) will require additional resources that they do not have. There is need to identify ways that national and provincial spheres of government and other institutions can assist and support municipalities. This assertion is supported by Shine (2008) who argues that a coordinated programme of capacity building and support for local authorities should be developed and implemented while existing initiatives such as conversation planning handbooks and maps for local authorities and planners should be supported and expanded. This includes guidelines, policy and procedures that focus on planners and local authorities building on lessons from existing products and projects that are being undertaken nationwide.

The existing programmes for the control of invasive species in particular the WfW's socio-economic benefits could be further expanded and improved on, including strategies for alternatives to invasive species used in areas where eradication is possible. There is also a need to link more closely with landowners (public, private, and communal land) provide incentives and improve follow-up support such as support for the rehabilitation (Shine, 2008; US EPA, 2008). Education and advocacy is also important to raise awareness and promote a sense of responsibility amongst all South Africans and encourage action.

Furthermore, a study on the legislative framework capacities to adapt to changing conditions shows that few municipalities and regions have developed strategies and associated tasks that specifically address climate change or consider potential changes in environmental conditions in general. While this is not a surprising finding, since organs of state and regions currently are not mandated to consider climate change effects and have limited sources for IAS management activities, management plans could incorporate more strategies to increase a regions capacity to adapt to changing conditions.

This analysis according to Gordon & Arne (2013) highlights that some capacity exists to deal with the additional stressor of climate change, particularly though revisions of management plans, could incorporate more strategies to increase a region's capacity to adapt to changing conditions. These results provide managers and decision-makers with information on what aspects of management plans can be readily revised to incorporate climate change information and where adaptive management approaches may be most beneficial.

2.9 REPRODUCTION OF THE WATER HYACINTH

The water hyacinth reproduces sexually by seeds and vegetatively by budding and stolen production. For rapid spreading, the vegetative propagation is more efficient (Verma *et al*., 2003). Daughter plants sprout from the stolons and doubling times have been reported of 6-18 days. Under favourable conditions of temperature and nutrient availability, the vegetative propagation is very fast and the edge of mat can even enhance by 60cm/month. Plant canopy shade reduces the quantity and quality of light available to the plant, thereby limiting the growth. However, clonal plants such as *E. crassipes* might increase light interception via horizontal growth of stolons or rhizomes and placements of new ramets, in less shaded microsites (Malik, 2007).

The seeds of the water hyacinth can germinate in a few days or remain dormant for 15-20 years. They usually sink and remain dormant until periods of stress (droughts). Upon re-flooding, the seeds often germinate and renew the growth (Zhang *et al.*, 2010). Therefore, its successful invasion may mainly be attributed to the phenotypic plasticity responding to new habitat, competitive ability increased by rapid clonal growth and strong tolerance to environment stress rather than the genetic diversity.

2.10 THE WATER HYACINTH ENVIRONMENTAL PROBLEMS

The water hyacinth is listed as one of the most productive plants on earth and is considered one of the world's worst aquatic plants. It can double its size in 5 days and a mat of medium sized plants may contain 2 million plants per hectare that weigh 270 to 400 tonnes (Patel, 2012). These dense mats interfere with navigation, recreation, irrigation and power generation. Many large hydropower schemes have to devote significant time and money in clearing the weed in order to prevent it from entering the turbine and causing damage and power interruptions. The blockage of canals and rivers can even cause dangerous flooding.

On the other hand, increased evapotranspiration due to water hyacinth can have serious implications where water is already scarce (Malik, 2007). The water hyacinth can also present many problems for the fishermen such as decreased fish population and difficult access to the fishing sites. The water hyacinth is blamed for the reduction of biodiversity as well. It has apparently become a problem in different parts of the world due to its uncontrolled and rapid rate of spread. There is therefore, a great need to manage its spread through suitable control measures.

2.11 CONTROL MEASURES

The control of the water hyacinth is absolutely essential (Villamagna and Murphy, 2010). At an annual productivity of 50 dry (ash-free) tons per hectare per year, water hyacinth is one of the most productive plants in the world (Malik, 2007). Mathematical models of the growth of the water hyacinth have been developed to provide a sound basis for assessing existing and potential control options. These studies show that under constant experimental conditions, the water hyacinth shows logistic growth (Wilson *et al.,* 2005). As shown in Table 2.1, to combat the problems caused by the water hyacinth, various efforts to control its spread have been taken up that include weed management methods such as physical removal, chemical methods (application of herbicides) and release of biological control agents. (Wilson *et al.,* 2007; Forpah, 2009; Jafari, 2010; Patel, 2012; van Wilgen *et al.*, 2012).

Table 2.1: Methods for the control of water hyacinth

Control method	*Agents*	*Limitations*
Physical	Permanent drainages of area. Manual removal by hand pulling or harvesting nets	Not always feasible Difficult and labour intensive, may involve health risk
	Mechanized removal through land-based cranes, draglines or, by water-based machinery such as mowers, dredges, barges or aquatic weed harvesters	Expensive, energy intensive, need a convoy of water and land-based vehicles for transportation of harvested mats
Chemical	2,4-dichlorophenoxyacetic acid (2,4-D) + complexed copper 2,4-D amine spray at 21/ha followed by 2^{nd} spray at 11/ha Endothall dipotassium salt, endothall dimethylalkylamine salts, glyphostate	Expensive, cannot control large infestations, long term adverse effects on other communities and environments
Biological	Classical control by insects: *Neochetina eichhorniae*, N. *bruchi* and *Sameodes albiguttalis*	Insufficient reduction and resurgence in growth.
	Allelopathic plants *Coleus amboinicus leaf powder* (40g/l) *Lantana* *Partheniu* *Cassytha powder* *Fungal pathogens* such as *Alternariaeichorniae*	Still under R&D stage, may not suffice alone and better if used with mechanical/chemical control methods

(Source: Malik, 2007)

2.11.1 Manual and Mechanical Control

Physical methods for control of water hyacinth involve drainage of the water body, manual removal of the weed or pulling through nets (Patel, 2012). Removal by hand is extremely labour intensive and not cost-effective. Employing machines like weed harvesters, crusher boats, and destruction boats prove expensive, (Malik, 2007; Vallamagna and Murphy, 2010). Besides, the use of mechanical harvesters has generally not been successful in South Africa because of shallow water depth and obstructions. Cables or floating booms have been very successful on some rivers and dams. Floating aquatic plant bank up against the cables and are then treated with herbicide. The other disadvantage of the mechanical removal of alien plants is that the infestations soon return because shredded bunches of the weed are carried by waves to other unaffected areas where they establish and start proliferating (Shanab *et al.*, 2010)

2.11.2 Chemical Control

A generally cheaper method that has been used worldwide to reduce the water hyacinth populations is the use of chemical herbicides (Paraquat, Diquat, Glyphosate, Amitrole, 2, 4–D acid) (Villamagna and Murphy, 2010). However, their use directly interferes with the bio-control agents currently deployed against this weed. Long term use of chemicals may degrade water quality and put aquatic life at risk, as well as impacting negatively the socio-economic benefits or multiple water uses like drinking and cooking (Malik, 2007). Considering that hundreds of thousands of hectares have been invaded by the weed, it is unlikely that it will be controlled by chemical means alone (Borokini and Babalola, 2012).

2.11.3 Biological Control

The biological control method of invasive alien plants involves the use of natural enemies, usually insects or pathogens, to reduce their spread to manageable levels. This is the widely used method in many parts of the world (Dagno *et al.*, 2012; Villamagna and Murphy, 2010). The aim of any biological control is not to eradicate the weed, but to reduce its abundance to a level where it is no longer problematic. There exists several native enemies of water hyacinth, two South American weevil beetles *(Neochetina eichhorniae and Neochetina bruchii)* and two water hyacinth moth species *(Niphograpta Albiguttalis* and *XubidaInfusella*) have had effective long-term control of the water hyacinth in many countries, notably at Chivero (Zimbabwe), Lake Victoria (Kenya), Louisiana (USA), Mexico, Papua New Guinea and Benin (Gichuki *et al.,* 2012; Dagno *et al.,* 2012).

Bio-control is the preferred method for large infestations because it is environmentally acceptable and cost effective. In most instances acceptable control of major aquatic weeds can be achieved through bio-control alone. The level of control achieved will vary greatly and depend on the specific characteristics of the system such as weed species present, nutrient conditions, water flow, climate and many others (Henderson, 2010). The control of the water hyacinth using fungal pathogens has greatly stimulated interest in the management of the weed. Several fungal species among them *Cercosporarodmanii*, *Alternariaalternata* and *A. eichorniae*are recognised as potential myco-herbicide agents although no commercial myo-herbicide is available for water hyacinth (Dagno *et al.,* 2012).

The weevil, shown on Figure 2.4 reduces the water hyacinth vigour by decreasing plant size, vegetative reproduction and flower and seed production. They also facilitate the transfer and ingress of deleterious microorganisms associated with the weevils (both fungi and bacteria) into the plant tissues (Venter *et al.,* 2012).

Figure 2.4: The Water hyacinth weevil *(Neochetina eichhorniae)*
(*Source: UNEP, 2012*)

Oberholzer (2001) further argues that the larva of the weevils bore into the petiotes and the crown (growth point) of the plant causing waterlogging and ultimately death of the plant. Adult feeding causes the leaves of the plant to dry out. Dense mats of the weed start to break up as the new growth is damaged. Long-term damage results in the reduction of the production of flowers, leaves and daughter plants and a stunting of plant growth. Under the correct environmental conditions, these two agents, in combination with the other biological control agents that have been released on water hyacinth can bring the weed under complete control. Groote *et al.* (2003) showed that biological control turns out to be a very cost effective method.

Nevertheless, each of these methods has limitations and the most appropriate management strategy is often site specific. Since any of the above control methods alone may be ineffective, a logical and site specific integration of different techniques is desirable. For instance, Center *et al*. (1999) suggest that biological and herbicidal controls should be integrated; using herbicides to maintain water hyacinth infestations below management thresholds but in a manner that conserves biological control agent populations. Williams *et al.* (2005) inferred that although weevils likely played a role in the rapid disappearance of water hyacinth in Lake Victoria, the Cloudy weather of 1997/1998 was probably a major contributory factor to poor growth and reduction in water hyacinth biomass lake-wide. Hence to be fully effective, control strategies must involve favourable external factors apart from the direct weed control (Sulien *et al*., 2001 in Malik 2007).

2.12 IMPLICATIONS FOR POLICY

The water hyacinth infestation is a symptom of broader watershed management and pollution problems. It calls for a concise national and transboundary water hyacinth policy designating the plant as noxious weed to aquatic systems. In October 2010, world leaders adopted the Strategic Plan for Biodiversity (2011–2020) targeting the need for identification of invasive alien species and pathways, the need to control and eradicate priority species, and to manage pathways in order to prevent further invasions (UNEP, 2012).

Awareness needs to be raised among local communities and stakeholders on the inherent dangers of the water hyacinth infestations. One practical approach is to involve communities in manual and biological control activities, for example, in rearing weevils. There are excellent examples of community involvement in the rearing and distribution of the weevils to control the hyacinth around Lake Victoria (Wilson *et al.,* 2007). However, in the case of Lake Victoria, the success points to the classical biological control as the major factor. Methods for water hyacinth control should include reduction of nutrient load in the water bodies through treatment of water flowing from sewage works, agricultural, urban and industrial wastes. Changing land use practices in the riparian communities through watershed management will help reduce agricultural runoff as a mechanism for controlling the proliferation of water hyacinth. This is considered by many as one of the most sustainable long-term management actions.

In order for policy makers to make informed decisions, more economic information is required on the costs and benefits of environmental programmes. For example, it is frequently stated that there are insufficient resources to control hyacinth. However, if the costs of improved water treatment are compared with the costs of decreased fish catches and the costs of increased water-borne diseases, it is likely that resources needed for hyacinth control are modest in comparison to potential losses from its proliferation.

2.13 POTENTIAL UTILISATION OF WATER HYACINTH

Although the water hyacinth is often seen as a weed responsible for many of the problems outlined in this study, there are other schools of thought that advocate useful applications for the plant. The water hyacinth is one of the plant species that attracted considerable attention because of its ability to grow in heavily polluted water together with its capacity for metal ion accumulation. It is quite versatile plant as far as phytoremediation capability is concerned. Natural wetland systems colonised by the water hyacinth could serve as “nature’s kidneys” for proper effluent treatment to preserve the earth’s precious water resources from getting polluted (Malik, 2007; Patel, 2012).

It is being speculated that the biomass can be used in wastewater treatment, heavy metal and dye remediation, as substrate for bioethanol and biogas production, electricity generations, industrial uses, medicines, animal feed, agriculture and sustainable development (UNEP 2012). Malik (2007) suggested that despite considerable information on the influence of aquatic plants on metal fluxes at larger scales, many studies take a black box approach, focusing on influent and effluent pollutant concentrations.

The fibres from the stems of the water hyacinth plant can be used to make ropes, baskets, or even good quality paper if blended with waste paper or jute. Several small-scale cottage industry paper making projects have been successful in countries like The Philippines, Indonesia and India (Malik, 2007; Jafari, 2010). Another application of water hyacinth is the production of fibreboards for a variety of end user such as bituminised board for low-cost roofing material, indoor partition walls and etc. Extensive utilization of the water hyacinth can also be made through proposed technology for briquetting of charcoal dust obtained from the pyrolysis of the water hyacinth. In India, many natives use the water hyacinth as a medical plant mainly to treat the goitre disease (Malik 2007).

Anti-oxidising agents are also essential compounds that improve the body physiological self-defence against cancer, cardiovascular and neurodegenerative diseases, HIV etc. Bodo *et al.* (2004) demonstrated that the water hyacinth displays effective anti-oxidative activity like soya and garlic. Certain components of the water hyacinth seem to display anti-oxidative properties and some studies state that it exhibits nearly the same anti-oxidising agent properties as Vitamin C and E (Malik, 2007; Ndimele *et al.,* 2011; UNEP, 2012).

A recent research on the water hyacinth has enhanced knowledge about the basics as well as applied aspects of this plant. There is now a clear picture of the environmental factors that affect the survival and growth of this plant. This information may have positive implications for the control as well as utilization of the water hyacinth for the waste water treatment. Significant research has focused on the biological control methods using classical insect agents but the use of allelopathic plant species and mycopathogents has also been explored (Chikwenhere, 2001; Stanley *et al.,* Patel, 2012).

However, the problem caused by water hyacinth to the communities far outweighs the benefits that might occur through utilization. Therefore, utilization and control strategies should go hand in hand and rather should try to complement each other.

2.14 CLIMATE CHANGE AND INVASIVE ALIEN SPECIES: IMPLICATIONS FOR ECOSYSTEMS

Climate change is defined as changes in the earth's temperature, wind patterns and rainfall (Turpie *et al.*, 2008). Biological invasions are gaining attention as a major threat to biodiversity and an important element of global change. Recent studies by Bradley and Mustard (2006); Bradley and Wilcore (2009), and Hume (2009) indicate that other components of global change, such as increases in nitrogen (N) deposition and atmospheric carbon dioxide (CO_2) concentration favour groups of species that share certain physiological or life history traits. This new evidence suggests that many invasive species share traits that will allow them to capitalise on the various elements of global change. Increases in the prevalence of some of these biological invaders would alter basic ecosystem properties in ways that feedback to affect many components of global change.

Predicting the effects of the many other elements of global change on biological invasions is a daunting and complex task (Dukes and Mooney, 1999). Biologists are beginning to understand how species and ecosystems respond to many single aspects of global change. The understanding of responses to the full complement of these factors is rudimentary (Cannon, 1998; Bradley and Wilcore, 2009). The task also has spatial complexity. Although the ongoing increase in CO_2 is imposing a relatively uniform direct perturbation across all regions of the world, changes in climate, nitrogen deposition and other processes affects these elements of global change on invasions.

According to Bradley *et al.* (2009) there are two fundamental reasons why invasion risk is expected to increase with climate change. First, invasive species are by definition well suited to succeed in novel environments. Second, many invasive species are most successful in environments with high resources availability and several types of global change directly increase the availability of plant resources. For example, increased CO_2, N deposition and changes in landuse or landcover have been observed to facilitate invasion.

However, the effects of climate change per se are more difficult to predict. For example, while changes in temperature and precipitation could benefit invasive species by creating novel environments, they do not consistently increase resource availability. Indeed, rising global temperature might decrease water availability even when precipitation remains the same (Bradley *et al.,* 2009). Modelling and experimental studies have shown both increased (Hulme, 2009; Bradley and Wilcore, 2009) and decreased invasion risk (Morin and Thuiller (2009) associated with climate change. Hence, the relative impacts of climate change or plant invasions will depend on the dominant forces of change, the geographical location of the area and the invasive species under consideration.

A pattern is beginning to emerge from these predictions: it is expected that most aspects of global change favour invasive alien species and thus exacerbate the impacts of invasions on ecosystem as is shown in Table 2.2.

Table 2.2: Possible general impacts of climate change elements on prevalence of invasive alien species[a]

Element of global change	*Prevalence of invaders* [b]
Increased atmospheric CO_2 concentration	+/-
Climate change	+
Increased nitrogen deposition	+
Altered disturbance regimes	+
Increased habitat fragmentation	+

[a]Although these predictions are speculative, they are based on observations that are mentioned or cited in the text.
[b]key: +/-, might increase prevalence of some invaders and reduces prevalence of others; +, expected to increase prevalence of invaders in many affected regions
Source: Dukes and Mooney, 1999

These impacts include competitive effects whereby an invading species reduces resources available to other species, and ecosystems effects, whereby an invader alters fundamental properties of the ecosystem. Either type of effect can threaten native biodiversity, and some ecosystem effects feedback to elements of global change, demonstrated by Figure 2.4.

A variety of forces can affect the prevalence of alien species. In the conceptual model shown in Figure 2.4, various elements of climate change favour alien species, and changes in global commerce increase the rate of alien propagules. Together, these forces lead to increased numbers and coverage of biological invaders. As alien species become prevalent, they will alter ecosystem processes and properties, many of which interact with elements of global change. Feedbacks on climate change will be positive or negative, depending on the invading species and on the element of global change.

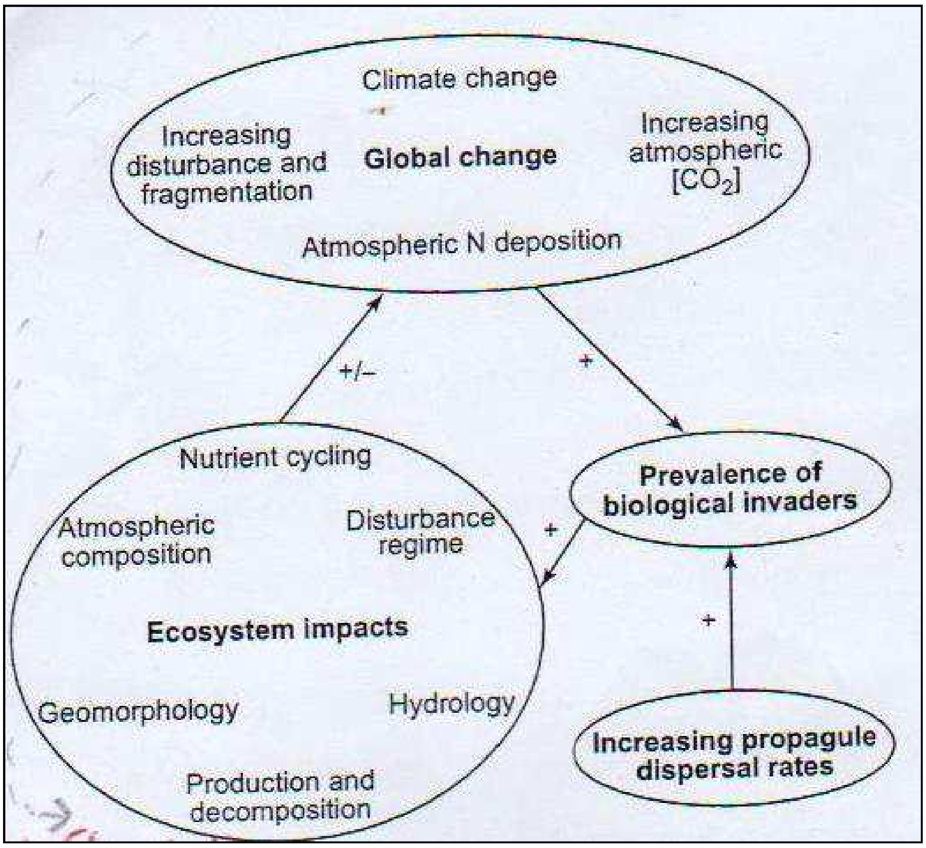

Figure 2.5: Impact of climate change on invasions, and feedbacks from invaders to global change
(Source: Dukes and Mooney, 1999)

2.14.1 Effects of rising CO_2 on biological invasions

Rising atmospheric CO_2 has a direct "fertilization" effect on plants, increasing resource availability in a relatively uniform manner across terrestrial ecosystems and this is expected to favour invasive plants (Daehler, 2003; Blumental, 2006). Although previous studies had reasoned that rising CO_2 levels could help or hinder invasive plants (Dukes and Mooney, 1999), recent studies show advantages for invasive plants for a range of species and growth habits, including annual grasses invading perennial shrublands, and invasive perennials out-competing native annuals along an urban to rural CO_2 transect. These driven changes in ecosystem nutrient dynamics could also affect a system's vulnerability to invasion. In addition, in mixed-species competition, the CO_2 response of groups of species (such as N-fixers and C4 species) might depend on local resource availability, which in turn could be affected by elevated CO_2. For example, most plants increase their water-use efficiency if grown in CO_2 - enriched environments. If increased CO_2 decreases the rate at which plants transpire in a given ecosystem, the soils beneath those plants will dry out more slowly (Dukes and Mooney, 1999; Aranjo and New, 2007).

The IPCC (2007) asserts that in ecosystems where plant growth is limited by water availability, species that can take advantage of the extra moisture might eventually become more abundant. Such an increase in water availability might also benefit phonologically similar non-native species. CO_2 - driven changes in ecosystem nutrient dynamics could also affect a system's vulnerability to invasion. Complex interactions among these CO_2 effects and factors such as climate change will affect competition among natives and aliens in ways that we cannot yet predict with confidence.

2.14.2 Changes in land use and land cover

Continued changes in landuse or landcover are likely to affect ecosystems as profoundly as climate and resource changes (Hulme, 2009; Richardson, 2006). Roads, settlements and energy infrastructure at the wild land-urban interface doubled between 1970 and 2000 and are expected to continue to rise in coming decades (Bradley *et al.*, 2009). These novel disturbances harm native species and provide opportunities for invaders to prosper; they also form "corridor pathways" that act as invasion conduits into both fragmented (With, 2002) and undistributed landscapes.

Recent studies have found strong positive relationships between invasive plant presence and disturbances such as roads (Gelbard and Belnap, 2003; Bradley and Mustard, 2006), deforestation and forest canopy mortality (Schneider, 2004; Eschtruth and Battles, 2009), urban areas, energy development, grazing and agriculture (Bradley and Mustard, 2006). Although changes in land use or decrease biological diversity, and therefore limit the potential for diversity loss associated with enhanced plant invasion *per se.* Considering the costs associated with control and restoration once invasive plants are established, minimising new disturbances, such as roads, might be the cheapest, most effective method of controlling invasion.

2.14.3 Global commerce

Global commerce increases invasion risk as plants or plant parts are brought in accidentally (for example, seed contaminants) or intentionally (for example, trade). Climate change could push the horticulture industry to import additional novel species as farmers find that plants that that they have traditionally used to grow no longer thrive in their fields (Bradley *et al.*, 2009). Recent decades have seen a pronounced northward shift in the U.S. Department of Agriculture's Plant Hardiness Zones, which delineate the species capable of growing in different regions of the country. Thus, global commerce in conjunction with climate change seems likely to further alter invasion pathways by opening new trade routers and by causing importers to seek out new species. A "polluter pays" policy, whereby plant importers bear the cost of controlling escaped species that become pests, could reduce future invasions by making importers more cautious about the species they sell, however such a policy would require meticulous record–keeping and prompt detection of escapes, neither of which has proven easy.

2.14.4 Does global change favour invasive over native species?

Invasive plants are a tremendously variable group. However, on average, native and invasive plants differ with regard to some traits and some of these traits predispose invasive species to thrive in the face of global change. Perhaps most importantly, invasive species are generally well suited to change. To become a successful invader, a plant species must disperse into, tolerate, and then thrive in new environments, which is essentially what species coping with global change will have to do. According to Bradley *et al.* (2009) the following traits could enable evasive plants to thrive in the face of global change:

1. Short generation times, high fecundity and strong dispersal ability could help invasive plants expand into newly suitable habitat as the environment changes. Short generation times might also help invasive species evolve more rapidly and adapt to changing environments.
2. Broad environmental tolerances for processes such as germination, seeding survival and flowering could allow invasive species to persist in marginal conditions, providing more opportunities for adaptation to change.
3. Rapid growth and high fecundity might allow invasive species to rapidly colonize niches that are opened due to change. Furthermore, rapid growth, and associated traits such as low construction costs and strong enemy release, might make invasive species particularly well suited to changes to changes that increase resource availability (elevated CO_2, N deposition changes in land use or land cover and increased precipitation).
4. Independence from mutualists might help invasive species thrive in novel environments where they can take advantage of generalist pollinators, seed dispersers or mycorrhizae.

2.14.5 Critical research and management needs to improve forecasting and combating alien plants invasion risk in an era of climate change

Several areas of research related to invasive plants and climate change are currently under-represented in the literature (Bradley *et al.*, 2009). The most pressing research needs include: the need to use sensitivity analyses to generate hypotheses about global change impact that can be tested experimentally; use model ensembles (multiple envelope models, multiple climate change models/scenarios, multiple process-based models) to increase confidence (Aranjo and New, 2007; Morin and Thuiller, 2009). In addition further research is needed to perform meta-analyses of previously observed responses to seasonal climate conditions and factors of global change for particular invasive species (Richardson, 2006). Furthermore, research to compare existing projections for individual species based on different methodologies to improve projections is an area that needs attention (Pattison and Mack, 2008; Morin and Thuiller, 2009).

Despite uncertainly about future invasion risk at the local level, there are many proactive steps that the management and science communities can take to diminish impending threats from invasive plants. Bradley and Wilcore (2009) argue that managers need to identify areas where invasion is most likely to occur due to global change and increase surveillance for early invaders. Decision makers should also prepare for possible restoration opportunities in areas where climate change is likely to cause invasive plants to retreat. Transformation, restoration or the introduction of novel species assemblages should be evaluated and tested if necessary.

In many nations, laws and programmes exist to prevent and control invasive plants, but low funding levels and insufficient staff make them ineffective. Institutions need to hire additional personnel to control existing invasions and to create management plans for future invasions and target pathways of invasive plant introduction through stricter enforcement of import laws.

However this data enables the general assessment of seasonal and long-term water level trends. Further in situ validation of this data through ground networks and improvement of the techniques of satellite water level measurements are necessary.

2.15 THE USE OF GEOGRAPHICAL INFORMATION SYSTEMS AND REMOTE SENSING DATA IN MONITORING ALIEN INVASIVE SPECIES

Geographic Information Systems (GIS) and Remote Sensing, couples with Global Navigation Satellite Systems (GNSS) like the Global Positioning Systems (GPS), provide a mechanism to locate, view and analyse a physical process on earth for spatial analyses (Holcombe et al., 2007). GIS is a tool for data inventory and query, spatial analysis and decision-making. The ability of a GIS to integrate various forms of data and store relationships between features in addition to feature location and attributes are important strengths in invasive alien plants monitoring and analysis and management (Vairavamoorthy *et al.*, 2006). Combining these functions with modelling tools enables the conversion of large amounts information and then into knowledge that is useful in mapping alien invasive species.

Furthermore, due to the wide variety of applications of GIS and the myriad of spatial data available, models applicable to invasive species at local and regional levels can be created

(Holcombe *et al.,* 2007). This is important because of the fact that no two areas or situations are completely alike. This creates a situation for a local analysis in order to have more applicable and accurate results. The flexibility of modelling procedures allows for data processing that can suit the desired location and scope of the analysis (Bernhardsen, 1999; Kurucu and Christina, 2007). Similarly, GIS can also process geo-referenced data and be used to record an inventory of the environment, to provide information on the particulars of a given location; identify the relationships and systematic patterns of a region including the distribution of selected phenomena; identify, record and assess changes from a previous analysis; to extrapolate data and make predictions based on current practices and management plans or to predict the impact of a specific event; and for processing data to be displayed in digital map layers (Jha *et al.,* 2007).

Ecological data, in most cases, contains a spatial component. Biological information of non-native species provides insight to explaining expanding distributions and provides a watch list of spreading invasive species to managers for early detection and rapid response. Ecological and climatic data is used as an indicator to monitor possible invasion of alien species in an area for timely intervention for control purposes.

According to Avery (1977) Remote Sensing is defined as the detection, identification, and analysis of objects or features through the use of imaging devices (sensors) located at remote positions from the subjects of investigation. Remotely sensed data are digital in nature and can be effectively and efficiently interpreted and analysed using various kinds of software packages (Jha *et al.,* 2007). The combination of GIS and Remote Sensing plays an important role in the linkage and analysis of data. While Remote Sensing can provide extensive spatial coverage at regular intervals, which is essential for GIS to be effective, GIS data layers can contribute correlative data to improve the accuracy of the remote sensing data. Through technological progress, remote sensing has changed from a relatively qualitative art relying on inference for information to a quantitative science capable of detailed measurements (Jha *et al.,* 2007).

2.16 SUMMARY

The literature review in this research has shown that alien plants invasions are a growing threat to ecosystems in many parts of the world. They are changing the structure and functioning of ecosystems, with negative consequences for the conservation of biodiversity and the delivery of ecosystem services. In the post-apartheid era, South Africa is experiencing a serious water supply crisis as demand increased from both rural areas and rapidly growing urban areas (Binns *et al.,* 2001). Given the complexity of control options and the potential for climate change to assist the spread of water hyacinth, it is critical to develop comprehensive management strategies and action plans. A multidisciplinary approach should be designed, which ensures that the highest political and administrative levels recognize the potential seriousness of the weed.

Incidences of growth of aquatic weeds and widespread infestation in the water bodies of the Southern African Development Community (SADC) region are increasing and constitute a great threat not only to the environment but also to its socio-economic conditions (Shekede *et al.,* 2008). The research on the water hyacinth has enhanced the knowledge about the basic as well as applied aspects of this plant. While researchers continue to investigate the perceived potential uses of the water hyacinth, the current negative impacts of the weed far outweigh its benefits. The use of the water hyacinth as raw material in cottage industry should not encourage propagation of the weed, but rather help control its growth. In addition, utilization and control strategies should go hand in hand and rather should try to complement each other.

This section has also shown that the relationship between plant invasion and global change is complex. Studies investigating the link between plant invasions and rising CO_2, increased global commerce and changes in landuse or landcover show that global change might increase the risk of invasive plants. Studies have shown that urban areas are likely to see a substantial rise in invasive plant abundance (Bradley *et al.*, 2009).

In many cases, the problem is not one of putting the appropriate programmes and policies into place, but rather of adequately funding programmes and policies that already exist, along with improving coordination among agencies, institutions and stakeholders. Ignoring invasive alien plants in the face of climate change will probably mean additional environmental damage, economic losses and missed opportunism for remediation

CHAPTER: 3

3. RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

This chapter presents an overview of the methodology used to determine the spatial distribution of the water hyacinth in the Benoni lakes, make an analysis of its impact on water availability and usability and to understand the evolution and its propagation rates. The section also describes the methods used to map the water hyacinth. The control measures put into effect by Ekurhuleni Metropolitan Municipality (EMM) have so far managed to contain the infestation of the water hyacinth in the lakes. But in light of the risk presented by this alien plant, capacity for reproduction and growth and the abiotic and biotic factors that favour its success, this study determines possible future distribution and suggest measures that can be taken to control its propagation. This is necessitated by the fact that it is always expected that recurrent infestations in the area that has been previously colonised can occur and possibly in spatial extend**.**

3.2 STUDY METHODOLOGY

In this study a quantitative research design was used. The study used satellite imagery for lake level modelling using Remote Sensing and GIS. This hydrological based model used hereafter is called Change Detection Modelling Approach (CDMA). Multiple regression and correlation analysis techniques were also used to show how evapotranspiration, solar radiation, temperature and rainfall trends influence the aquatic weeds propagation and affect water availability. The use of the quantitative research design helped in establishing methods to analyse the collected data. The quantitative research design enabled the data to be summarised, which facilitated communication of findings and to make comparisons (Leedy and Ormrod, 2005). Significantly, the quantitative research approach used in this research study helped to make inferences based on observed data, from several settings and times, and to compare the findings.

The hydrologic characteristics of lakes (lake level and volume) are important indicators of impacts of aquatic alien plants and changes in climate. The analysis of temporal and spatial variability of lake level dynamics is therefore important contributions on global research of alien aquatic plants and climate change. The purpose for the climatic analysis of these hydrological variables was to evaluate whether changes in these variables in the study area would impact on water hyacinth in creating novel environments. The lack of water quantity data for the study lakes necessitated the use of hydrological modelling. Therefore, the models used in this study were for filling in and replacing missing records from EMM. The modelling approach used helped to make efficient and cost effective quantitative estimates of water-related variables at these ungauged study lakes. Such estimates also help to make decisions relating to planning, design, operation and management of water related structures. This include how lakes may be regulated in terms of water quantity and quality (pollution, contamination) and what impacts changes in quantity and quality brought about by invasive plants, and assessing alternative solutions to the water hyacinth problem.

3.3 DAM LEVEL CHANGE DETECTION USING REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEMS

Managing limited surface water resources is a great challenge in areas where ground-based data are either limited or unavailable (Velpuri *et al.*, 2011). Due to this limitation in the study area indirect measurements of the surface water area in the lakes were used through Remote Sensing and GIS. The data required for this study was obtained from the Landset ETM for 2002, 2004, 2006, 2008, 2010 and 2012 respectively. The images were taken during summer and winter seasons and randomly selected. The satellite imagery were also used to compile and digitise the information in the form of polygons to monitor area changes of the invasive alien plants and also to monitor changes in water levels in time series (change detection) for all the three dams, that is Kleinfontein, Civic and Middle lakes.

Remote sensing then provided data input for GIS for calculations of area covered by weeds in each lake for the years 2002, 2004, 2006, 2008, 2010 and 2012. GIS was then used to create shape files as a means of obtaining useful information on spatial and temporal changes in aquatic weeds. GIS and a statistical package, SPSS, were then used for mapping the extent of weed coverage and water levels and spatial data analysis, and to assess the trends of water hyacinth in the area and how they impact on lakes water usability and scarcity. Multiple regression analysis and correlation analysis were then used to describe and evaluate relationships between the areas covered by water hyacinth as from 2002 to 2012 in the three lakes compared to lake water surface area available. The use of multiple regression and correlation analysis served as a basis for drawing inferences about the extent of the relationships of the weed infestations and water quantity and usability of the dams through time.

The Change Detection Modelling Approach using Remote Sensing was used to:

- Simulate patterns of water level variations in data as recorded data was not available.
- Operationally monitor lake water levels as influenced by aquatic weeds.
- Derive historical dam level information using satellite rainfall and evapotranspiration data.
- Augment the information provided by the satellite imagery on changes in lake water levels.

Remote sensing and GIS techniques provided a means of obtaining useful information on spatial and temporal changes in aquatic weeds in the study lakes. The use of historical satellite imagery enabled the quantification of long-term changes of aquatic weeds and hence opens up opportunities for applying targeted management efforts on areas of interest. GIS and Remote Sensing are invaluable assets for detection of invasions, assessment of infestation levels, monitoring rate of spread, and determining the efficiency of migration efforts for weed management as presented in this study.

Furthermore, information on the variations in lake water levels is often required on a regular basis for climate assessment purposes. Hence monitoring changes, in water levels is essential because they reflect changes in the seasonal distribution of river inflows, precipitation, and evapotranspiration (ET). However, measurements of the variability of water levels over lakes/ reservoirs are one of the critical missing pieces in the terrestrial water budget (NASA, 2007). Furthermore, while monitoring of surface water variability is a challenging task in basins, much of the greatest human impacts are occurring in basins that have none or very limited data (Silvapan, 2003).

GIS and Remote Sensing were used in this study as they were found to be complementary and useful tools to get time series of lake water levels that are often difficult to obtain from field measurements. Remote sensing is used here as a potential data source, and GIS as an analytical tool in developing a management system based on studying impacts of IAS on lake water quantity and usability.

3.4 DATA COLLECTION AND DESIGN

Firstly the hydrological data for the study area from 2002-2012 was collected and complied from the Agricultural Research Council of South Africa. Data from the selected meteorological variables such as evapotranspiration, solar radiation, temperature and rainfall spanning from 2002 to 2012 was compiled and analysed by using SPSS statistical package software. This statistical package is one of the widely used packages in different sectors.

SPSS is used widely since it can handle any type of data. The data was first recorded on Excel Spreadsheets which are compatible with SPSS. It was then copied on SPSS Excel spreadsheets. Without loss of generality, monthly means of evapotranspiration, solar radiation, temperature and rainfall were employed instead of actual data during the analysis. Actual data was simulated to come up with monthly averages. The data was then used to calculate trends using multiple regression and correlation coefficients from 2000-2012 and represented in various types of graphs. Next, the evapotranspiration, solar radiation ,rainfall and temperature trends from 2002-2012 were then compared with the observed patterns in the studied lakes by Remote Sensing and GIS to examine how climate change impacts water hyacinth and lake water levels.

3.5 REASONS FOR MODELLING THE AQUATIC HYDROLOGICAL SYSTEM

The fundamental objective of hydrological modelling in this study is to provide information on water hyacinth for management purposes for sustainable water resources management. Hydrological modelling has been used in this study to make efficient and cost effective quantitative estimates of water related variables of the ungauged study lakes.

According to Schulze (1995) such estimates may take a step further, when models are applied in regard to making decisions relating to planning, design, operation and management of water related structures, including making estimates of:

1. Rates of surface, near surface and underground water movement
2. Amounts of water stored in dams
3. Amounts of sediment and solute load
4. How these rates and amounts vary in time
5. How they may regulate or be regulated in terms of
    - water quantity
    - water quality (pollution, contamination and
6 What impacts changes in quantity and quality brought, for example by effects of changing land use, may have
7 And assessing alternative solutions to a particular problem (Schulze, 1995).

Results from a model, particularly risk analysis, are thus a means of communicating information for planning environmental resources and the decision makers, who may lack appropriate technical training in a way for them to understand the complexity and ramifications of the decision they are making. Hydrological data, because of the long uninterrupted sequences required, is expensive to obtain. A model, through advances in computer, conveniently handles, organises and synthesises large amounts of existing hydrological data and information (Shine, 2008) to facilitate their usability. Therefore models help make data collection financially more viable justifiable.

On the other hand a model can also generate useful information from limited data. Models may be used for filling in and replacing missing records. This is particularly true of the study of the lakes in Benoni where water quantity data in each of the lakes (Kleinfontein, Middle and Civic lakes) were unavailable. Hence, multiple regression analysis techniques were used to fill in and replacing these missing records.

A well-structured model promotes an improved understanding of and provides added insights into the actual physical and/or chemical and/or biological processes involved in the hydrological system (Schulze, 1995). As such a model can stimulate new research and detect areas where hydrological information is lacking. Finally, a well-structured hydrological model, by synthesising the complex interactions of hydrological and biological systems, provides a way of bringing together knowledge about the components of the systems in order to give a more coherent view of the behaviour of the entire continuum of the soil, plant, atmosphere, water system (Schulze, 1995).

A comprehensive research methodology approach was also done involving visiting selected lake sites in order to survey the complexity of the problem. This involved observations and pictorial representations of the infested lakes. Focus group meetings were also carried out to seven officials of the Ekurhuleni Metropolitan Municipality Wetland Team. The focus group was structured around a set of carefully predetermined ten questions and discussions were free-flowing. The questions were about their perceptions, opinions, beliefs and attitudes towards the water hyacinth problem in the Benoni lakes. In addition data sources varied from textbooks, research articles, internet and newspapers. Figure 3.1 is a flow chart showing the major steps used in the research methodology.

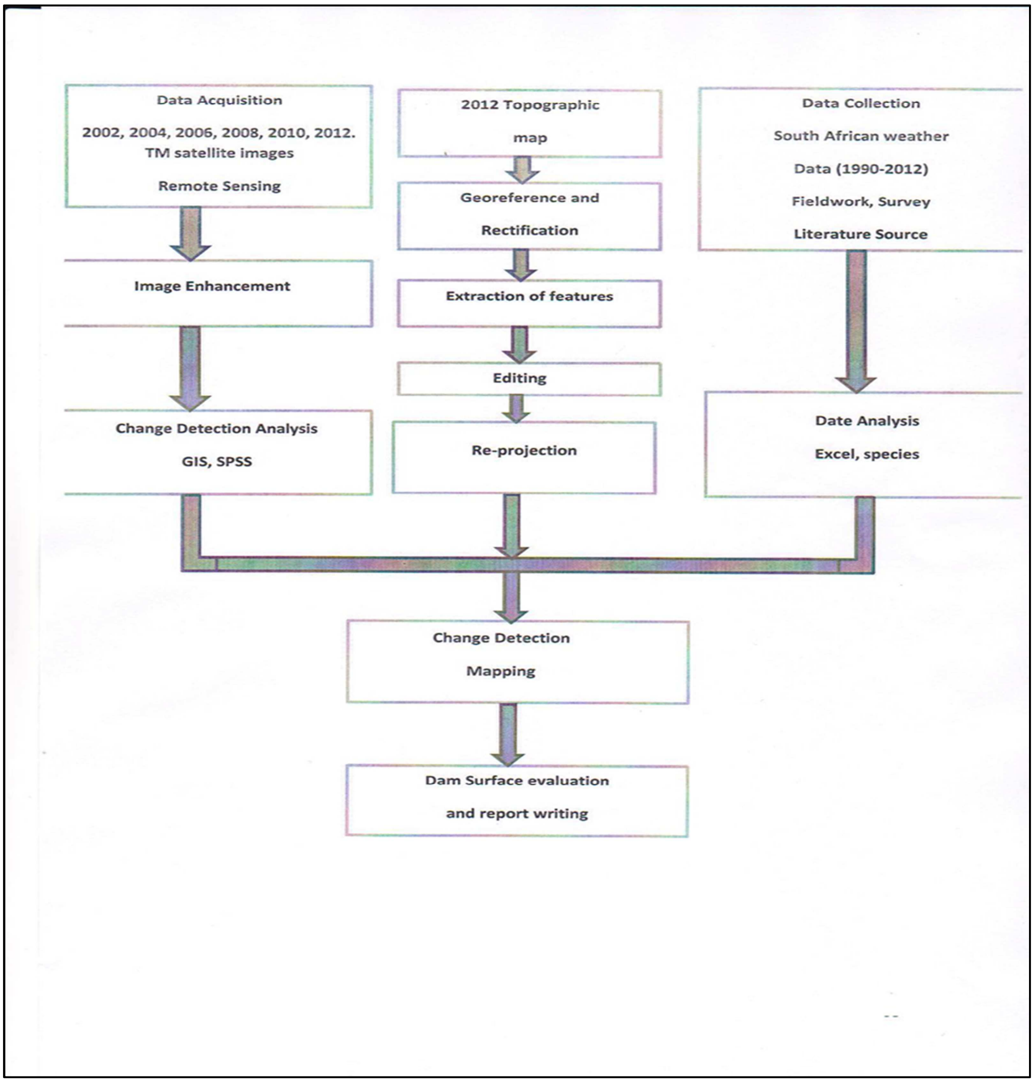

Figure 3.1: Flow chat of major steps in the study methodology

3.6 STATISTICAL MODELS TO DETERMINE DISTRIBUTION OF IAS

A growing number of statistical models called Species Environmental Matching (SEM) models are being used to determine current and potential distributions and abundance of harmful invasive species (Miller, 2012).These models include:

(i) **Species Environmental Matching (SEM)** models relate to observed species distributions to the environment (climate, topographic, edaphic) envelopes. Then, assuming the same stable relationships, they project species spatial shifts (local, enrichment, or extinction) in response to envelope changes under current conditions (Miller, 2012). Conceptually, the SEM models assume the fitted observational relationships to be an adequate representation of the realised niche of species under a stable equilibrium or quasi-equilibrium constraint. As such, the SEM model results only in a first approximation of future distributions of individual species (Peterson and Dawson, 2004). SEM model results are also determined by other processes such as dispersal, adaptation, competition, succession, fire and grazing pressure (Miller, 2012).

An important consideration for invasive management is that recent invaders may not have filled all suitable habitats, while species naturalised long ago may have filled a larger proportion of suitable habitat .In short, it will be possible to better manage and assess risk associated with harmful invasive species because risk assessments require accurate modelling of current and potential species distributions. No two SEM models are identical and each has advantages and disadvantages. Logistic regression is a type of Generalised Linear Model (GLM) appropriate for data with a binary distribution such as species or absence (McCullagh and Nedler, 1989).

(ii) **Environmental Niche and Distribution Modelling.** Apart from the use of SEM Environmental Niche and Distributional Modelling can also be used to study AIS distributions. In particular, most modelling approaches developed for prediction of plant or animal species distributions have their roots in quantifying species-environment relationships (Guisan and Thuiller, 2005). Species Distribution Models are empirical models relating field observations to environmental predictor variables, based on statistically or theoretically derived response surface (Miller, 2012). Species data can be simple presence, presence–absence or abundance observations based on random or stratified sampling, or observations obtained opportunistically, such as those in natural history collections. Usually they are used to reflect three main types of influences or species:

a) Limiting factors (or regulations), defined as factors controlling species eco-physiology (e.g. temperature, water, soil composition).

b) Disturbances, defined as all types of perturbations affecting environmental systems (natural or human – induced).

c) Resources, defined as all commands that can be assimilated by organisms (e.g. energy and water).

These relationships between species and their overall environment can cause different spatial patterns to be observed at different scales, often in a hierarchical manner (Pearson *et al.*, 2004). Patchy distribution observed over a small area and at fine resolution is more likely to result from a patchy distribution of resources, driven by micro-topographic variation or habitat fragmentation (Miller, 2012).

Species distribution models and their output habitat suitability maps have been used with relatively good success to investigate a variety of scientific issues. As both species and environmental data are usually sampled during a limited period of time and or space, models fitted using these can only reflect a snapshot view of the expected relationship. This is an assumption behind models and the niche concept (Guisan and Zimmermann, 2000).

Distribution models and ecological niche models are being used not only to understand species ecological requirements, but also to understand aspects of biogeography, predict existence of unknown populations and species, identify sites for translocations and reintroductions, plan area selection for conservation, and forecast effects of environmental change. A basic dichotomy that pervades both the list of uses to which these methods are put and even the terminology used to refer to them is that of Ecological Niche Modelling (ENM) versus distributional modelling (DM). Niches and distributions of species were visualised as a set of three intersecting circles, representing three classes of determinants: physical conditions necessary for a species survival and reproduction (a biotic niche) biotic conditions necessary for a species survival and reproduction (biotic niche), and accessibility (Peterson, 2006).

Environmental niche proponents are interested in using distributional information to estimate ecological niches and potential distributions of species, which then provides a means of understanding and anticipating ecological and geographical features of species distribution biology (Miller, 2012). Distribution model proponents, on the other hand, include effects of abiotic, biotic, and accessibility considerations in their models from the outset. Distributional information in an expression of a realised ecological niche, as such the realised niche is the target of modelling. Meaning a distribution modelling proponent would often include in the modelling approach independent variable that summarise biotic considerations and that bring in spatial considerations that may be relevant to dispersal ability and accessibility (Peterson, 2003).

Furthermore, the functionalities and possibilities of environmental niche modelling are vast. All of the rich detail of natural history, ecology, and behaviour can be essentially unknown, but some information can be inferred from ecological niche models. Environmental niche models, in their simplest manifestations, provide a framework by which one can interpolate between known populations of a species to anticipate existence of other unknown populations. They can be used to plan conservation efforts for methods or reintroduction or eradication efforts. Further advancements in this realm can be derived from the use of niche modelling to identify areas of high probability of population persistence (Aranjo *et al.,* 2002) and identifying optimal dispersal corridors.

3.7 STATISTICAL TECHNIQUES

There are statistical techniques that can be used in combination with GIS and Remote Sensing in mapping and analysing alien invasion plants. Of the many techniques that can be used in this regard, this section explores Multiple Regression Analysis and Correlation Analysis.

3.7.1 Regression Analysis and Correlation Analysis

Apart from using GIS and Remote Sensing, regression analysis can equally be used to identify relationships between variables. Chimedza (2003) defines regression analysis as a collection of statistical techniques that serve as a basis for drawing inferences about the relationships among variables in a real life system. In fact, it tells us the exact kind of linear association that exists between those variables. Correlations on the other hand as the name suggest, it is a measure of the degree to which the variables are related. For instance, if x and y are two variables, correlation would be a linear association between them. The most common measure of correlation is called the "Pearson Product-moment correlation coefficient". Significantly, however, correlation does not measure how two variables are related but measures the strength of their relationship.

It has been observed in some African countries that more emphasis in policy decision making has been placed on descriptive analysis techniques (Chimedza, 2003), yet little emphasis is placed on regression analysis techniques. For this reason this study emphasises more on the use of regression analysis. This is because in real life situations there is more interest in relationships between variables. For example, it is difficult to study the impact of climate change on IAS by using descriptive techniques only, without looking at the relationships of temperatures, and rainfall etc. Thus, regression analysis equips one with a way of handling real situations. Additionally, regression analysis allows multiple variables to be examined simultaneously.

3.7.2 When to apply Regression Analysis?

There are conditions which must be satisfied before applying regression analysis. The first condition to be met is that the variables of concern should be related to each other otherwise the idea of regression collapses. The second condition is that one variable should change in response to the other, i.e. there should be a dependence relationship (Chimedza, 2003; Stockwell *et al.,* 2008). This is often checked by:

a) Constructing a scatter plot,

b) Calculating the correlation of the variables,

c) Cross-Tabulations**.**

3.7.3 Scatter Plots

The first step in the investigation of the relationship between two continuous variables is a scatter plot. This procedure is best done using statistical computer packages. By looking at the scatter plot one can get a feel of the relationship between variables, that is, whether the variables are linearly related or related in some other way.

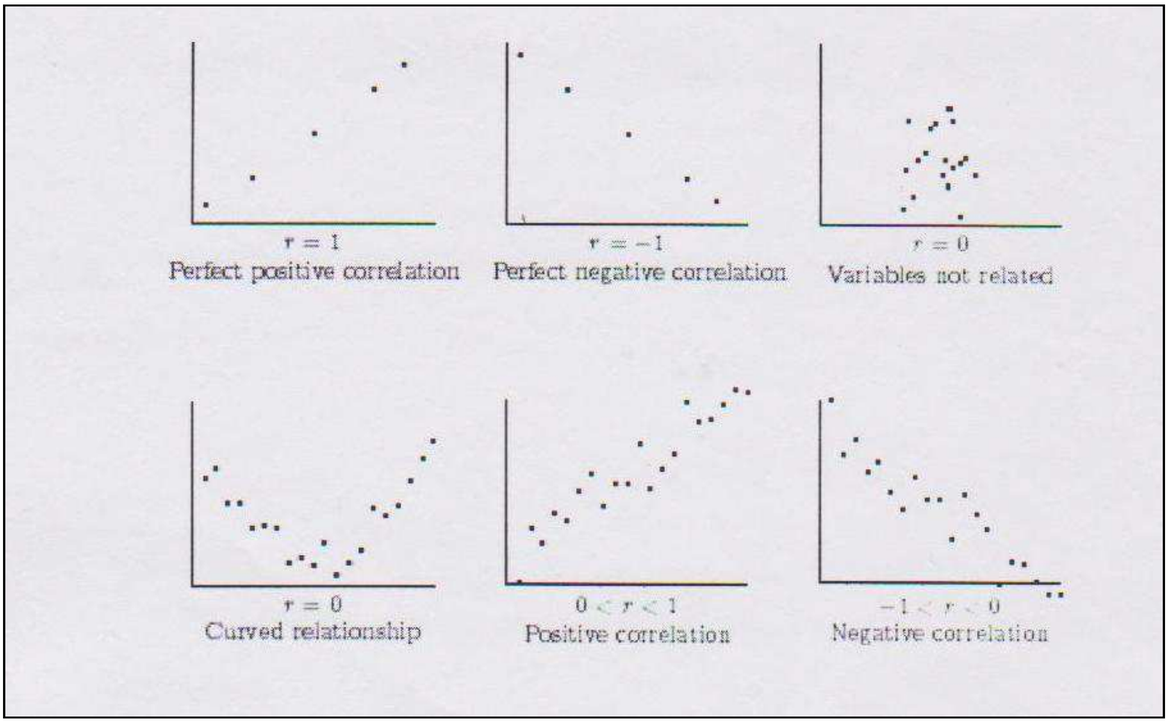

Figure 2.6: Scatter plots
(*Source: Cohen et al., 2003*)

From the scatter plots shown in Figure 2.6, the sign of the correlation coefficient tells us of the trend in the relationship. A positive (negative) coefficient means that one variable increase (decreases), when the other increases. Perfect positive correlation and perfect negative correlations indicate strong relationships in the data set while if $r = 0$ means no relationships and hence weak relationships. When graphed this way, it is difficult to establish any visual linear relationship between the two variables. In fact, this set of data points has a slightly negative correlation (Chimedza, 2003). Therefore, constructing a scatter plot, guides in decision or choice of the equation to use.

According to Chimedza (2003) the following questions are to be answered with the help of scatterplot:

a) Does a relationship exists that can be described by a straight line (which means is there a linear relationship)?

b) Is there a relationship, which is not linear?

c) If the scatterplot of the variables look like a cloud there is no relationship between both variables and one would stop at this point.

3.7.4 Multiple Regression Analysis

Multiple regression analysis is one of the multivariate techniques. It is used in quantitative data analysis where the effects several independent factors or variables on one depended variable are investigated (Cohen *et al.,* 2003). In other words it investigates correlations between the predictor variables and the criterion variable. Furthermore, it tests hypotheses of a research and another goal of multiple regression is to model a forecast model which can be employed in predicting future values (Cohen *et al.,* 2003). In fact, it is used in correlational studies.

According to Cohen *et al.* (2003), the prediction equation (multiple regression model) was stated as (equation 2.1):

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki} + \varepsilon_i \qquad (2.1)$$

Where

β_0 = Y-intercept

β_1 = change in *Y* corresponding to a change of 1 unit in the variable X_1 when variables X_2, X_3, …,X_k are held constant.

β_2= change in *Y* corresponding to a change of 1 unit in the variable X_2 when variables X_1, X_3, X_4,…, X_k are held constant β_k = change in *Y* corresponding to a change of 1 unit in the variable X_k when variables X_1, X_2,…, X_{k-1}.

β_i = random error in *Y* for observation *i*

The ever-widening applications of multiple regression fall into two broad class of research problems: predictions and explanations. These research problems are met mutually exclusive, and an application of multiple regression analysis can either address either or both types of research problems (Hair *et al.,* 2010). However, one fundamental purpose of multiple regressions is the prediction of dependent variable with a set of independent variables. It provides an objective means of assessing the predictive power of a set of independent variable. In selecting suitable applications of multiple regressions, the researcher must consider three primary issues:

1. The appropriateness of the research problem

2. Specification of a Statistical Relationship,

3. Selection of the dependent and independent variables (Meyers *et al.*, 2010).

3.7.5 Multiple Regression Objectives

Only structural equation modelling (SEM) can directly accommodate measurement error, but using summated scales can mitigate it when using multiple regressions.

When in doubt there is need to include potentially irrelevant variables (as they can only confuse interpretation) rather than possibly omitting a relevant variable (which can bias all regression estimates).

3.7.6 Assessing Statistical Assumptions

According to Gregory and Mundfrom (2008), testing for assumptions must be done not only for each dependent and independent variable, but for the variants as well. Graphical analyses (i.e., partial regression plots, residual plots and normal probability plots) are the most widely used methods of assessing assumptions for the variants. Remedies for problems found in the variants must be accomplished by modifying one or more independent variables.

3.7.7 Sample Size and Generalisability

When using multiple regression purposes, the issue of minimum required sample size often needs to be addressed. As the popularity of multiple linear regressions has increased, the question of how large a sample is required to produce reliable results has become increasingly more important to address (Gregory and Mundfrom, 2008). This notion was also supported by Hair *et al.* (2010), when they hinted that sample size was good for statistically significant relationships (statistical power) and generalisation of results. In particular, as with any statistical analysis that is computed using sample data, the size of the sample (n) in large part determines the "value" of the statistical results of a multiple regression analysis.

However, small samples less than 30 observations are suitable for analysis by simple regression (Hair *et al.*, 2010). For generalisability, the minimum criteria of the sample size is 5 : 1, that is, five observations to one independent variable and the desired one is between 15 and 20 observations to each independent variable (Hair, *et al.*, 2010). Below a threshold of 5:1, the model will be on be appropriate to the sample and not to the whole population (Hair *et al.*, 2010).

The selection of adequate and appropriate sample sizes is not always an easy matter in regression. Sample sizes for multiple regressions, particularly when used to develop prediction models, must be chosen so as to provide adequate power for statistical significance and also for generalisability, of the model (Hair *et al.*, 2010; Meyers *et al.*, 2010).

From a statistical power perspective, multiple linear regressions provide several alternative statistical significance tests that can be the basis for sample size selection. Two statistical tests are most common in practice:

(a) the test of the full model (i.e. the overall or omnibus test), and

(b) the test of the individual regression coefficients in the model. The primary goal of precision efficacy analysis for regression is the provide a means by which the research can assess the predictive power potential (i.e. generalisability) of a regression model relative to its performance in the derivation sample (Gregory and Mundfrom, 2008).

Therefore, the safest way to determine that a model will generalize to future subjects is to test it with new data. Indeed, replication is basic to all science and is essentially to confidence in both the stability and generalisability of results. Additionally, Hair *et al.* (2008) have reminded us of the importance not only of model validation, but also of model adequacy, which requires residual analyses for violations of assumptions, searching for high leverage or overly influential observations, and other analyses that test the fit of the regression model to them available data. Darlington, noted, however, that robustness to certain violations of assumptions continues to increase as sample size increases.

3.7.8 Multiple Regression correlation and Analysis of Variance (ANOVA)

Using multiple regressions one can test theories (or models) about precisely which set of variables is influencing other variables. Analysis of variance (ANOVA) and multiple regressions seek to account for the variance in the variables observed or identified (Hair *et al.*, 2010). The main function of ANOVA is compare means of different groups whereas multiple regression measures the strength of relationships between the predictor and criterion variables (Hair *et al.,* 2010). In other words ANOVA tries to determine how much of the variance is accounted for by the manipulation of the independent variables (relative to the percentage of the variance not accounted for).

In multiple regressions there is no direct manipulation of independent variables, but instead measure the naturally occurring levels of the variables and see if this helps predict the score on the independent variable. Thus, according to Meyers (2010), ANOVA is actually a rather specific and restricted example of the general approach adopted in multiple regression.

To put this in another way, in ANOVA there is direct manipulation of the factors and measurement of the resulting change in the dependent variable. In multiple regressions there is simply measurement of the naturally occurring scores on a number of predictor variables and to try to establish which set of the observed variables gives rise to the best prediction of the criterion variable (Gregory and Mundfrom, 2008). A current trend in statistics is to emphasize the similarity between multiple regression and ANOVA, and between correlation and the t-test. All these statistical techniques are basically seeking to do the same thing – explain the variance in the level of one variable on the basis of the level of one or more other variables. This underlying single approach is called the General Linear Model.

3.7.9 Testing Significance of the model and ANOVA

Testing significance of the model is done by testing the hypothesis that the model is a true representative of the population (Hair *et al.,* 2010). Hair *et al.* (2010), further pointed out two forms of statistical tests that test variation explained (coefficient of determination) and also testing each regression coefficients. The significance of the model is tested by F-test which is obtained by partitioning of variance in multiple regression (Myers *et al.,* 2010). The F ratio is given by:

$$F\ ratio = \frac{\frac{SS_{regression}}{df_{regression}}}{\left(\frac{SS_{residual}}{df_{residual}}\right)}$$

Where

$df_{regression}$=Number of estimated coefficients (including the intercept) – 1

$df_{residuals}$= Sample size –Number of estimated coefficients (including the intercept) (Hair, *et al.,* 2010). It is convenient to show the F ratio in an ANOVA (ANALYSIS OF VARIANCE) table. The general ANOVA is shown in Table 2.3

Table 3.1: General ANOVA table for multiple regressions

Source of variation	df	SS	MS	F
Regression	p	$\sum (\hat{Y}_i - \bar{Y})^2$	$\frac{SS_{regression}}{p}$	$\frac{MS_{reg}}{MS_{res}}$
Residual	$n-1-p$	$\sum (Y_i - \hat{Y}_i)^2$	$\frac{SS_{res}}{n-1-p}$	
Total	$n-1$	$SS_Y = \sum (Y_i - \bar{Y})^2$		

Adapted from Myers et al. (2010)

The hypothesis for testing each regression coefficient is (equation 2.2):

$$H_0 : \beta_1 = \beta_2 = \cdots = \beta_p = 0 \quad (2.2)$$

Where $p \in \{1, 2, 3, \dots\}$

H_0: constant term and other regression coefficients are not significant different from zero.

An appropriate test to be employed is the t test where the t value is divided by the standard error (Hair *et al.*, 2010; Myers *et al.*, 2010). Now to test the hypothesis, the computed t value of the coefficient, is compared with the table value and it is significant provided this computed t value is less than the table value of significance (Hair *et al.*, 2010).

3.8 WHEN TO USE MULTIPLE REGRESSION

According to Gregory and Mundfrom (2008), multiple regressions can be used when:

1. Exploring linear relationships between predictor and criterion variables – that is, when the relationship follows a straight line.

2. The criterion variable that a researcher is seeking to predict should be measured on continuous scale (such as interval or ratio scale). There is a separate regression method called logistics regression that can be used for dichotomous dependent variables.

3. The predictor variables that a researcher selects should be measured on a ratio interval, or ordinal scale. A nominal predictor variable is legitimate but only if it is dichotomous, that is there are no more than two categories.

4 Multiple regressions require a large number of observations. The number of cases (participants) must substantially exceed the number of predictor variables one is using in regression. A more acceptable ratio is 10:1, but some people argue that is should be as high as 40:1 for some statistical selection methods.

3.9 INTERPRETING THE REGRESSION VARIANTS

Some aspects which should be taken into consideration when interpreting the regression variants are as follows:

(i) **Using the Beta (Standardized Regression Coefficients).** The regression coefficients are also called the Beta (β) coefficients and show both the type of correlation and strength (Gregory and Mundform, 2008).

The beta value is a measure of how strongly each predictor variable influences the criterion variable. The beta is measured in units of standard deviations. For example, a beta value of 2, 5 indicate that a change of one standard deviation in the predictor variable will result in a change of 2, 5 standard deviations in the criterion variable. Thus, the higher the beta value the greater the impact of the predictor variable on the criterion variable (Gregory and Mundfrom, 2008). Regression coefficients are used in prediction and for explanation purposes. A good regression model should be able to forecast using observations which are not in the data set. If the coefficients are used for explanatory purposes, all the independent variables need to be on comparable scales.

However, a good comparison during inference of regression coefficients, they are standardised to a common scale. Standardization gives new co-efficient knows as beta coefficients and computation of different units is solved by these standardized coefficients. Beta coefficients are used to find an independent variable with the most impact, by comparing their magnitude (Gregory and Munfrom, 2008).

(ii) **R Square and Adjusted R Square.** R is a measure of the correlation between the observed value and the predicted value of the criterion variable. R Square (R^2) is the square of this measure of correlation and indicates the proportion of the variance in the criteria variable which is accounted by the model. In essence, this is a measure of how good a prediction of the criterion variable one can make by knowing the predictor variables (Hair *et al.*, 2008). However, R square tends to somewhat over-estimate the success of the model when applied to the real world, so an Adjusted R Square is calculated which takes into account the number of variables in the model and the number of observations the model is based on

(Gregory and Mundfrom, 2008). This Adjusted R Square value gives the most useful measure of the success of the regression model. If, for example the researcher has an Adjusted R Square of 0,75; it simply means that the regression model has accounted to 75% of the variance in the criterion variable.

3.10 ASSESSING MULTICOLLINEARITY

The task here is to:

1. Assess the degree of multicollinearity,
2. Determine its impact on the results, and
3. Apply the necessary remedies if needed.

When choosing a predictor variable there is need to select one that might be correlated with the criterion variable, but that is not strongly correlated with the other predictor variables (Hair *et al.*, 2008; Myers *et al.,* 2010). The term multicollinearity (or co linearity) according to Gregory and Mundfrom (2008) is used to describe the situation when a high correlation is detected between two or more predictor variables. It therefore means multicollinearity is the undesirable situation where the correlations among the independent variables are strong. Such high correlations cause problems when trying to draw inferences about the relative contribution of each predictor variable to the success of the model. In other words, it results when one has factors that are a bit reluctant. To measure multicollinearlity, two methods are used called multicollinearity diagnostics, which are:

1. **Variance Inflation Factor (VIF)**: This measures how much the variance of the regression coefficients is inflated by multicollinearity problems (Myers *et al.,* 2010). If VIF equals to 0, there is no correlation between the independent measures. A VIF measure of 1 is an indication of some association between predictor variables, but generally not enough to cause problems. A maximum acceptable VIF value would be 10; anything higher would indicate a problem with multicollinearity.

2. **Tolerance**: The amount of variance in an independent variable that is not explained by other independent variables (Hair *et al.*, 2010). If the other variables explained a lot of the variance of a particular independent variable there is a problem with multicollinearily. Thus, small values for tolerance indicate problems of multicollinearily. The minimum cut off value for tolerance is typically .10. That is, the tolerance value must be smaller than .10 to indicate a problem of multicollinearity. (Myers *et al.*, 2010).

In assessing multicollinearity in a regression model the following points are needed to be taken into consideration (Gregory and Mundfrom, 2008);

(a) A regression coefficient is not significant even though, theoretically, that variable should be highly correlated with y, (b) when adding or deleting $\boldsymbol{X}$ variable, this regression coefficient change dramatically. (c) a negative regression coefficient is seen when the response is increasing along with $\boldsymbol{X}$. (d) a positive regression coefficient is seen when the response is decreasing as $\boldsymbol{X}$ is increasing (e) $\boldsymbol{X}$ variables have pair wise correlations.

3.10.1 How to deal with multicollinearity

If multicollinearity is a problem in the researcher's model- that is if the VIF for a factor is near or above 5 the solution may be relative simple. The researcher can try one of the following as given by Hair *et al.* (2008) and Myers *et al.* (2010):

1. Remove highly correlated predictions from this model. If there are two or more factors with a high VIF, one factor should be removed from the model. This is done because they supply redundant information, removing one of the correlated factors usually does not drastically reduce the R-squared. However, the researcher should consider using stepwise regression, best subsets regression, or specialized knowledge of the data set to remove these variables. Select the model that has the highest R-squared value.

2. Use Partial Least Squares Regression (PLSR) or Principal Components Analysis, regression methods that cut the number of predictors to a small set of uncorrelated components.

3.11 SUMMARY

This chapter has examined the models used in this study. The chapter has shown the use of the Change Detection Modelling Approach (CDMA) using Remote Sensing and GIS combined with Multiple Regression analysis and Correlation analysis in mapping the spatial distribution of aquatic plants in lakes. Climatic data from 2002, 2004, 2006, 2008, 2010 and 2012 was used to estimate the spatial extent of the water hyacinth in the lakes and its impacts on water quantity and usability. The data was subsequently compiled and analysed using multiple regression analysis and correlation analysis statistical techniques. The next chapter will explore and interpret the results.

CHAPTER: 4

4. RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter presents results from the use of hydrological based models discussed in the preceding chapter (Chapter 3). Apart from presenting the results from CDMA, the results from the modelling of meteorological factors (temperature, rainfall, solar radiation and evapotranspiration) are also presented. The research methodology used was quantitative research design. As stated earlier in Chapter 1 the aim was to determine how water hyacinth have impacted on water availability and usability in the Benoni lakes of Gauteng Province, South Africa. The results were then used to discuss the lake water level changes and to show how climate change is impacting on water availability and in turn affect these aquatic weeds.

4.2 WATER HYACINTH CHANGE DETECTION, IMPACT ANALYSIS AND MONITORING

The satellite imageries represented by Figures 4.1, 4.2, 4.3 and 4.4 capture the extent of the water hyacinth coverage in the study lakes. Comparing the imageries Figures 4.1 and 4.2, taken during similar seasons and months but different years, by 2008 Kleinfontein was starting to be invaded by water hyacinth while Civic Lake was almost completely covered by water hyacinth by 2010.In this year it is clear that eutrophication had become an increasing threat to the usability of Benoni lakes. The imageries show that by 2010 the lakes were almost completely covered by the weeds as shown by Figures 4.2 and 4.3.However in 2012, the images for Civic Lake shows it is clear of water hyacinth, this is because the EMM had managed to control the weeds but as is always expected there is evidence of resurfacing as shown in Figure 4.4. at the lake sides. This is also validated by the statistical analysis shown in Table 4.1.

Figure 4.2: Area covered by water hyacinth in the Civic Lake
(*Satellite imagery of March 2010***)**

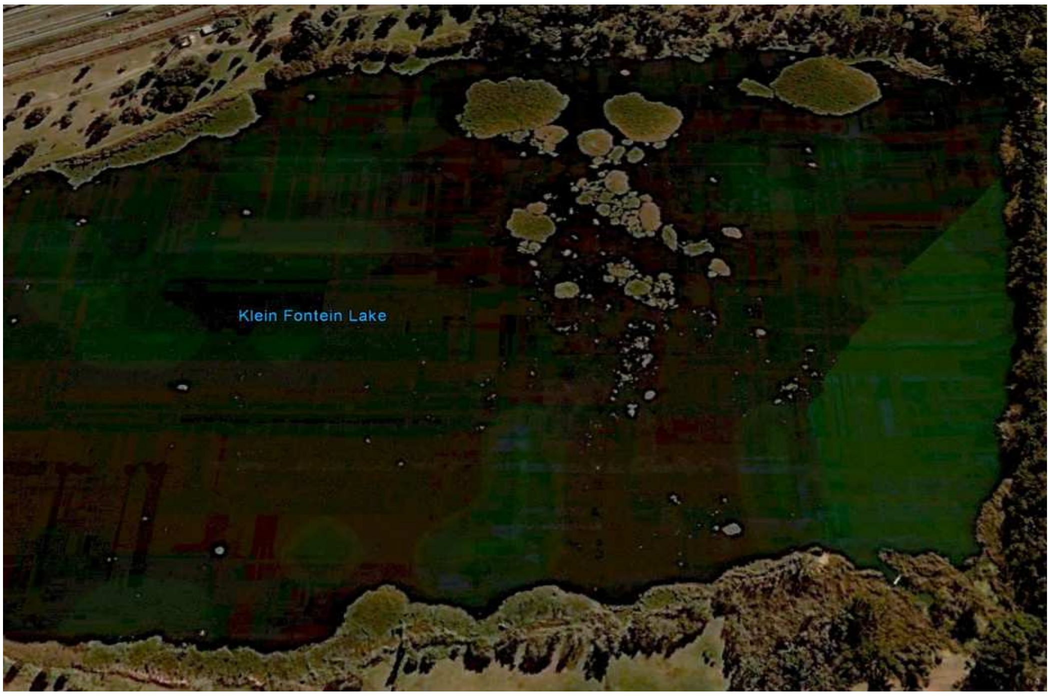

Figure 4.1: Area covered by water hyacinth in the Kleinfontein Lake
(*Satellite imagery of March 2008*)

Figure 4.3: Area covered by water hyacinth in the Civic Lake
(Satellite imagery of December 2010)

Figure 4.4: Area covered by water hyacinth in the Civic Lake
(Satellite imagery of December2012)

4.3 WATER LAKE LEVEL ANALYSIS

Table 4.1 shows the descriptive statistics of the surface area variability covered by water hyacinth in the three lakes Civic, Kleinfontein and Middle lakes.

Table 4.1: Descriptive statistics of area not covered by water hyacinth

		Civic Lake	*Kleinfontein Lake*	*Middle Lake*
N	Valid	6	6	6
	Missing	0	0	0
Mean		0.085	0.3233	0.1917
Std. Deviation		0.03332	0.08641	0.01722
Variance		0.001	0.007	0
Skewness		-2.02	-2.271	-1.435
Std. Error of Skewness		0.845	0.845	0.845
Kurtosis		4.2	5.269	2.723
Std. Error of Kurtosis		1.741	1.741	1.741
Minimum		0.02	0.15	0.16
Maximum		0.11	0.37	0.21

The results in Table 4.1 shows that Kleinfontein Lake had the highest mean area of 0,3233km^2 covered by water hyacinth from 2002 up to 2012, followed by Middle Lake with 0,917km^2 and then lastly Civic Lake 0,850km^2.

Table 4.2 shows a very high positive correlation of 0.986km^2 between Civic Lake and Kleinfontein Lake and a weak negative correlation of -0,018km^2 between Kleinfontein and Middle Lakes. The high positive correlation suggest that Kleinfontein Lake as the biggest lake downstream followed by Civic Lake and then Middle Lake has a chance of receiving most pollutants from the lakes upstream and even the flow of water hyacinth during the rainy seasons and therefore had large area covered by water hyacinth.

Table 4.2: Correlations of lake area among the three lakes

	Civic Lake	*Kleinfontein Lake*	*Middle Lake*
Civic Lake	1	0.986	0.052
Kleinfontein Lake	0.986	1	-0.018
Middle Lake	0.052	-0.018	1

Figure 4.5 shows the variability of the area covered by the water hyacinth as from 2002 to 2012.The results of the study showed a sharp decline in the surface area of the study lakes as indicated by the reduction from 2002 to 2012. For Kleinfontein it declined from 0,37km^2 to 0,15km^2 in 2010. Civic Lake declined from 0,10km^2 in 2002 to 0,02km^2 and Middle Lake from 0,19km^2 to 0,16km^2. The significant reduction in the surface area of the lakes is as a result of the weeds infestations and an indication of high pollution levels contained in the

lakes. This is confirmed by Phaleng (2009) who conducted a study of the anthropogenic impacts on the integrity of the Blesbokspruit Catchment area.

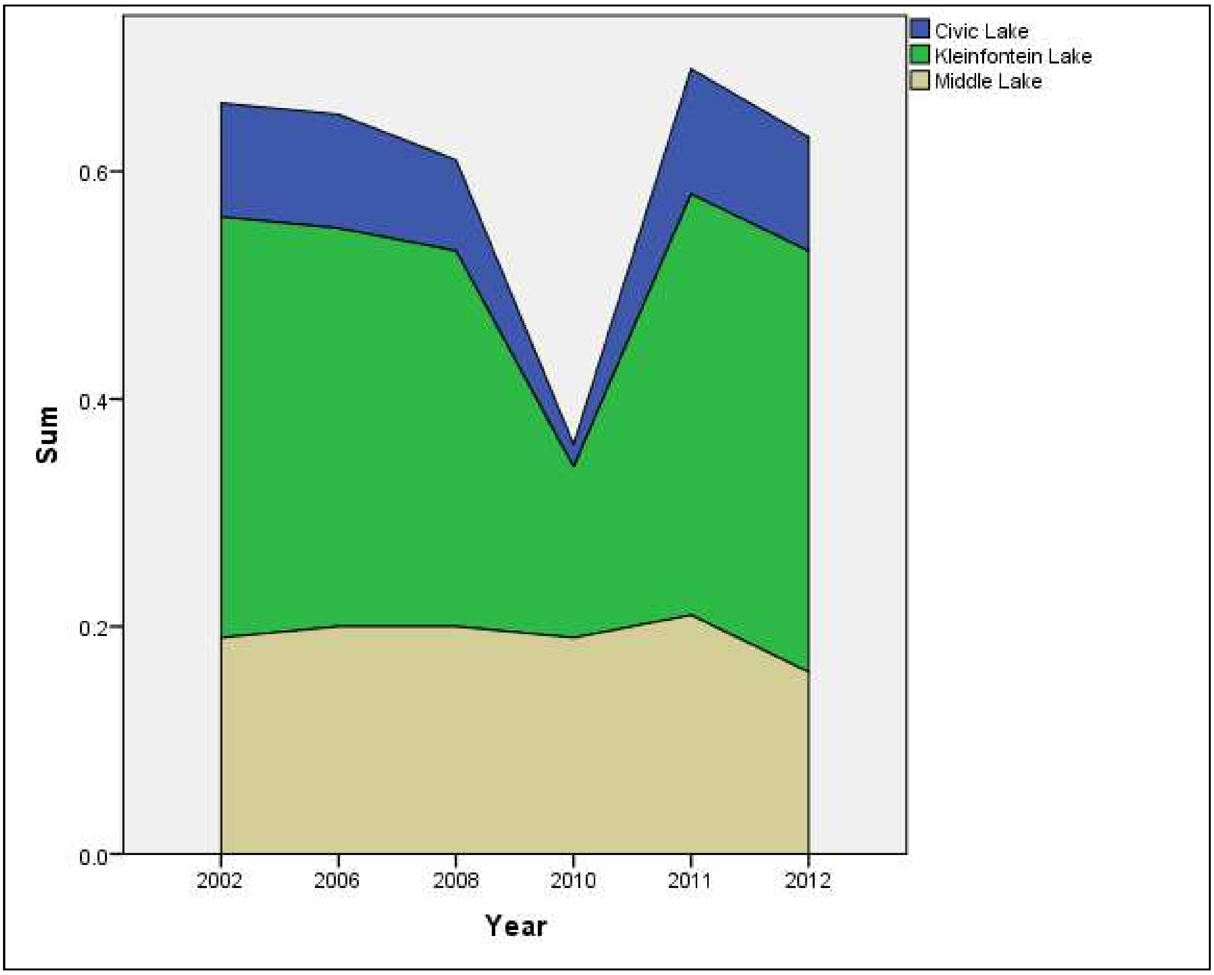

Figure 4.5: Area of lakes covered by water hyacinth from 2002 to 2012

The results of the analysis also show the poor ecological status of the Blesboksspruit River which has compromised the water quality of the lakes downstream. Using Remote Sensing and GIS environment, coupled with field observation helped to detect the surface area changes in the lake levels. The results show that the water hyacinth started to invade the area in 2002 but colonised the lakes as from 2006. In 2008 weed infestations in all three lakes intensified and by 2010 when the lakes were completely under a blanket of the water hyacinth. These findings point out that in 2010 all lakes were in a hypertrophic state. However, this is a symptom of poor water quality. Figure 4.6 shows that although all three lakes had weed infestations problems the greatest impact was on Kleinfontein Lake. This is probably because Kleinfontein Lake is the last recipient of all the pollutants from the main river downstream. In addition it also receives floating water hyacinth and seeds from upstream during periods of heavy flooding.

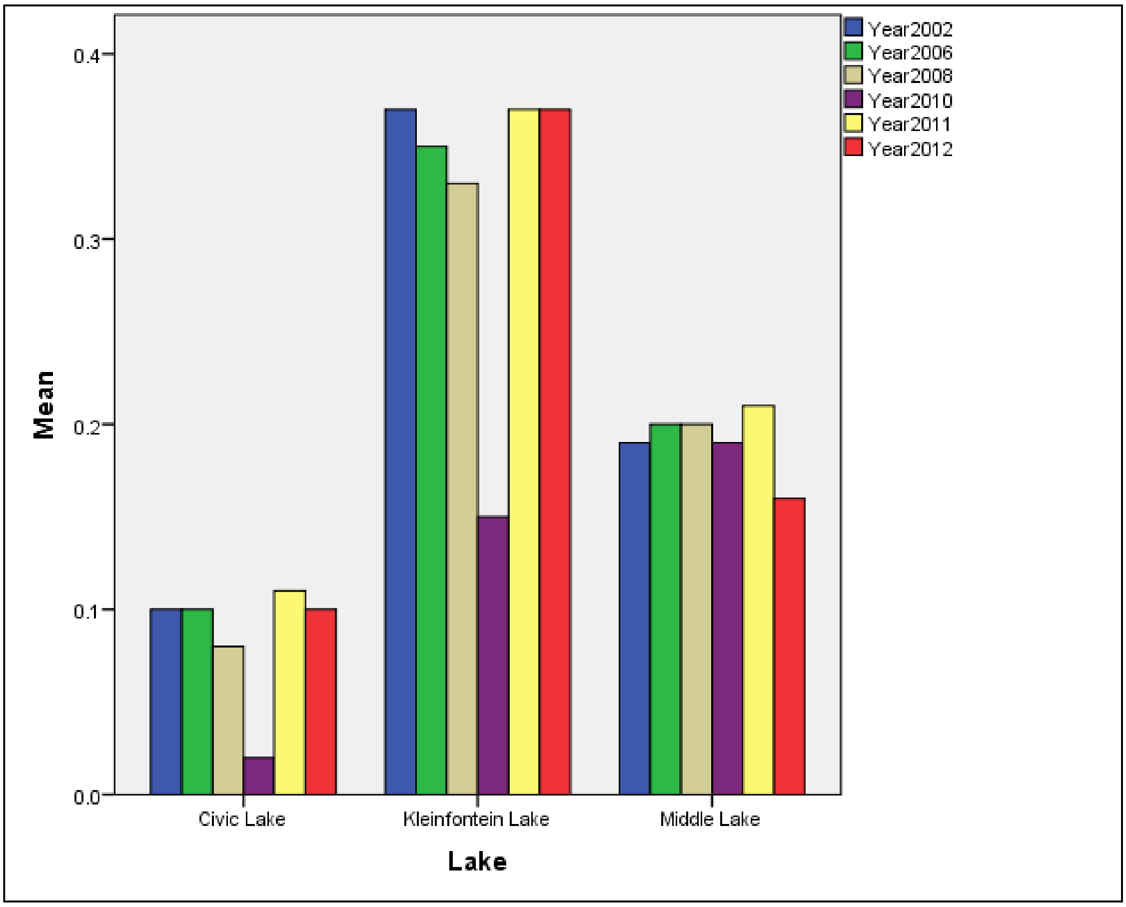

Figure 4.6: Comparison of mean yearly surface water area per lake

In light of the above results, to prolong the life-span of the study lakes, there is need to carry out a site specific integration of the different control techniques. This will further help to ascertain the current volume of water contained in the lakes. Therefore, there is urgent need to monitor the dynamics of the lake water surfaces and water levels with a view to ensure continuous supply of water in adequate quantity and quality to the communities they are designed for. Furthermore the information on the dynamics of these lakes is very important for the sustenance and management of lake/water schemes projects in Gauteng Province. In addition, this confirms studies of water surface changes in lakes and lake level fluctuations which were also observed by many researchers (Adejiji and Ajibande, 2008; Trinidad *et al.*, 2008; Gordon, 2013).

The results of the analysis confirm that the Benoni lakes face serious challenges as reliable sources of water for domestics, agricultural, industrial and recreational uses. This agrees with studies of invasive alien plants on water quality, with particular emphasis to South Africa by Gorgens and van Wilgen, (2004), Richardson and van Wilgen, 2004). These studies point out that water quantity and quality in South Africa is rapidly deteriorating and all factors that influence this deterioration need to be taken into account when formulating actions to address the IAS problem. The changes in water quantity and usability brought about by water hyacinth invasions can exacerbate the already serious water scarcity problem in South Africa.

The impact of the water hyacinth and mainly its contribution to the poor water quality of the study lakes is shown in Figure 4.7. Furthermore, Figure 4.7 shows that by 2010 Kleinfontein Lake was totally covered by the water hyacinth. This is a clear indication of the hypertrophic state of the Lake meaning that there are excessive nutrients such as phosphorus and nitrogen trapped in the Lake. The excessive high nutrient levels in the lake can be ascribed to a combination of factors mainly caused by waste that originate from sewage effluent, fertilisers, washing powders and poorly maintained sanitation system that flow in the lakes on a daily basis and at an increased rate during rainy events.

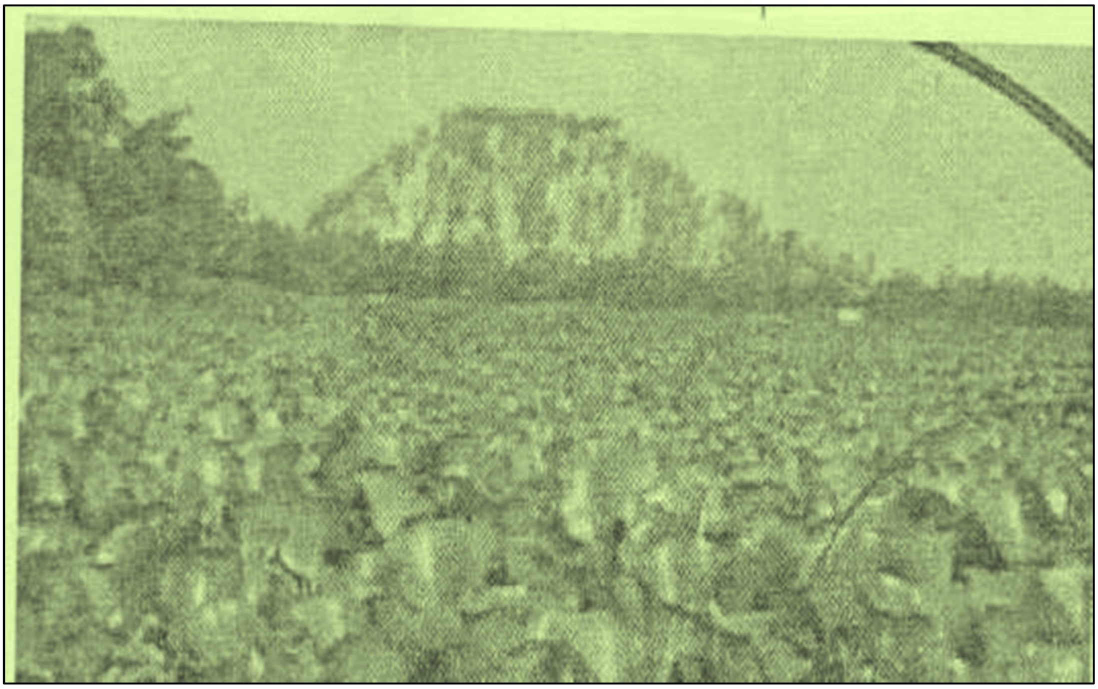

Figure 4.7: Kleinfontien Lake totally covered by water hyacinth in 2010
(Source: Meela, 2010)

4.4 FOCUS GROUP RESULTS

The above results are also confirmed by findings from the focus meetings held with the EMM and The Environmental Management Wetland Team. The focus group meetings indicated the main challenges facing EMM in controlling water hyacinth contained in the lakes. The Blesbokspruit River which contains the study lakes originates from the north of Benoni and Daveyton and flow southwards through Springs and Nigel towards the Vaal. The eastern part of the catchment contains extensive natural wetlands, while the western part is highly modified by agriculture and human settlements. The key industries such as mines (mine dumps and slimes dams), waste disposal sites, intensive agriculture and sewage works impacts negatively on water quality in these lakes. In addition the informal settlements upstream are found in close proximity to the hydrological systems. One such informal settlement is Wattville in Benoni. This has led to an increase and proliferation of the water hyacinth in the lakes due excessive runoff from these areas.

The decrease in the surface area from 2011 shown in Figure 4.6 showed that the water hyacinth had been under control. This is mainly as a result of the use of the Watermaster Classic 111 machine in 2011 to remove the weeds (Meela, 2011). However, it is pertinent to note that although the Dregner Watermaster machine procured to remove all the water hyacinth in the lakes has been quite effective, the battle of weed infestations is far from over. From the focus group meetings it was indicated that the Watermaster as a mechanical method of controlling the aquatic weeds, it only removes the surface weed plants but the seeds can settle down at the bottom of the lake and they can always re-infest again. The focus group meetings were so helpful in providing information on the complexity of the water hyacinth problem and the logistical control and management problems of this aquatic weed in the study lakes.

4.5 WATER HYACINTH SPATIAL AND TEMPORAL VARIATIONS

As can be appreciated from Figures 4.8; 4.9 and 4.10 and also observed during the field survey, the edges of the study lake surfaces are frequently colonised by the water hyacinth.

Figure 4.8: Middle Lake partly covered by water hyacinth
Photograph taken in December 2013.

Figure 4.9: Frequent colonisation of water hyacinth on lake edges in Middle Lake
(*Photograph taken in November 2012*)

Figure 4.10: Bank of the Middle Lake infested by water hyacinth
(*Photograph taken in November 2013*)

As seen in the photographs shown by Figures 4.8, 4.9 and 4.10, the problems associated with the water hyacinth are its rapid growth rate, its ability to successfully compete with other aquatic plants and its ease of propagation. According to Trinidad *et al.* (2008), these characteristics give rise to enormous amounts of biomass that cover the water surface of a great variety of habitats often interfering with the use and management of water resources.

The colonisation by invasive alien plants along the banks of the lakes is enhanced by deposited sediments from the inter-fluvial area around the lakes. In addition during the field survey, foot-paths used by fishermen and the local community, and also those created in the golf course were noticed around the lakes particularly Middle Lake as shown in Figures 4.11 and 4.12. The golf course shown on Figures 4.11 and 4.12 is the major recreational activities to the east bank of Middle Lake.

Figure 4.11: Recreation around the study lakes, Benoni Golf Course
(Photograph taken in November 2012)

The results of this study confirm the findings of Naledzi (2007) who carried out a wetland inventory report on identification, classification, assessment and delineation in the Ekurhuleni Metropolitan Municipality. This Wetland Inventory report showed that the wetlands in the area have been affected by a number of stresses some of which are storm water and drainage channels, sewage spills and leakage, mining and industrial activities, improper waste disposal and gully erosion. Moreover, urban development particularly the construction of the Lakeside Mall in Benoni and the current ongoing development of Gauteng N12 Freeway Development Project are equally contributing to the current deterioration of the lakes. In many instances the outlets of the lakes are poorly maintained creating opportunities for dam bursting.

Figure 4.12: Recreation along Rynfield Lake
(*Photograph taken in December 2013*)

Figure 4.13: Recreation around the study lakes, Benoni Golf Course
(*Photograph taken in November 2012*)

4.6 ANALYSIS OF WATER AVAILABILITY AND USABILITY OF LAKES

Before the lakes were occupied by the water hyacinth in 2006, they were mainly used for recreation, such as boating, fishing, yachting and angling, especially the Kleinfontein and Middle lakes (Sydow, 2010). They provided an ideal environment for recreational activities since they had, by then, good water quality. What made the lakes important for recreation was their proximity to Benoni Town. However, after the infestation by invasive alien plants most recreational activities are now concentrated on Rynfield Lake situated north east of the study lakes as shown by Figures 4.13 and 4.14.

Figure 4.14: Surfing in Rynfield Lake
(Photograph taken in December 2013)

The reasons for the shift in recreational activities are ascribed to the free aquatic plant environment offered by the Rynfield Lake as compared to the study lakes. Therefore, the invasion of the lakes by the water hyacinth impacted negatively on the usability of the study lakes. Even though the EMM has managed to contain the weed, the frequent re-infestation and colonisation particularly during the summer season poses a serious challenge. According to Kokkinen and Marianne (2010) the water hyacinth and microcystis blooms are accelerated during the summer months when solar radiation and water temperatures are high.

The high nutrient loading, high incident of solar radiation, low wind speed or warm water during the summer make the study lakes an ideal environment for the massive green algae growth. These results from this study agree with the findings of Kokkinen and Morianne (2010) in their study of the Hartbeespoort Dam. The successful invasion of the water hyacinth in the study lakes is mainly due to the phenotypic plasticity responding to new habitat, competitive ability increased by rapid colonial growth and strong tolerance to environmental stress rather than the genetic diversity. Field survey observations in the study lakes have confirmed that the algal blooms and hyacinths spoil the beautiful appearance of the lakes as can be appreciated from Figure 4.15. The rotten water hyacinth cause unpleasant odours even when they are drifted and accumulated on the lake shores. This means the quality and even quantity of water is affected, as well as the cost to purify the water for household use. The projection of the distribution of the frequency of water hyacinth for the period 2002 to 2012 showed a significant change from the distribution of the past. The use of Remote Sensing and GIS to benchmark and model habitat and distribution of invasive species are effective tools in the battle against invasive species.

Figure 4.15: Algal blooms and water hyacinth in the Middle Lake
(*Photograph taken in January 2014*)

4.7 MULTIPLE REGRESSION ANALYSIS OF HYDROLOGICAL VARIABLES, MODELLING AND CLIMATIC VARIABILITY

The impact of hydrological variables (temperature, rainfall, solar radiation and evapotranspiration) on water hyacinth was assessed by the use of multiple regression model which is one of the general linear models (GLM). Time series was also considered. The data spanned from September 2002 up to December 2012 and readings were monthly averages. Trend analysis was used to uncover the impact of hydrological factors on water hyacinth. The data was obtained from Agricultural Research Council (ARC) of South Africa for Station number 30459.This station was used as it is the closest station to the study lakes.

4.7.1 Overview of hydrological variables

In accordance with the rules of sample size selection, a sample size of 140 observations was employed during the research (Hair *et al.,* 2010). It was above a threshold of 5:1, that is, five observations to one independent variable. Hence, it was a relatively large sample which was able to predict multiple regression estimates. Descriptive statistics which were used in the analysis of the hydrological variables are shown on Table 4.3 below.

Table 4.3: Descriptive statistics of hydrological variables

		Temperature	*Rainfall*	*Solar Radiation*	*Evapotranspiration*
N	Valid	140	140	140	140
	Missing	0	0	0	0
Mean		16.268	50.6842	16.7468	97.8274
Std. Error of Mean		0.3312	5.02353	0.32756	2.35867
Median		17.7	31.95	16.825	98.315
Std. Deviations		3.91886	59.43924	3.87577	27.90814
Variance		15.358	3533.023	15.022	778.864
Skewness		-0.526	1.283	-0.512	-0.269
Std. Error of Skewness		0.205	0.205	0.205	0.205
Kurtosis		-1.082	0.933	1.603	-0.051
Std. Error of Kurtosis		0.407	0.407	0.407	0.407
Minimum		8.05	0	0	0
Maximum		21.46	238.3	24.55	161.68

The mean of evapotranspiration (ET) was 97.827 and there was greater variability which was exhibited by the standard deviation of 27.908. With the exception of rainfall, other variables showed less variability. The mean of rainfall was greater than the median indicating the presence of outliers (outliers are observations with extreme values) but other variables showed the opposite which showed that outliers were absent.

4.7.2 Correlation analysis of hydrological variables

Table 4.4 showed association of independent variables with ET, solar radiation and temperature exhibiting high positive correlations of 0.940 and 0.714 respectively. Rainfall showed a weak positive correlation of 0.374 with ET. This implied that as solar radiation, temperature and rainfall increases this led to an increase in evapotranspiration. On the other hand, the correlation among the independent variables was also shown by the correlation matrix shown in Table 4.4. Correlation among these variables had an adverse effect on water hyacinth in the study lakes.

Table 4.4: Correlation matrix

	Evapotranspiration	*Temperature*	*Rainfall*	*Solar Radiation*
Evapotranspiration	1.000	0.714	0.374	0.940
Temperature	0.714	1.000	0.595	0.678
Rainfall	0.374	0.595	1.000	0.406
Solar Radiation	0.940	0.678	0.406	1.000

4.7.3 Forecasting hydrological model: Multiple regression analysis

Multiple regression analysis was used to analyse the effect of rainfall, temperature and solar radiation on evapotranspiration. Regression coefficients were used to assess the importance of independent variables (temperature, rainfall and solar radiation) in the forecasting model. The regression criterion of evapotranspiration was modelled applying the following Equation 4.1:

$$ET = -24.009 + 1.356T - 0.038R + 6.074S \quad (4.1)$$

Where ET is evapotranspiration, T is temperature, R is rainfall and S is solar radiation as in Table 4.5. Equation 4.1 depicts that solar radiation was most important since it has the greatest coefficient. Also using the same argument, the analysis shows that rainfall had little impact on evapotranspiration as shown by Table 4.5.

Table 4.5: Hydrological Coefficients

Model	*Unstandardized Coefficients*		*Standardized Coefficients*	*T*	*Sig.*
	B	Std. Error	Beta		
(Constant)	-24.009	3.936		-6.099	0
Temperature	1.356	0.302	0.19	4.494	0
Rainfall	-0.038	0.016	-0.081	-2.391	0.018
Solar Radiation	6.074	0.268	0.844	22.635	0

(*Dependent Variable: Evapotranspiration level of significance is 0.05*)

It is also evident that the set of independent variables showed a high positive association (0.948) and from Table 4.6, the regression model indicated that 89.6 % of the variation in ET was shared by the set of independent variables.

Table 4.6: Pearson correlation

					Change Statistics				
Model	*R*	*R Square*	*Adjusted R Square*	*Std. Error of the Estimate*	*R Square Change*	*F Change*	*df1*	*df2*	*Sig. F Change*
1	.948[a]	0.898	0.896	9.01463	0.898	398.745	3	136	0

[a]*Predictors: (Constant), Solar Radiation, Rainfall, Temperature*

The results show the goodness-of fit of the model since the model account 89.6% of the variance in Evapotranspiration. This was supported by an ANOVA as shown in Table 4.7

which shows significance of the model at 5 percent level of significance (ρ-value < 0.05 where the ρ-value signifies the probability which quantify the strength of the evidence against the null hypothesis in favour of the alternative hypothesis). Hence, there was no violation of an assumption of model adequacy.

Table 4.7: ANOVA

	Model	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
	Regression	97210	3	32403.4	398.75	.000[b]
1	Residual	11052	136	81.264		
	Total	108262	139			

4.7.4 Trend analysis to reveal impact of hydrological factors on aquatic weeds

It is in the interest of this study to assess the impact of hydrological variables on water hyacinth through trend analysis. In other words the study sought answers by using statistical methods which determine whether the probability distribution from which these variables have changed over time impact on aquatic weed abundance. One of the parametric procedures called multiple regressions was used in the analysis due to its advantage when working with multivariate variables. Smith and Rose (1991) also recommended multiple regression approach as the best method for trend analysis.

However, to obtain a powerful trend test, underlying regression assumptions were examined. These assumptions were linearity, constant variance (homoscedasticity), normality and multicolinearity. However, since these assumptions were tested during forecasting model building, they were not investigated for a second time.

4.7.5 Trend test

A parametric approach was employed during the research. Following Smith and Rose's (1991) format, the multiple regression models consisted with Evapotranspiration as the criterion and time and other covariates (explanatory variables) formed the predictor set. The general model was of the form (equation 4.2):

$$ET = \beta_0 + \beta_1 T + \beta_2 Temp + \beta_3 Rain + \beta_4 SR + \varepsilon \quad (4.2)$$

Where ET = Evapotranspiration

T = time in months

Temp = temperature

Rain = rainfall

SR = solar radiation

ε= error term

The null hypothesis was $H_0 = \beta_1 = 0$, that is, there was no trend. The beta coefficient of time is the one which is used in trend analysis. This was then tested by running an analysis on SPSS. The above model with time on the predictor set, it was shown as a good model with the adjusted R- square of 89.6% as shown in Table 4.8. It showed that the model explained 89.6% of the variance in the evapotranspiration model.

Table 4.8: Evapotranspiration model summary

Model	*R*	*R Square*	*Adjusted R Square*	*Std. Error of the Estimate*
1	.948[a]	0.899	0.896	8.99708

Furthermore, some deductions were drawn from the ANOVA table (Table 4.7). Table 4.9 assessed the overall significance of the model. Since the ρ-value < 0.05 significant level, it was concluded the model with the mentioned five variables was significant. This enabled an inference of the trend hypothesis since model adequacy was satisfied.

Table 4.9: ANOVA Table of Evapotranspiration

Model	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Regression	97334.2	4	24333.5	300.609	.000[a]
Residual	10927.9	135	80.947		
Total	108262	139			

[a]*Dependent Variable: Evapotranspiration*

Table 4.10 showed the ρ-value of time variable as 0.218. The null hypothesis was rejected since this ρ- value > 0.05 at significant level. Hence, it was concluded that there was trend over the researched period (from 2002-2012) and resulted to an impact to the invasive aquatic plants.

Table 4.10: Multiple regression coefficients

Model	*Unstandardized Coefficients*		*Standardized Coefficients*	*t*	*Sig.*	*95.0% Confidence Interval for B*	
	B	*Std. Error*	*Beta*			*Lower Bound*	*Upper Bound*
(Constant)	-22.094	4.223		-5.232	0	-30.445	-13.743
Months	-0.024	0.02	-0.035	-1.237	0.218	-0.063	0.015
Temperature	1.267	0.309	0.178	4.096	0	0.655	1.879
Rainfall	-0.033	0.017	-0.07	-2.004	0.047	-0.066	0
Solar Radiation	6.133	0.272	0.852	22.549	0	5.595	6.671

Dependent Variable: Evapotranspiration

The forecasting model (equation 4.3) was given as:

$$ET = -22.094 - 0.024T + 1.267Temp - 0.033Rain + 6.133SR \quad (4.3)$$

Furthermore, the impact was minimal after doing some inferences about the absolute value of the t-statistic.

The above results showed that the study attempted to statistically account for both trends and monthly variability in ET. Multiple regression was conducted to establish functional relationships between potential evapotranspiration (dependent variable) computed using the forecasting hydrological model and the Pearson's correlation model, and climatic parameters of solar radiation, temperature and rainfall (independent variables). This was also done to determine which of these climatic parameters are best for predicting ET.

In particular, evapotranspiration is the process by which precipitation reaching the earth's surface is returned to the atmosphere as vapour through evaporation from wet surfaces and transpiration by plants (Naval, 2012; Ukkola and Prentice, 2013). This hydrologic process is always important whenever moisture conservation and water control are desired. Analysing weather records and estimating ET rates, drought frequencies and excess water periods can show potential needs for irrigation and drainage. Evapotranspiration varies with climatic conditions in the way as open water evaporation. When temperature is high and dry, the rate of evapotranspiration is high; when it is cool or humid, the rate is low (Naval, 2012). When there is a wind it is higher than when the air is still. Ukkola and Prentice (2013) emphasised that the ET rate tells us how fast water vapour would be lost from a densely vegetated plant soil system, if soil water content were continuously maintained at an optimum level.

The results in this study show that multiple regression analysis was used to establish models describing monthly average potential ET as a function of some climatic parameters such solar radiation, temperature and rainfall. The used models show that an increase in solar radiation, temperature and rainfall will cause an increase on monthly ET. In addition, the results show smooth trends over the seasons between 2002 and 2012 (Appendix 1), with maximum evapotranspiration rates predicted for December/January when radiation and average temperatures are at a maximum. This creates novel environments for water hyacinth in the study lakes as shown by the proliferation of these weeds in these months. This is confirmed by field observations carried out during this period (Figures 4.8; 4.9 and 4.15). Predictive models based on good quantitative data (such as the climate-based models used in this study) should therefore be used whenever possible, particularly when dealing with species with limited distribution such as the emerging plant invaders (Bradley *et al.*, 2009).

Thus, the regression models can accurately estimate the monthly average ET and hence, they are recommended for estimation purposes (Teuling *et al.*, 2009). ET is a key ecosystem variable linking hydrological, energy and carbon cycles and account up to 60% of global land precipitation (Oki and Kanae, 2006; Teuling *et al.*, 2009).

The results of the analysis done, showed that climate change will alter the global hydrological cycle, with the inevitable consequence of fresh water scarcity. Solar radiation might be expected to exert a strong effect on ET because it is the main determinant of the energy available for evaporation followed by temperature (Ukkola and Prentice, 2013). The study has shown that among interesting climatic parameters, it may be asserted that ET has received a particular attention. The present study, by considering a station nearer to the study lakes has tried to determine the most important factors affecting ET through using multiple regression theory. This in turn was used to relate the impacts of climate change on water hyacinth.

The results showed the impact of climate change on ET as a hydrological process occurs as a result of changes in precipitation, temperature and solar radiation which are key drivers of this hydrological process (Ukkola and Prentice, 2013). To assess the impact of climate change on water and IAS therefore requires understanding of how changes to these drivers will affect hydrological processes in the system under consideration. This is achieved through hydrological modelling as this research has shown, to predict how the system will respond when its drivers are altered as a result of climate change. Climate change will have an effect on water resources in South Africa and therefore poses a challenge to water resource managers.

The changes in the hydrological drivers show acceleration in the period between the intermediate and distant future thus amplifying the impacts. The research confirms that while hydrology directly affects aquatic environmental conditions, the configuration of water use and supply system has a significant impact on the availability of water to meet demands.

It is important, however to note the upward trend in the numbers of alien species arriving in South Africa (Shine, 2008). As South Africa becomes warmer under the influence of global climate change as shown by the multiple regression models in this study, it seems likely that its ecosystems will become increasingly prone to climate events such as floods which will exacerbate the problem, allowing alien plants to move into riverine areas and spread across floodplains. The first line of defence in combating the spread of invasive species must be prevention. This is confirmed by US EPA (2008) which stated that once an invasive species is firmly established, the costs of control or eradication are high and compete with other demands on scarce financial resources. Due to the extent of the problem in South Africa, containment of existing invasive alien species is also required with the ultimate goal, where possible, being eradication.

The results of the multiple regression analysis done in this study, show that high solar radiation can be associated with heat waves that can lead to short term water quantity and quality impacts and increased fish mortality due to low oxygen concentrations brought about by a rapid increase in decomposition processes, and stress on temperature sensitive fish species. It is however, imperative to note that effects of climate change *per se* are more difficult to predict. Hence, predicting the effects of the many other elements of climate change on plant invasions is a daunting and complex task (Dukes and Mooney,1999; Bradley *et al*.,2009). Ecologists are beginning to understand how species and ecosystems respond to many single aspects of global change, but the understanding is rudimentary (Bradley and Wilcore, 2009). The task has a spatial complexity, for example, while changes in temperature and precipitation could benefit invasive species by creating novel environments, they do no consistently increase resource availability. Hence, the relative impacts of climate change will depend on the dominant forces of change, the geographical location of the area and the invasive species under consideration

4.8 SUMMARY

This chapter has shown how remote sensing and GIS techniques provide a means of obtaining useful information on spatial and temporal variations in water hyacinth in Benoni lakes. The results show the applicability of these tools for detecting changes in emergent and floating leaved aquatic weeds, as well as assessment of infestation levels and monitoring of rate of spread of water hyacinth. The use of satellite imageries enabled the quantification of long-term changes of the water hyacinth in the lakes since there was no water quantity data available for all three lakes from EMM to do a proper assessment of the dynamics of these study lakes. From 2002 to 2010 there was an increase in water hyacinth abundance in the lakes. By end of 2011 to 2012 the results show a reduction in surface area covered by water hyacinth. This was mainly due to the introduction of the Watermaster Classic III by the EMM to clear these aquatic weeds.

Multiple Regression was used to establish a functional relationship between evapotranspiration (ET) computed using the forecasting hydrological model and the Pearson's correlation model, and climatic parameters of solar radiation, temperature and rainfall. This was done to show the impact of climatic change on ET as a result of changes in precipitation, temperature and solar radiation. This was done to predict how the aquatic weeds will respond when these hydrological variables are altered as a result of climatic change.

CHAPTER 5

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The water hyacinth remains a problematic aquatic weed not only in the Benoni lakes, but throughout as it degrades aquatic ecosystems and impacts all aspects of their utilisation. Findings from this study confirm that the water hyacinth infestation is a symptom of a broader watershed management and pollution problems. As the Blesbokspruit is a tributary to the Vaal River, the core water resources of Gauteng Province, the results of this study show that the Benoni Lakes found along this river face serious challenges as reliable sources of water for domestic, recreational, agricultural and industrial uses. And also for the fact that when the weed dies it accumulates on the lake floor reducing the lake depth, they can cause flooding in the area. On-going management of these lakes by EMM ensures that the weed does not exceed 15% cover of the lakes. However, the main challenge is the fast re-infestations of the lakes by the water hyacinth.

The water hyacinth infestations have been controlled biologically in a number of sites around the world, notably Lake Chivero (Zimbabwe), Lake Victoria (Kenya), Louisiana (USA) and Papua New Guinea (Dagno *et al.*, 2012; Gichuki *et al.*, 2012).The bio-control process is a challenge to implement in the Benoni lakes because of the level of pollutants in the lakes. The amount of pollutants in the lakes has to be addressed first as they are favouring the rapid spread of the water hyacinth. The water quality issue has to be addressed through an integrated approach rather than a pure mechanical control. In other words, methods for water hyacinth control should include reduction of nutrient load in the water bodies through treatment of water flowing from sewage works, urban wastes and factories. Because of the water hyacinth's persistent pervasive nature, the costs it causes to eliminate, increased time and waste of resources during its control, and also being a threat to biodiversity, its prevention from further propagation to areas not yet infested should be of high priority.

In light of the above, to prolong the lifespan of Benoni lakes, the EMM need to ascertain the current volume of water in the lakes, through bathymetric survey of the impounded reservoirs (lakes). The purpose of a bathymetric survey is to describe the physical characteristics of the bottom of a water body. This information is important for constructing maps showing depth, contours and underwater structure and is also used to calculate volume, mean and maximum depth of water. The lack of this bathymetric data in the study area was one of the major limitations of this research study.

Findings from this study also suggest that IAS infestations in the study lakes may be used as powerful predictors of correlations between plant abundance and climate change. Therefore both invasive species and climate change are major ecosystem stressors not only for the Benoni lakes but all the lakes in Gauteng Province.

From the meteorological variables data in this research, it is clear that climate change is likely to accentuate social and ecological vulnerability and limit capacity to adapt to changes in ecosystem functioning. These changes have serious economic implications. Furthermore, from the findings of this research it is essential to correlate plant richness in South Africa with climatic variables and environmental variability, and it is expected that changing climate could have significant impacts on plant diversity.

Changes in the climatic parameters selected in this study, particularly increased rainfall, will trigger cyclone intensity which could result in more frequent and intense flood events, which can facilitate water hyacinth dispersal (US EPA, 2008). Water hyacinths are able to survive these extreme events. The increased frequency and intensity of disturbing events in the environment may create unsuitable conditions for native species, making ecosystems even more vulnerable to invasion by water hyacinth and enabling spread. This confirms findings of Masters and Norgrove (2010) who showed that high levels of precipitation in Lake Victoria area which led to increased nutrient levels into the water due to increased runoff, and also a resurgence of water hyacinth, particularly in the northwest corner of the lake in Kenya. Future combinations of increased temperature and increased heavy rainfall could have a dramatic effect on the spread and impact of water hyacinth in the Benoni Lakes under climate change.

However, the effects of climate change *per se* are more difficult to predict (Bradley *et al.*, 2009). For example, while changes in temperature could benefit invasive species by creating novel environments they do not consistently increase resource availability. Indeed, the global temperature might decrease water availability when precipitation remains the same. Modelling and experimental studies have shown both increased and decreased invasion risk associated with climate change.

Hence, the relative impacts of global change on plant invasions will depend on the dominant forces of change, the geographical location of the area and the invasive species under consideration. Forecasting global change is fraught with complexity and uncertainty.

In order to design and conduct effective IAS management, state managers should put in motion efforts that will allow them to consider the projected effects of climate change on IAS prevention, control and eradication actions. This assessment of the current status of climate in IAS management underscores the need to consider climate change effects in every part of IAS management plans and programmes in order to address IAS threats effectively.

Further research, development of models and predictors and data collection should be conducted in order to provide managers with the tools (Shine, 2008) and information they need to conduct effective prevention, control and eradication of IAS. Information needs include both immediate data needs and long-term research to better understand the complex interactions between climate change and aquatic invasions. It is however, true that large uncertainties still plague quantitative assessments of climate change impacts on IAS and water resource management, yet what is known for certain is that climate is changing, that this will have an effect on water resources. Therefore increased efforts will be needed to plan and manage water supplies in future, through increased monitoring and understanding of the interrelationships between climate change and water availability.

Findings from this study confirm and illustrate the potential usefulness of a variety of modelling approaches in projecting potential invasive species distributions under climate change. Challenges still remain in integrating climate change projections and mechanisms of invasions, particularly in aquatic ecosystems and in translating model results into information useful to managers and decision-makers.

While it is important to recognise many of the weaknesses across South Africa that may complicate effective responses to climate change, such as poor institutional capacity, high levels of poverty, paucity of data, and limited modelling of climate change impacts at the local scale, it is equally important that immediate action is taken to improve the resilience of communities and societies to the impacts of climate on dams. Conclusively, however, to prolong the lifespan of the study lakes, there is need to frequently remove the hydrophytes which have colonised the banks of the lakes, reducing their spatial extend. This will increase the surface area and subsequently increase the volume of the study lakes.

5.2 RECOMMENDATIONS

Based on the results obtained in this study, this section summarises recommendations that are designed to maintain and improve the country’s IAS management programmes and activities in a changing climate:

1. A comparison of available information in the scientific literature reveals that more scientific multi-stressor, long-term studies are necessary to understand more fully the interaction between climate change and IAS and more species-specific information are needed for improved management.

2. To prolong the life-span of lakes there is need to ascertain the current volume of water in lakes, bathymetric survey of the lakes should be frequently be carried out.

3. Further work involving multivariate and dynamic conditional correlation methods may provide more insights regarding the relationships among climatic variables such as temperature, rainfall, solar radiation and evapotranspiration.

4. Attempts to incorporate scenarios of climate change should be considered in future integrated water resource management efforts, but scenarios should be curtailed to realistic ranges commencing with projections based on detectable (if any) trends in the historical climatic and hydrological records.

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APPENDICES

Appendix 1: Hydrological variables

Hydrological variables from September 2002 to December 2012 (Data received from Agricultural Research Commission of South Africa-station no.30459).

Months	*Temperature (^0C)*	*Rainfall (mm)*	*Solar Radiation (MJ/m^2)*	*Evapotranspiration (mm)*
1	15.22	20.1	17.52	96.36
2	18.39	105.2	20.43	124.95
3	17.72	112.9	20.19	116.57
4	20.13	79.2	20.32	127.43
5	20.81	49.4	24.1	151.38
6	19.08	137.6	18.88	101.87
7	18.78	59.8	16.95	102.71
8	16.34	16.1	12.7	75.03
9	12.93	41.6	12.98	73.7
10	10.72	7.9	12.38	64.66
11	9.16	0.3	12.87	69.24
12	13.55	2.2	14.06	95.71
13	15.28	4.1	16.8	108.62
14	18.01	47.7	17.48	109.63
15	18.5	78.4	16.56	96.14
16	20.13	87.7	20.38	123.38
17	21.04	71.4	23.96	145.68
18	19.83	53.2	19.08	105.1
19	19.24	4.3	18.27	112.57
20	17.45	3.2	16.39	96.76
21	12.97	6.5	13.3	76.94
22	9.9	4.8	11.8	58.51
23	9.84	0.1	12.94	72
24	14.02	3.1	12.5	78.69
25	15.53	1	17.16	106.1
26	18.55	30.5	18.37	124.04
27	18.93	2.4	22.08	141.82
28	20.09	34.4	16.31	108.58
29	21.23	127.3	18.92	126.56
30	21.37	121.7	18.07	104.51
31	19.22	67.3	17.55	109.67
32	17.9	0.7	14.03	88.15
33	10.87	0.2	11.8	73.26
34	8.13	11.7	10.37	55.95
35	12.95	1	11.78	68.64
36	11.63	1.5	14.53	89.1
37	16.61	3.1	15.86	109.04
38	18.22	75.8	17.46	128.08
39	20.15	33.5	18.77	117.8
40	20.45	54.8	24.55	161.68
41	20.87	118.6	21.15	129.03
42	19.46	174.9	5.33	29.28
43	18.11	96.9	0	0
44	15.76	41.6	17.76	91.41
45	13.14	2.3	16.85	90.46
46	9.9	3.6	13.91	66.17
47	8.89	8.7	14.55	70.46
48	13.77	0.4	15.24	63.15
49	13.15	0.2	14.31	43.54

50	12.32	0.3	12.89	71.6
51	11.15	0.1	13.38	75.09
52	14.64	1.4	14.32	91.17
53	18.02	0.9	17.2	123.18
54	19.78	11.7	18.8	133.53
55	19.79	166	20.83	128.74
56	20.04	57.4	22.22	138.8
57	20.31	99	17.08	99.9
58	20.03	129.2	18.06	93.88
59	17.37	62.8	15.46	86.89
60	15.38	26.2	15.71	81.99
61	10.61	2.4	13.82	71.48
62	9.69	0.1	13.35	65.91
63	11.85	0	14.14	77.34
64	11.07	34	15.97	82.51
65	15.31	0.6	20.17	115.51
66	19.33	3.4	18.33	123.35
67	18.93	94.2	18.97	111.56
68	21.13	32.7	20.4	129.9
69	20.51	42.9	15.6	104.37
70	20.97	9.9	14.85	97.82
71	19.67	31.2	19.96	123.57
72	16.41	20.5	15.74	89.54
73	12.53	0.3	14.65	83.59
74	9.96	34.4	12.18	62.03
75	9.49	0.9	13.25	71.48
76	12.53	0.1	15.42	88.93
77	18.54	36.5	18.12	114.78
78	16.41	145.6	16.46	91.43
79	19.32	48	20.94	122.44
80	19.01	74.4	21.75	125.6
81	19.03	238.3	17.42	98.81
82	19.75	45.6	21.94	120.72
83	17.72	159.5	14.54	83.6
84	14.86	11.1	15.72	85.53
85	13.29	39	11.93	64.51
86	10.51	11.7	11.74	58.36
87	10.1	0.3	12.08	63.24
88	17.69	0.8	14.38	87.07
89	16.11	0	18.87	114.25
90	19.7	67.4	19.86	129.37
91	21.19	120.8	19.72	116.46
92	21.46	72.7	20.95	129.64
93	21.42	114.8	18.31	110.55
94	20.29	35.1	15.45	57.92
95	18.07	55.88	16.66	55.51
96	15.95	4.57	16.27	90.46
97	12.62	25.15	12.67	67.11
98	10.87	2.03	11.52	58.09
99	8.05	0.76	13.62	67.29
100	11.71	1.02	15.87	85.03
101	17.2	33.02	18.23	113.03
102	18.95	34.04	19.39	118.12
103	18.39	116.84	19.89	114.59
104	20.34	125.98	24.29	143.67
105	20.23	166.12	17.09	99.13
106	20.27	112.77	21.03	112.29
107	19.4	73.66	17.26	101.23
108	16.39	33.27	12.29	66.57
109	13.56	4.06	12.81	70.27
110	9.42	0	12.76	64.99
111	9.99	0	12.59	68.41
112	12.67	0	16.69	97.41
113	17.24	0	19.92	125.96

114	19.66	27.94	21.63	143.34
115	19.76	86.11	19.77	122.01
116	20.26	173.47	21.6	132.63
117	19.93	211.59	19.55	114.55
118	19.57	25.15	20.33	110.02
119	19.7	206.75	18.5	112.48
120	15.52	75.69	13.07	71.12
121	12.99	5.33	13.26	72.78
122	9.49	16.25	12.92	64.8
123	8.31	0	13.36	67.7
124	12.01	15.49	16.15	90.34
125	16.46	7.62	20.15	121.88
126	18.42	106.17	22.52	138.31
127	19.59	90.17	24.02	142.82
128	20.03	169.67	21.38	130.06
129	20.46	148.08	23.68	141.85
130	21.15	42.92	21.3	121.74
131	19.03	76.2	19.3	117.16
132	15.02	9.14	15.53	88.27
133	13.88	0	14.13	82.78
134	9.86	2.03	10.05	57.14
135	10.75	0	11.95	70.43
136	13.53	0.51	14.51	92.58
137	14.8	100.33	17.93	104.19
138	18.04	224.02	19.81	120.04
139	19.18	157.99	23.83	140.28
140	19.98	232.9	20.99	127.33

N.B: *Data for September – December 2004 and January – April 2005 was not recorded on the original data.*

Appendix 2: Authorisation Letter.

Ekurhuleni
METROPOLITAN MUNICIPALITY

15th January 2013

Ref: HN/ym

Mr. L. Rwizi
3 Heilbrone Street
Crystal Park
Benoni
1501

Head of Department

Environmental Resource Management

Crn Hendriek Potgieter & van Riebeck Street
Edenvale

Private Bag X 25
EDENVALE
1610

Tel : (011) 999 3106/9412
Fax : (011)
www.ekurhuleni.com

Subject: PERMISSION TO CONDUCT RESEARCH STUDY INCLUDING TAKING PHOTOS AT LAKES WITHIN EMM

We acknowledge receipt of your letter dated the 11th January 2013.

Permission is granted on condition that the Ekurhuleni Metropolitan Municipality (EMM) is not liable for any costs and injury incurred on site and that the final report is made available to EMM to inform planning processes.

You are also requested to liaise with the Wetland Team, see contact details below.

1. Mr. Bheki Sibeko – 082 469 0598
2. Mr. Sekhonyana Lerotholi – 083 582 1682
3. Mr. Christopher Mthombeni – 083 293 7774

Yours sincerely,

HEZEKIEL S. NKOSI
HOD: ENVIRONMENTAL RESOURCE MANAGEMENT
EKURHULENI METROPOLITAN MUNICIPALITY

Appendix 3: Ethics Letter

UNISA university of south africa

2013-04-29

Ref. Nr.: 2013/CAES/040

To:
Student: L Rwizi **Student nr: 36763500**
Supervisor: Dr L Nhamo
Department of Environmental Science
College of Agriculture and Environmental Sciences

Dear Dr Nhamo and Mr Rwizi

Request for Ethical approval for the following research project:

Evaluating the effects of invasive alien plants on water availability and usability of lake water in Gauteng Province

The application for ethical clearance in respect of the above mentioned research has been reviewed by the Research Ethics Review Committee of the College of Agriculture and Environmental Sciences, Unisa. Ethics clearance for the above mentioned project (Ref. Nr.: 2013/CAES/040) **is approved** after careful consideration of all documentation submitted to the CAES Ethics committee.

The researcher is reminded of the stipulation of the municipality stated in the feedback letter which the researcher should adhere to. The researcher is also reminded that there is risk to any form of research and that the researcher should take cognisance of the fact that all research is done under the Ethics and Research policies of Unisa which should be followed at all times.

Kind regards,

Prof E Kempen,
CAES Ethics Review Committee Chair

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 429 12 429 4150
www.unisa.ac.za